LIBEROHELLENIC
REGISTER

Rules and Regulations

for the Classification and Construction of

Steel Ships

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Steel Ships

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CHAPTER 1 General Requirements

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SECTION 1 Scope

1.1 General

1.1.1 These Rules for Materials apply to materials and components which are intended to be used in the construction, repair or equipping of ships, offshore marine structures and other installations which are classified by Libero Hellenic Register (LHR) or whose classification has been applied for.

1.1.2 The materials and components which are to conform to these Rules are, mainly, defined in the relevant Rules dealing with design and construction. At the discretion of LHR these requirements may be applicable to materials and products not necessarily mentioned in the Rules for design and construction.

1.1.3 LHR reserves the right to adopt more complete requirements with respect to the manufacture, properties and testing of materials and components wherever recent research results or operational experience deem them necessary. Moreover, LHR reserves the right to depart from these Rules where this is technically justified.

1.1.4 Materials conforming to national or international standards or to special material specifications may be permitted by LHR, if their properties are recognized by it as equivalent to those specified in these Rules for Materials or where LHR has given special approval for their use. Where there are differences between these Rules and the relevant standards or specifications with regard to their requirements, the test results shall be in accordance with the more rigorous ones.

1.1.5 The builder of the ship, structure or machinery is to inform the manufacturer of the material that this shall comply with these Rules with regard to manufacture, inspection and testing procedures, especially in cases where optional or additional conditions are applicable.

1.1.6 Materials or components not covered by these Rules are subject to the standards applicable to the component or to the material specifications which have to be complied with by the manufacturer of the material. LHR will monitor the compliance with these additional requirements, where this has been specially agreed with the manufacturer of the material or with the purchaser.

SECTION 2 General manufacturing and surveying procedures

2.1. Manufacture

2.1.1 All materials are to be made at works which have been approved by LHR for the type of product being supplied.

2.1.2 To prove the efficiency of works, the manufacturer is required to demonstrate to LHR that the necessary manufacturing and testing facilities are available and are supervised by qualified personnel. A specified program of tests is to be carried out under the supervision of the Surveyors, and the results are to be to the satisfaction of LHR. When a manufacturer has more than one works, the approval is only valid for the individual works which carried out the test program.

2.1.3 All materials must be manufactured by sufficiently well proven techniques, which ensure that the required properties are achieved. Where new processes are to be employed, preliminary proof of their suitability is to be submitted to LHR. According to the discretion of LHR, this shall take the form of special procedure tests and/or the presentation of works documentation of tests performed or of expert assessments by independent testing bodies.

2.1.4 Where, in special cases, individual tests have to be carried out by outside bodies, such tasks are to be entrusted by the manufacturer only to those firms or institutes which also meet the aforementioned conditions and have been approved by LHR.

2.2. Condition of supply and heat treatment

2.2.1 Products are to be supplied in the prescribed heat-treated condition. Where the final heat treatment is to be performed by the steel user, the condition in which the material is supplied must be clearly stated in the relevant certificates.

2.2.2 All heat treatments are to be carried out in suitable furnaces, which are efficiently maintained.

The furnaces must be provided with devices for controlling and recording the temperature.

2.2.3 If it is intended to apply other treatments in place of the prescribed heat treatment such as normalizing or quenching and tempering, the manufacturer must first prove to LHR that, when other processes are used, the mechanical properties of the products meet the requirements.

2.3. Weldability

2.3.1 Materials intended for the manufacture of welded structures must be capable of being welded by standard workshop techniques. Depending on the discretion of LHR, procedure tests may be required to prove the efficiency of the proposed method for welding.

2.4. Freedom from defects

2.4.1 All materials are to be free from defects. Defects which have been proved of no significant effect on the suitability of the material may be allowed after an agreement with LHR. Insignificant surface defects may be removed mechanically, provided that the dimensional tolerances permitted for these products are not exceeded. Defects in the material may be repaired by welding only where this is permitted by the specifications relating to the product. Moreover, the Surveyor must give his consent and the welding technique must be approved by LHR.

2.5. Surveying procedures

2.5.1 The Surveyors are to be allowed access to all relevant parts of the works and are to be provided with the necessary facilities and information to enable them to verify that manufacture is being carried out in accordance with the approved procedure. Facilities are also to be provided for the selection of test materials, the witnessing of mechanical tests and the inspection of materials, as required by these Rules. Acceptance tests shall normally be performed in the works in the presence of the Surveyor.

2.5.2 The manufacturers are to conform to the following procedures:

Prior to the submission of material for acceptance, they are to provide the Surveyors with details of the order, specification and any special conditions additional to the Rule requirements.

All materials are to be submitted to the specified tests and inspections under conditions acceptable to the Surveyors. The results are to comply with the Rules and all materials are to be to the satisfaction of the Surveyors.

2.5.3 The tests and inspections are to be carried out prior to the delivery of all finished materials. Where materials are supplied in the unfinished condition, as many as possible of the specified tests are to be carried out by the manufacturer, and only tests or inspections not completed are to be carried out at a subsequent stage of manufacture.

2.5.4 In the event of any material proving unsatisfactory during subsequent working, machining or fabrication, such material is to be rejected, notwithstanding any previous certificates.

2.5.5 Where materials are manufactured in quantity by semi-continuous or continuous processes under closely controlled conditions, an alternative system for testing and inspection may be adopted, subject to the approval of LHR. In order to be considered for approval, manufacturers are to comply with the requirements of SECTION 6.

SECTION 3 General test conditions

3.1 Demonstration of chemical composition

3.1.1 The chemical composition of materials is normally demonstrated by the manufacturer, determined by ladle sample analyses in an adequately equipped and competently staffed laboratory.

3.1.2 The chemical composition shall cover all those elements for which limited values are prescribed in the Rules of Materials or in the relevant standards, or which are added in order to guarantee the required mechanical properties.

3.1.3 The certificate of the manufacturer is generally recognized as proof of the chemical composition. At the discretion of LHR, a chemical check analysis of suitable samples from products may also be required. Possible deviations between the ladle and product analyses must conform to the relevant standards or specifications.

3.2 Test material

3.2.1 Sufficient test material is to be provided for the preparation of the tests detailed in the specific requirements. The manufacturer may also provide additional material for any retests which may be necessary.

3.2.2 The following definitions are applicable to this Part:

– Item is called a single forging, casting, plate, tube or another rolled product as delivered.

– Piece is called the rolled product from a single slab or billet or from a single ingot if this is rolled directly into plates, strip, sections or bars.

– Batch is called a number of similar items or pieces presented as a group for acceptance testing.

3.2.3 The test material is to be representative of the item or batch and is not to be separated until all the specified heat treatment has been completed, except where provision for an alternative procedure is made in subsequent Chapters.

3.2.4 All test material is to be selected by the Surveyor or an authorized deputy, and identified by suitable markings which are to be maintained during the preparation of the test specimens.

3.3 Tests

3.3.1 The testing procedures for mechanical properties shall be in accordance with the general methods and test specimens mentioned in Part 2, Chapter 2. Test requirements and results shall be stated in SI units. Tests not referred to in Part 2, Chapter 2 are to be carried out in accordance with national or international standards unless otherwise agreed.

3.3.2 Where non-destructive tests are specified for the various product types, these shall be performed by the manufacturer and the results together with details of the test method shall be stated in a certificate. The Surveyor is entitled to be present at the tests.

3.3.3 All products are to be checked by the manufacturer for the verification of dimensions. They shall also be inspected by the manufacturer for possible defects and shall, when this is called for, be presented to the Surveyor. For this purpose, the products must normally be in the prescribed "as delivered" or heat-treated condition and must have a clean surface, prepared for inspection, which is free from coatings or other protective media which impair the detection of defects. Unless otherwise specified or specially agreed, the Surveyor shall perform a random test of the dimensions and surface finish as he sees fit. Products which do not meet the requirements shall be set aside by the manufacturer beforehand.

3.3.4 Where products are manufactured in large runs by series manufacturing techniques and/or using continuous processes with constant, monitored conditions, LHR may, instead of its own tests, recognize those performed by a works quality control section using a quality assurance (QA) system approved by LHR. This is subject to the conditions that:

The quality control section is independent of the management of the production or the processing departments.

The works meets the requirements stated in SECTION 6.

It has proved to LHR that the QA system ensures faithful compliance with the specified properties of the material.

3.3.5 LHR gives no guarantee that products which have been subjected to testing of the prescribed extent, either individually or grouped together in test batches, fulfill in all respects the requirements contained in these Rules or in other relevant documents.

3.4 Re-test procedures

3.4.1 When the result of any test, other than an impact test, fails to meet the requirements, two further tests of the same type may be made from the same piece. If both of these additional tests are satisfactory, the material is being accepted.

3.4.2 When the average value of the three initial impact test specimens does not comply with the stated requirement, or the value for more than one specimen is below the required average value, or when the value of any one specimen is below 70% of the specified average value, three additional specimens from the same material may be tested and the results added to those previously obtained to form a new average. If this new average complies with the requirements and if not more than two individual results are lower than the required average and of these, not more than one result is below 70% of the specified average value, the piece or batch may be accepted.

3.4.3 The additional tests detailed in 3.4.1 and 3.4.2 are, where possible, to be taken from material adjacent to the original tests. For castings, where insufficient material remains in the original test samples, the additional tests may be prepared from other test samples representative of the castings.

3.4.4 When unsatisfactory results are obtained from tests representative of a batch of material, the item or piece from which the tests were taken is to be rejected. The remainder of the material in the batch may be accepted, provided that two further items or pieces are selected and tested with satisfactory results. If the tests from one or both of these additional items or pieces give unsatisfactory results, the batch is to be rejected.

3.4.5 When a batch of material is rejected, the remaining items or pieces in the batch may be resubmitted individually for test, and those which give satisfactory results may be accepted.

3.4.6 At the option of the manufacturer, rejected material may be re-submitted as another grade and may then be accepted, provided that the test results comply with the appropriate requirements.

3.4.7 When material which is intended to be supplied in the "as rolled" or "hot finished" condition fails test, it may be suitably heat-treated and re-submitted for test. Similarly, materials supplied in the heat-treated condition may be re-heat-treated and re-submitted for tests.

SECTION 4 Identification and marking of materials

4.1. General

4.1.1 The manufacturer must use an identification system which enables every finished material to be traced to the original cast. On request, the Surveyor shall be given every facility for retracing the manufacturing process.

4.1.2 Before final acceptance, every finished item is to be clearly marked by the manufacturer in at least one position with the necessary particulars as detailed in the appropriate specific requirements.

4.1.3 The marking shall normally be impressed with a punch, unless such marking is precluded by materials with a sensitive surface or which are too thin. In such cases marking may be done with paint, rubber stamps, adhesive stickers or electro engraving. All marks shall be so applied that their legibility cannot be impaired by the transportation or storage of the products.

4.1.4 Where a number of identical items are securely fastened together in bundles, the manufacturer need only brand the top item of each bundle. Alternatively, a durable label giving the required particulars may be attached to each bundle.

SECTION 5 Certification of materials

5.1 The manufacturer is to provide the Surveyor with a test certificate or shipping statement giving the necessary particulars for each item or batch of items which has been accepted, as they are depicted in the appropriate Sections of the following Chapters.

SECTION 6 Materials manufactured under an approved quality assurance scheme

6.1. General

6.1.1 When materials are manufactured under a quality assurance scheme that meets the requirements of the ISO 9000 series or equivalent, and which ensures the compliance with the requirements of the Rules, LHR is prepared to adopt alternative procedures for survey and testing of materials. LHR reserves the right to decide about the compliance of the used quality assurance scheme with the Rules.

SECTION 7 Jurisdiction

7.1. Governing law

7.1.1 The governing law is the Greek law.

7.2. Disputes

7.2.1 Any dispute shall be submitted to the court of Piraeus or, at the option of LHR, to the court competent for the third party's place of residence.

CHAPTER 2 Testing procedures for materials

CONTENTS

SECTION 1 Scope (IACS UR W2, Rev.3 (2021))

1.1 General

1.1.1 This Chapter gives the requirements for test specimens when testing ferrous and nonferrous metals.

1.1.2 The corresponding testing procedures generally are to follow established practice, as laid down in international and national standards. Some testing procedures are given in this Chapter.

1.1.3 Alternative specimens, such as those complying with recognized national standards, may be accepted, subject to special approval by LHR. The same applies to the given testing procedures.

SECTION 2 General requirements

2.1. Preparation of test specimens

2.1.1 Test samples from which test specimens are cut are to have undergone the same treatment as the material from which they have been taken (e.g. heat treatment).

2.1.2 If test samples are cut from material by flame cutting or shearing, a reasonable margin is required to enable sufficient material to be removed from the cut edges during final machining.

2.1.3 The preparation of test specimens is to be done in such a manner that test specimens are not subjected to any significant straining or heating.

2.1.4 Any of the test specimens referred to as "alternative" may be used, except as otherwise stated or agreed.

2.2. Testing machines and personnel

2.2.1 All tests are to be carried out by competent personnel. Testing machines are to be maintained in a satisfactory and accurate condition and are to be recalibrated at approximately annual intervals. This calibration is to be carried out by a nationally recognized authority and is to be to the satisfaction of LHR.

2.2.2 Impact testing machines are to be calibrated in accordance with ISO 148-2:2016 as amended or other recognised standard.

2.2.3 The accuracy of tensile test machines is to be within ± one per cent.

2.2.4 Tension/compression testing machines are to be calibrated in accordance with ISO 7500-1:2018 as amended or other recognised standard.

SECTION 3 Tensile tests

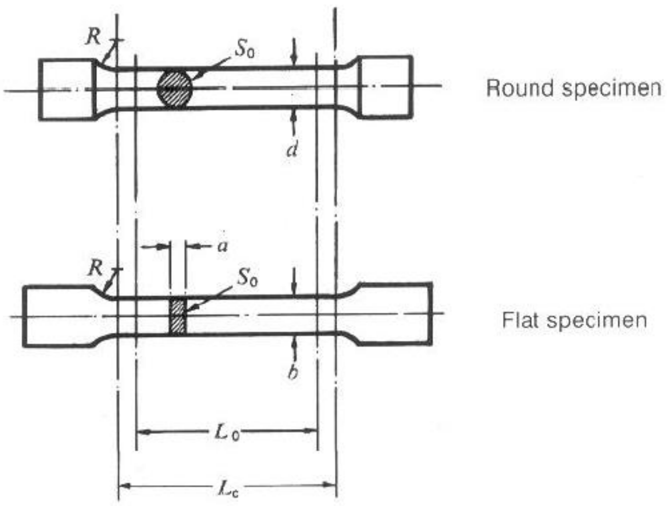
3.1. Tensile test specimens

3.1.1 Designations.

The following designations are used (see Figure 2.3.1):

d = diameter [mm]
a = thickness [mm]
b = width [mm]
L_o = original gauge length [mm]
L_c = parallel test length [mm]
S_o = original cross-sectional area [mm²]
R = transition radius [mm]
D = external tube diameter [mm]
t = plate thickness [mm]

Figure 2.3.1 Tensile test specimens



3.1.2 Standard proportional test specimen.

A proportional specimen with gauge length:

$$L_o = 5{,}65 \cdot \sqrt{S_o}$$

or = 5d is called a standard proportional test specimen and should preferably be used as the minimum percentage elongation values specified in the Rules referring to this gauge length. L_o should preferably be greater than 20mm. The gauge length may be rounded off to the nearest 5 mm provided that the difference between this length and L_o is less than 10% of L_o.

3.1.3 Tolerances.

The tolerances on specimen dimensions are to be in accordance with ISO 6892-1:2019 as amended, ISO 6892-2:2018 as amended or other recognised standards as appropriate

3.1.4 Plates, strips and sections

Flat specimens are usually to be used with dimensions as specified below:

a) Proportional flat specimen

a = t

b = 25 mm

$L_o = 5{,}65\sqrt{S_o}$

$L_c = L_o + 2\sqrt{S_o}$

R = 25 mm

b) Non-proportional flat specimen

a = t

b = 25 mm

L_o = 200 mm

L_c ≥ 212,5 mm

R = 25 mm

When the capacity of the available testing machine is insufficient to allow the use of test specimen of full thickness, this may be reduced by machining one of the rolled surfaces. Alternatively, for materials over about 40 mm thick, proportional round test specimens with dimensions as specified below, may be used.

c) Round specimen

d ≥ 10 mm to 20 mm, preferably 14 mm

L_o = 5d

$L_c \geq L_0$ + d/2

R = 10 mm (for nodular cast iron and materials with a specified elongation less than 10%, R ≥ 1,5 d)

The axes of the round test specimens are to be located at approximately one quarter of the thickness from one of the rolled surfaces.

3.1.5 Aluminium Alloys

Flat tensile test specimens shall be used for specified thicknesses up to and including 12,5mm. The tensile test specimen shall be prepared so that both rolled surfaces are maintained. For thicknesses exceeding 12,5 mm, round tensile test specimens will be used. For thicknesses up to and including 40mm, the longitudinal axis of the round tensile test specimen shall be located at a distance from the surface equal to half of the thickness. For thicknesses over 40 mm, the longitudinal axis of the round tensile test specimen shall be located at a distance from one of the surfaces equal to one quarter of the thickness.

3.1.6 Forgings, castings and bars (excluding grey cast iron).

Proportional round test specimens with dimensions as specified in 3.1.4 (c) are usually to be used. For small size bars and similar products the test specimens may consist of a suitable length of bar or other product tested in the full cross-section.

3.1.7 Pipes and tubes.

The test specimen shall conform with the following.

a. Full cross section tensile test specimen with plugged ends (Figure 2.3.2):

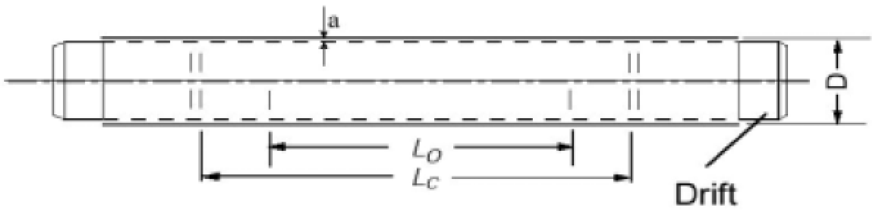
$$L_o = 5{,}65 \cdot \sqrt{S_o}$$

$$L_c \geq 5{,}65\sqrt{S_o} + \frac{D}{2}$$

where:

L_c = the distance between the grips or the plugs, whichever is the smallest.

Figure 2.3.2



b. Strips cut longitudinally (Figure 2.3.3):

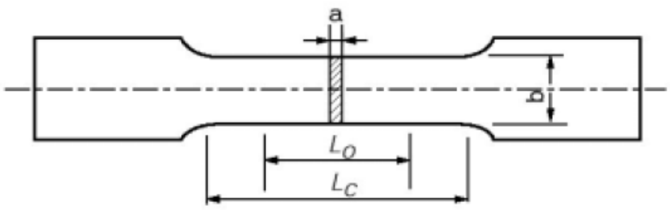
a = t

b ≥ 12 mm$L_o = 5{,}65 \cdot \sqrt{S_o}$

$L_C = L_o + 2 \cdot b$

The parallel test length is not to be flattened, but the enlarged ends may be flattened for gripping in the testing machine.

Figure 2.3.3



Round test specimens may also be used provided that the wall thickness is sufficient to allow the machining of such specimens to the dimensions given in 3.1.4 c), with their axes located at the mid- wall thickness.

3.1.8 Wires.

Full cross section tensile test specimen with the following dimensions is to be used:

L_o = 200 mm

$L_c = L_o$ + 50 mm

3.1.9 Weldments

a. Deposited metal tensile test

Round specimen with the following dimensions is to be used:

d = 10 mm

L_o = 50 mm

L_c ≥ 55 mm

R ≥ 10 mm

For specially small or large dimensions other specimens may be used after agreement with LHR, provided they conform with the geometrical relationship given in 3.1.4 c).

b. Butt weld tensile test (Figure 2.3.4)

Flat specimen, the weld to be machined (or ground) flush with the surface of the plate, with the following dimensions is to be used:

a = t

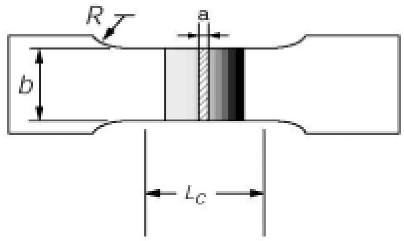
b = 12 for t<2

b = 25 for t>2

L_c = width of weld + 60 mm

R > 25 mm

Figure 2.3.4



3.1.10 Through thickness tensile test specimen

Round test specimens including built-up type by welding are to be prepared in accordance with a recognised standard.

3.1.11 Retest Procedure

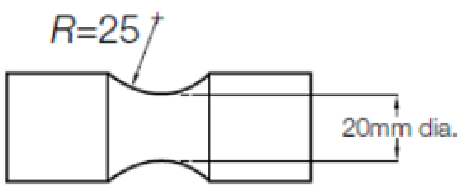
When the tensile test fails to meet the requirements, two further tests may be made from the same piece. If both of these additional tests are satisfactory the item and/or batch (as applicable) is acceptable. If one or both of these tests fail the item and/or batch is to be rejected.

The additional tests detailed above are to be taken, preferably from material taken adjacent to the original tests, but alternatively from another test position or sample representative of the item/batch.

3.2. Tensile test specimen for grey cast iron

3.2.1 Round non-cylindrical machined test specimen as shown in Figure 2.3.5 is to be used. Usually test specimens are machined from separately cast standard test coupons with 30 mm diameter.

Figure 2.3.5



3.3. Tensile properties at ambient temperature

3.3.1 Yield stress (yield point), R_e.

The value of stress measured at the commencement of plastic deformation at yield, or the value of stress measured at the first peak obtained during yielding even when that peak is equal to or less than any subsequent peaks observed during plastic deformation at yield. The test is to be carried out with an elastic stress within the following limits:

Modulus of Elasticity of the material (E) N/mm^2	Rate of stressing N/mm^2s^{-1}	
	Min.	Max.
< 150 000	2	20
≥ 150 000	6	60

3.3.2 Proof stress (yield strength) R_p.

When no well-defined yield phenomenon exists, the 0,2% proof stress (Rp0.2) is to be determined according to the applicable specification. For austenitic and duplex stainless-steel products, the 1% proof stress (Rp1) may be determined in addition to Rp0.2. The rate of loading shall be as stated in 3.3.1 above.

3.3.3 Tensile strength (R_m).

After reaching the yield or proof load, for ductile material the machine speed during the tensile test is not to exceed that corresponding to a strain rate of 0,008 s^{-1}. For brittle materials, such as cast iron, the elastic stress rate is not to exceed 10 N/mm^2 per second.

3.3.4 Fracture elongation (A)

The elongation value is, in principle, valid only if the distance between the fracture and the nearest gauge mark is not less than one third of the original gauge length. However the result is valid irrespective of the location of the fracture if the percentage elongation after fracture is equal to or greater than the expected value. The elongation generally means elongation A_5 determined on a proportional gauge length:

$$5{,}65\sqrt{S_0} = 5d$$

but may also be given for other specified gauge lengths.

If the material is a ferritic steel of low or medium strength and not cold worked and the elongation as measured on a non-proportional gauge length, the required elongation A_0 on that gauge length L_0 may after agreement be calculated from the following formula:

$$A_o = 2 \cdot A_5 \cdot \left(\frac{\sqrt{S_o}}{L_o}\right)^{0{,}40}$$

For tables and graphs see ISO 2566-1:1984 as amended, ISO 2566-2:1984 as amended.

3.3.5 For proportional test specimens other than the standard one, the required elongation Ao on that proportional gauge length L_O may be calculated from A_5 using the following multiplying factors:

L_o	Multiplying factor
$4{,}00 \cdot \sqrt{S_o}$	1,149
$8{,}16 \cdot \sqrt{S_o}$	0,863
$11{,}30 \cdot \sqrt{S_o}$	0,759
$4{,}00 \cdot d$	1,093

$8{,}00 \cdot d$	0,828

3.3.6 For non-proportional test specimens with gauge lengths of 50 mm and 200 mm, elongation values corresponding to those obtained on the standard proportional test specimen are given in Table 2.3.1 and Table 2.3.2 respectively. For other tables and graphs reference is made to ISO 2566/1-1984(E), as amended: Steel - Conversion of elongation values - Part 1: Carbon and low alloy steels.

3.3.7 The above conversions are considered to be reliable when applied to carbon, carbon manganese, molybdenum and chromium molybdenum steels within the tensile strength range 300 to 700 N/mm^2 and in the hot rolled, hot rolled and normalized or annealed conditions, with or without tempering.

3.3.8 For materials other than those mentioned in 3.4.6, any conversion factors to be used are to be approved by the Surveyor.

Table 2.3.1 Elongation values on 50 mm corresponding to those obtained on $5{,}65 \cdot \sqrt{S_o}$ gauge length

Actual elongation (%) on $5{,}65 \cdot \sqrt{S_o}$ gauge length	**Corresponding elongation (%) on 50 mm gauge length if cross-sectional area in square millimeters is:**												
	80	**100**	**150**	**200**	**250**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**
10	10	11	11	12	13	13	14	14	15	16	16	16	17
11	11	12	13	13	14	14	15	16	17	17	18	18	18
12	12	13	14	14	15	16	17	17	18	19	19	20	20
13	13	14	15	16	16	17	18	19	20	20	21	21	22
14	14	15	16	17	18	18	29	20	21	22	22	23	23
15	15	16	17	18	19	20	21	22	23	23	24	24	25
16	16	17	18	19	20	21	22	23	24	25	25	26	27
17	17	18	19	21	21	22	24	25	26	26	27	28	28
18	18	19	21	22	23	24	25	26	27	28	29	29	30
19	19	20	22	23	24	25	26	28	29	29	30	31	32
20	20	21	23	24	25	26	28	29	30	31	32	33	33
21	21	22	24	25	27	27	29	30	32	33	33	34	35
22	22	23	25	27	28	29	30	32	33	34	35	36	37
23	23	24	26	28	29	30	32	33	35	36	37	37	38
24	24	25	27	29	30	31	33	35	36	37	38	39	40
25	25	26	28	30	32	33	35	36	38	39	40	41	42
26	26	27	30	31	33	34	36	38	39	40	41	42	43
27	27	28	31	33	34	35	37	39	41	42	43	44	45
28	28	29	32	34	35	37	39	41	42	43	45	46	47

29	29	30	33	35	37	38	40	42	44	45	46	47	48
30	30	32	34	36	38	39	42	43	45	47	48	49	50

Table 2.3.2: Elongation values on 200 mm corresponding to those obtained on $5,65 \cdot \sqrt{S_o}$ gauge length

Actual elongation (%) on $5,65 \cdot \sqrt{S_o}$ gauge length	**Corresponding elongation (%) on 50 mm gauge length if cross-sectional area in square millimeters is:**															
	100	**150**	**200**	**250**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1200**	**1500**	**2000**	**2500**
10	6	7	7	7	8	8	8	9	9	9	9	10	10	10	11	11
11	7	7	8	8	8	9	9	9	10	10	10	11	11	11	12	13
12	7	8	8	9	9	10	10	10	11	11	11	11	12	12	13	14
13	8	9	9	9	10	10	11	11	12	12	12	12	13	13	14	15
14	8	9	10	10	11	11	12	12	12	13	13	13	14	15	15	16
15	9	10	10	11	11	12	12	13	13	14	14	14	15	16	16	17
16	10	10	11	12	12	13	13	14	14	15	15	15	16	17	18	18
17	10	11	12	12	13	14	14	15	15	16	16	16	17	18	19	20
18	11	12	12	13	14	14	15	16	16	16	17	17	18	19	20	21
19	11	12	13	14	14	15	16	16	17	17	18	18	19	20	21	22
20	12	13	14	14	15	16	17	17	18	18	19	19	20	21	22	23
21	13	14	15	15	16	17	17	18	19	19	20	20	21	22	23	24
22	13	14	15	16	17	18	18	19	20	20	21	21	22	23	24	25
23	14	15	16	17	17	18	19	20	20	21	22	22	23	24	25	26
24	14	16	17	17	18	19	20	21	21	22	22	23	24	25	26	28
25	15	16	17	18	19	20	21	22	22	23	23	24	25	26	27	29
26	16	17	18	19	20	21	22	22	23	24	24	25	26	27	29	30
27	16	18	19	20	20	21	22	23	24	25	25	26	27	28	30	31
28	17	18	19	20	21	22	23	24	25	26	26	27	28	29	31	32
29	17	19	20	21	22	23	24	25	26	27	27	28	29	30	32	33
30	18	20	21	22	23	24	25	26	27	27	28	29	30	31	33	34

SECTION 4 Toughness tests

4.1. General

4.1.1 Toughness (impact) tests are to be performed on Charpy V-notch specimens. Furthermore, material intended for service at below ambient temperatures shall be tested using Charpy V-notch specimens.

4.1.2 For material under 10 mm in thickness, the largest possible size of subsize Charpy V-notch specimen is to be prepared with the notch cut on the narrow face. Generally, toughness tests are not required when the thickness of the material is less than 5 mm.

4.2. Dimensions of test specimens

4.2.1 Charpy V-notch impact specimens

The Charpy V-notch impact test specimens shall comply with the requirements of Table 2.4.1 (see also Figure 2.4.1).

Figure 2.4.1: Charpy V-notch impact specimen

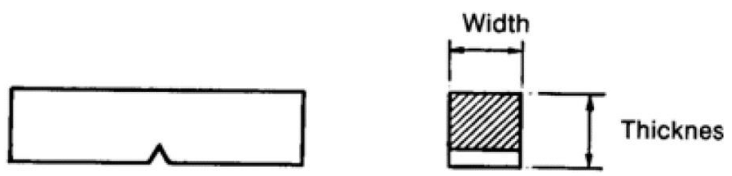


Table 2.4.1: Dimensions and tolerances for Charpy V-notch impact specimen

Dimensions	Nominal	Tolerances
Length	55,0 mm	±0,60 mm
Width -standard specimen	10,0 mm	±0,11 mm
- subsize specimen	7,5 mm	±0,11 mm
- subsize specimen	5,0 mm	±0,06 mm
Thickness	10,0 mm	±0,06 mm
Angle of notch	45 deg.	±2 deg.
Depth below notch	8,0 mm	±0,06 mm
Root radius	0,25 mm	±0,025 mm
Distance of notch from end of test specimen	27,5 mm	±0,42 mm
Angle between plane of symmetry of notch and longitudinal axis of test specimen	90 deg	±2 deg

4.2.2 Sub size Charpy requirements

The testing and requirements for smaller than 5,0mm size specimens are to be in accordance with the general practice of LHR. Minimum average values for subsized specimens are as follows:

Charpy V-notch specimen size	Minimum energy, average of 3 specimens
10 mm x 10 mm	E
10 mm x 7,5 mm	5E/6
10 mm x 5,0 mm	2E/3

E = the values of energy specified for full thickness 10 mm x 10 mm specimens

All other dimensions and tolerances are to be as specified in 4.2.1.

Only one individual value may be below the specified average value provided it is not less than 70% of that value. In all cases, the largest size Charpy specimens possible for the material thickness shall be machined.

4.3. Testing procedure

4.3.1 All impact tests are to be carried out on Charpy machines complying with the requirements of ISO 148-2:2016 as amended or other national and international recognised standards and having a striking energy of not less than 150 J.

Where the test temperature is other than ambient the temperature of the test specimen at the moment of breaking shall be the specified temperature within ±2°C.

4.4. Charpy re-test procedure

4.4.1 Where specified the following Charpy re-test procedure will apply:

When the average value of the three initial Charpy V-notch impact specimens fails to meet the stated requirement, or the value for more than one specimen is below the required average value, or when the value of any one specimen is below 70% of the specified average value, three additional specimens from the same material may be tested and the results added to those previously obtained to form a new average. If this new average complies with the requirements and if not more than two individual results are lower than the required average and of these, not more than one result is below 70% of the specified average value the piece or batch (as specified for each product) may be accepted.

4.5. Drop weight specimens

4.5.1 Drop weight specimens for the determination of no-break performance according to ASTM E-208:2019 are to comply with this ASTM standard and have one of the following dimensions (mm):

1. Type P-1: 25 by 90 by 360
2. Type P-2: 19 by 50 by 130
3. Type P-3: 16 by 50 by 130

4.5.2 The following is to be noted if not otherwise specified:

1. the specimen sides shall be saw-cut or machined (minimum 25 mm to flame-cut surface)
2. the machining of the plate to prescribed specimen thickness shall be on one side only
3. the specimens may be of any orientation, but the orientation shall be the same for all specimens.

SECTION 5 Ductility tests for pipes and tubes

5.1. General

5.1.1 All tests are to be carried out at ambient temperature unless otherwise specified.

5.2. Tensile test

5.2.1 The tensile test is to be performed according to the general rules for tensile tests (see SECTION 3) and results are to comply with the appropriate requirements given in the relevant Section.

5.3. Flattening test specimens

5.3.1 Length is to be from 10 mm to 100 mm. Plain and smoothed ends cut perpendicular to the tube axis. Reference is made to ISO 8492:2013 as amended.

5.3.2 The specimens are to be flattened between two plain parallel and rigid platens to the prescribed distance H (see Figure 2.5.1), given by the following formula:

$$H = \frac{t \cdot (1 + C)}{C + \frac{t}{D}}$$

where

H = distance between the parallel platens, mm

t = thickness of pipe wall, mm

D = outside diameter of pipe, mm

C = constant given in the relevant specific requirements, depending on the steel grade.

After flattening, the specimens are to be free from cracks or other flaws. Small cracks at the ends of the test specimens may be disregarded.

5.3.3 In the case of welded pipes, the specimen shall be placed in the press so that the seam is set at 90° to the direction of the force applied.

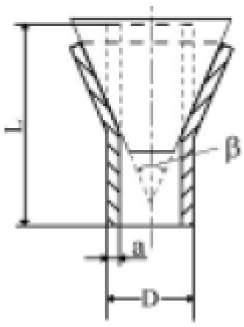
5.4. Drift expanding test

5.4.1 The lengths L of the drift expanding test specimens are to be as follows (Figure 2.5.1). Reference is made to ISO 8493:1998 as amended.

Metallic tubes: L equal to twice the external diameter D of the tube if the angle of the drift β is 30°, and L equal to 1,5D if the angle of the drift is 45° or 60°. The test piece may be shorter provided that after testing the remaining cylindrical portion is not less than 0,5D.

The rate of penetration of the mandrel shall not exceed 50mm/min.

Figure 2.5.1: Drift expanding test specimen

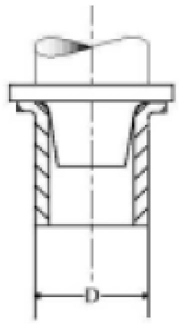


5.5. Flanging test

5.5.1 The flanging test specimen (Figure 2.5.2) is to be of length L equal to approximately 1,5D. The test piece may be shorter provided that after testing the remaining cylindrical portion is not less than 0,5D.

The rate of penetration of the forming tool shall not exceed 50mm/min. Reference is made to ISO 8494:2013 as amended.

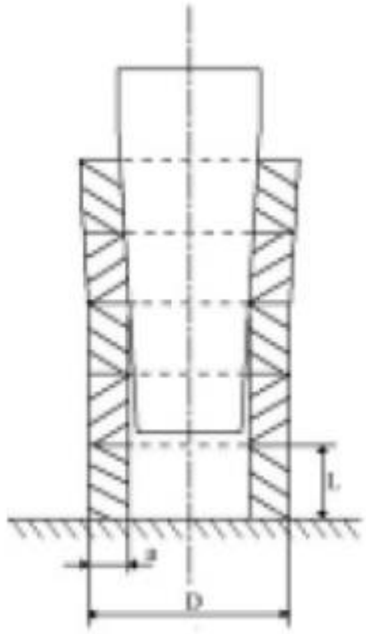
Figure 2.5.2: Flanging test specimen



5.6. Ring expanding test

The test piece consists of a ring having a length of between 10 and 16mm. The rate of penetration of the mandrel shall not exceed 30mm/s. Reference is made to ISO 8495:2013 as amended.

Figure 2.5.3: Ring expanding test piece



5.7. Ring tensile test

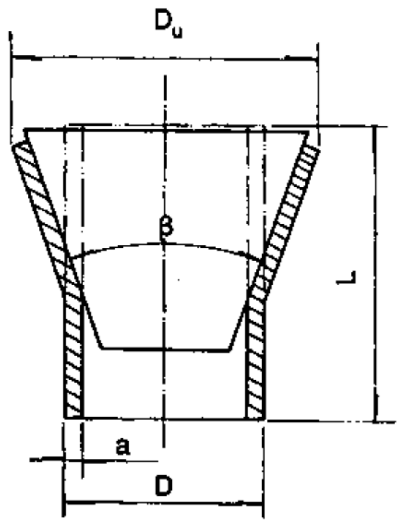
The ring shall have a length of about 15mm with plain and smoothed ends cut perpendicular to the tube axis. The ring is to be drawn to fracture by means of two mandrels placed inside the ring and pulled in tensile testing machine. The rate shall not exceed 5mm/s.

Reference is made to ISO 8496:2013 as amended.

5.8. Flanging

5.8.1 Flanging is to be carried out in two stages: first with a conical mandrel having an included angle of 90°, Figure 2.5.3(a), and then with a forming tool as shown in Figure 2.5.3(b). The test is completed when a flange perpendicular to the specimen axis is formed, with an outside diameter not less than the value given in the specific requirements for boiler and superheater tubes (see Part 2, Chapter 6). After the test, the specimens shall be visually examined and will be considered satisfactory if they are free from cracks.

Figure 2.5.2: Symbols for drift expanding test



Symbol	Designation	Unit
D	Original outside diameter of tube	mm
A	Wall thickness of tube	mm
L	Length of test piece before test	mm
D_u	Max outside diameter after testing	mm
β	Angle of the mandrel	degree

5.9. Hydraulic test

5.9.1 Pipes and tubes are to undergo hydraulic test to a pressure determined from the following formula, but the maximum pressure used should not be more than 140 bar (14 N/mm²):

$$p = 20 \cdot s \cdot \frac{t}{D}, \quad [bar]$$

where:

p = test pressure, bar

D = outside diameter, mm

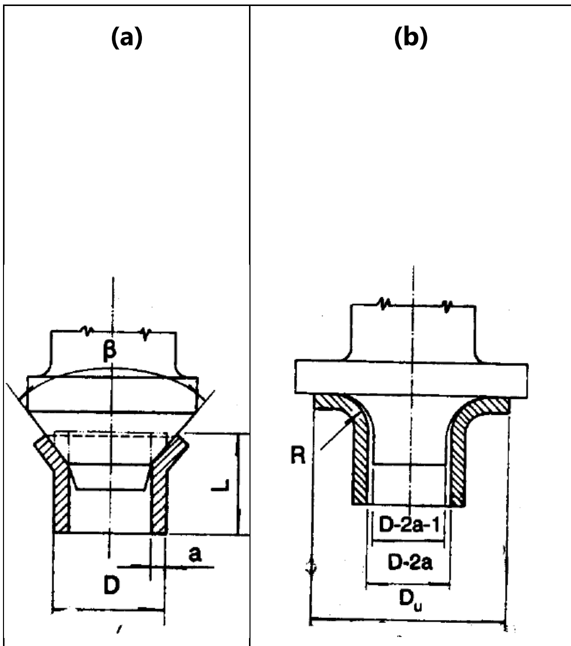
t = wall thickness, mm

s = 0,8 of the specified minimum yield stress, in N/mm², for ferritic steels, and 0,7 of the specified minimum 1,0 per cent proof stress, in N/mm², for austenitic steels. These relate to the values specified for acceptance testing at ambient temperature.

5.9.2 The test is considered satisfactory if the pressure is maintained for sufficient time to permit proof and inspection.

5.9.3 Subject to special approval, either an ultrasonic or an eddy current test may be accepted in place of the hydraulic test.

Figure 2.5.3: Symbols for flanging test



Symbol	Designation	Unit
D	Original outside diameter of tube	mm
a	Wall thickness of tube	mm
L	Length of test piece before test	mm
R	Corner radius of 2nd forming tool	mm
D_u	Max outside diameter after testing	mm
β	Angle of the mandrel	degree

5.10. Bend test

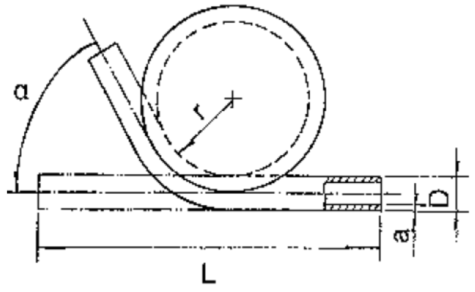
5.10.1 A test piece is to be taken from the end of the pipe and to be of sufficient length for the test.

5.10.2 The test piece is to be bent around a former of a diameter equal to 6 times its outside diameter to an angle of 90° (see Figure 2.5.4).

5.10.3 The test is considered satisfactory if upon visual examination no cracks or flaws are observed.

5.10.4 Reference is made to: ISO 8491-1986, as amended: Metallic Materials - Tube (in full section) - Bend test.

Figure 2.5.4: Symbols for bend test



Symbol	Designation	Unit
D	Original outside diameter of tube	mm
a	Wall thickness of tube	mm
L	Length of test piece before test	mm
r	Inside radius at bottom of groove	mm
α	Angle of the bend	degree

5.11. Impact test

5.11.1 This test, where requested, shall be performed and evaluated as described and specified in SECTION 4.

5.11.2 The average energy required will be as specified in the relevant section for low temperature ferritic steels (see Part 2, Chapter 6).

5.12. Intercrystalline corrosion test

5.12.1 This test shall be requested for austenitic stainless steel.

5.12.2 The test shall be performed in accordance with a recognized national standard (e.g. DIN 50914).

5.13. Stress corrosion cracking test

5.13.1 This test is applicable to aluminum brass only.

5.13.2 The test shall be performed in accordance with a recognized national standard (e.g. DIN 50911).

5.14. Non-destructive tests and visual examination.

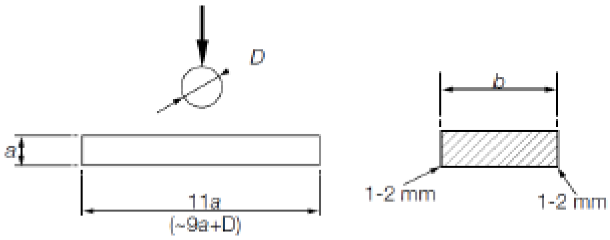
5.14.1 NDT tests shall be performed in a continuous manner using ultrasonic or eddy current methods. Radiographic inspection may be also used for welded pipes.

5.14.2 These tests shall be performed in accordance with a recognized national or international standard.

SECTION 6 Bend tests

6.1 Flat bend test specimen, as given in the following, is to be used (Figure 2.6.1). Edges on tension side to be rounded to a radius of 1 to 2 mm.

Figure 2.6.1: Flat bend test specimen



6.2 Forgings, castings and semi-finished products

a = 20 mm

b = 25 mm

6.3 Plates, structural sections, sheets:

a = t

b = 30 mm

6.4 Butt welds, transverse specimen

a. face and root bend

a = t
b = 30 mm

If the as rolled thickness t is greater than 25 mm, it may be reduced to 25 mm by machining on the compression side of the bend specimen.

The surfaces of the weld are to be machined (ground) flush with the surface of the plate.

b. side bend

a = 10 mm
b = t
If t ≥ 40 mm, the side-bend specimen may be subdivided, each part being at least 20 mm wide.

6.5 Butt weld, longitudinal specimens

The test specimens, for longitudinal face and root test, are to be in accordance with an appropriate recognised standard.

CHAPTER 3 Rolled steel

CONTENTS

SECTION 1 Scope

1.1 General

1.1.1 This Section gives the general requirements to be applied in the manufacture and testing of hot rolled steel plates, wide flats, strips, sections and bars intended for use in hull construction of ships and other marine structures and machinery equipment.

1.1.2 Hot-rolled round bars intended for the manufacture by machining of shafts, bolts, tie rods and similar parts are subject to the requirements of Part 2, Chapter 5.

1.1.3 The manufacture and testing of the products are also subject to the requirements of:

- Part 2, Chapter 1 - General Requirements
- Part 2, Chapter 2 - Testing Procedures for Materials

1.1.4 Materials conforming to national or international standards may be approved, if their specifications are considered to be equivalent to those of the types of steel mentioned in these Rules or if special approval for their use has been granted.

SECTION 2 General requirements

2.1. Manufacture

2.1.1 Manufacturers wishing to supply products accepted by these Rules must be approved by LHR for the type and grade of steel which is being supplied by their works.

2.1.2 Steel is to be manufactured by the basic oxygen, electric furnace or open-hearth process or by other methods approved by LHR.

2.1.3 The steel may be cast in ingots or in a continuous casting process approved by LHR. The size of the ingot or the continuous cast billet or slab is to be chosen in relation to the final dimensions of the finished products in order that the amount of mechanical work will be such as to ensure a satisfactory structure in the finished product. In order to avoid laminations, segregations and other defects liable to impair the use of ingots and slabs, sufficient material shall be taken from the top and bottom ends of slabs.

2.1.4 The manufacturer is to adopt a system for the identification of ingots, slabs and finished pieces which will enable the material to be traced to its original cast. The Surveyor is to be given full facilities for so tracing the material when required.

2.2. Deoxidation practice and chemical composition

2.2.1 The steels may be rimmed, semi-killed, killed or fully killed and fine grain treated, as specifically indicated in the following sections of this Chapter.

2.2.2 The chemical composition of samples taken from each ladle of each cast is to be determined by the manufacturer in an adequately equipped and competently staffed laboratory. The chemical composition of the steels obtained by ladle analysis must conform to the specifications of the following sections of this Chapter. Minor positive or negative excesses beyond the limit values, established by analysis of the product, are acceptable, provided that they do not impair the properties of the product.

2.3. Condition of supply

2.3.1 All materials are to be supplied in the condition prescribed in the appropriate specifications of the individual sections.

2.3.2 When controlled rolling or thermo-mechanical controlled processing is permitted as an alternative to normalizing, these procedures may be used subject to the special approval of LHR.

2.3.3 These rolling procedures are defined as follows:

1. Controlled Rolling. This is a procedure in which generally the final rolling temperature is controlled within the range used for normalizing heat treatments so that the austenite recrystallises.
2. Thermo-Mechanical Controlled Processing. This is a procedure which involves the strict control of both the steel temperature and the rolling reduction. Generally, a high proportion of the rolling reduction is carried out close to or below the Ar_3 transition temperature and may involve rolling towards the lower end of the temperature range of the intercritical duplex phase region, thus permitting little if any recrystallisation of the austenite (before subjecting these steels to further heating for forming or stress relieving, or using high energy input welding, consideration must be given to the possibility of a consequent reduction in mechanical properties).

2.3.4 Notwithstanding the heat treatment specifications, products which are to undergo subsequent hot forming may be supplied in the untreated state or in a condition favorable for the late hot forming operation.

2.4. Freedom from defects

2.4.1 The steel is to be reasonably free from segregations and non-metallic inclusions. The finished material is to have a workmanlike finish and is to be free from internal and surface defects prejudicial to the use of the material for the intended application. Where necessary, suitable methods of non-destructive examination may be used for the detection of harmful surface and internal defects. The extent of such an examination is to be agreed with LHR.

2.4.2 The acceptance criteria for surface finish and procedures for the repair of defects, as detailed in IACS Recommendation, No 12, "Guidance for the Surface Finish of Hot Rolled Steel Plates and Wide Flats" are to be observed.

2.5. Tolerances

2.5.1 Unless otherwise agreed or specially required, the under-thickness tolerances of plates and wide flats are to be in accordance with ANNEX A to this Chapter. However, the requirements for plates and wide flats specified in the standards are to be fulfilled with respect to all other dimensional and geometrical tolerances.

2.5.2 Steel sections and bars are governed by the dimensional and geometrical tolerances specified in the standards.

2.6. Mechanical properties

2.6.1 For the tensile test, either the upper yield stress (R_{eH}) or the 0,2 percent proof stress (R_p 0,2) is to be determined and the material is to be considered to comply with the requirements if either value meets or exceeds the specified minimum value for yield strength (R_e). The tensile strength, R_m, and the elongation measured on $5{,}65 \cdot \sqrt{S_o}$ specimen (i.e. A_5 elongation) are the other results from the tensile tests depicted in the following sections. The requirements of Part 2, Chapter 2, SECTION 3 are also applicable.

2.6.2 The notch impact energy specified for the individual steels must be fulfilled by the average value of three specimens, one of which may produce a value below, though not less than 70% of, the average value. Dimensions and tolerances of Charpy V-notch specimens are to be in accordance with the requirements of Part 2, Chapter 2, SECTION 4.

2.6.3 Where special properties, such as resistance to intercrystalline corrosion, resistance to brittle fracture or high-temperature strength, are prescribed for certain groups of products, these must be proved by appropriate tests as necessary.

2.7. Testing and inspection

2.7.1 The manufacturer is to afford the Surveyor all necessary facilities and access to all relevant parts of the works to enable him to verify that the approved process is adhered to, for the selection of test materials, and the witnessing of tests, as required by the Rules, and for verifying the accuracy of the testing equipment.

2.7.2 The prescribed tests and inspections are to be carried out at the place of manufacture before dispatch, but in the event of any material proving unsatisfactory during subsequent working or fabrication, such material is to be rejected, notwithstanding any previous certificates, and the Surveyor may require further tests from other materials from the same batch. The test specimens and procedures are to be in accordance with Part 2, Chapter 2. All the test specimens are to be selected and stamped by the Surveyor and tested in his presence, unless otherwise agreed.

2.7.3 If plates and wide flats with thickness of 15 mm and over are ordered with through thickness properties, the through thickness tensile test in accordance with SECTION 8 of this Chapter with specified minimum Through Thickness Properties ("Z" quality) is to be carried out.

2.7.4 Verification of dimensions are the responsibility of the manufacturer and the acceptance by the Surveyor shall not absolve the manufacturer from this responsibility.

2.7.5 When steel is not produced at the works at which it is rolled, a certificate is to be supplied to the Surveyor at the rolling mill stating the process by which it was manufactured, the name of the manufacturer who supplied it, the number of the cast from which it was made and the ladle analysis. The Surveyor is to have access to the works at which the steel was produced.

2.8. Test samples

2.8.1 All material in a batch presented for acceptance tests is to be of the same product form e.g. plates, flats, sections, etc., from the same cast and in the same condition of supply.

2.8.2 The test samples are to be fully representative of the material and, where appropriate, are not to be cut from the material until heat treatment has been completed.

2.8.3 The test specimens are not to be separately heat-treated in any way.

2.8.4 Unless otherwise agreed, the test samples are to be taken from the following positions:

1. Plates and flats with a width ≥ 600 mm. The test samples are to be taken from one end at a position approximately midway between the axis in the direction of rolling and the edge of the rolled product (see Figure 3.2.1). Unless otherwise agreed, the tensile test specimens are to be prepared with their longitudinal axes transverse to the final direction of rolling.

2. Flats with a width < 600 mm, bulb flats and other sections. The test samples are to be taken from one end at a position approximately one third from the outer edge (see Figure 3.2.2, Figure 3.2.3, Figure 3.2.4) or, in the case of small sections, as near as possible to this position. In the case of channels, beams or bulb angles, the test samples may alternatively be taken from a position approximately one quarter of the width from the web centre line or axis (see Figure 3.2.3). The tensile test specimens may be prepared with their longitudinal axes either parallel or transverse to the final direction of rolling.

3. Bars and other similar products. The test samples are to be taken so that the longitudinal axes of the test specimens are parallel to the direction of rolling and are as near as possible to the following:
   - for non-cylindrical sections, at one third of the half diagonal from the outside,

- for cylindrical sections, at one third of the radius from the outside (see Figure 3.2.6)

Figure 3.2.1: Plates and flats

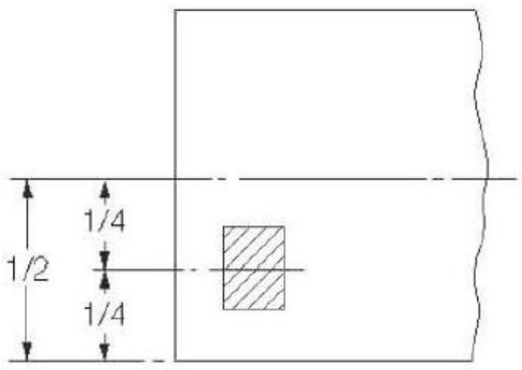


Figure 3.2.2: Angles

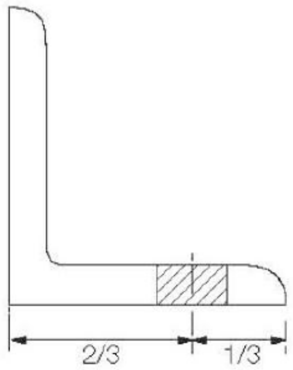


Figure 3.2.3: Channel and beams

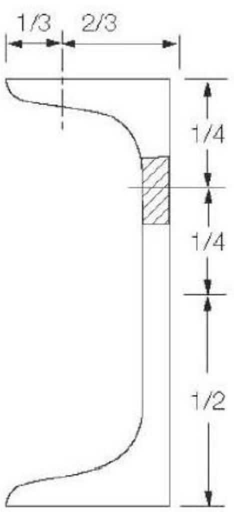


Figure 3.2.4: H-sections

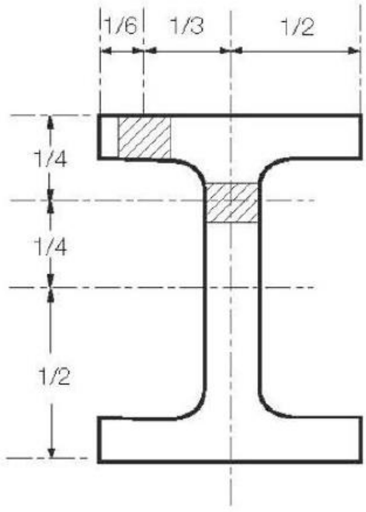


Figure 3.2.5: Bulb flats

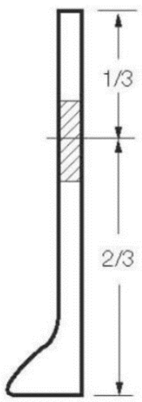
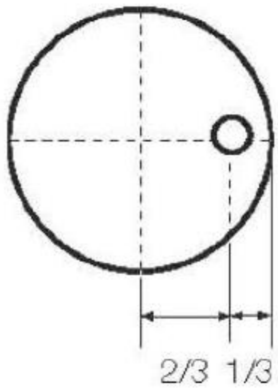


Figure 3.2.6: Bars



2.9. Mechanical test specimens

2.9.1 Tensile test specimens. The dimensions of the tensile test specimens are to be in accordance with Part 2, Chapter 2, SECTION 3. Generally, for plates, wide flats and sections flat test specimens of full product thickness are to be used. Round test specimens may be used for bars and other similar products when the product thickness exceeds 40 mm or for bards and other similar products. Alternatively, for small sizes of bars, etc. test specimens may consist of a suitable length of the full cross section of the product.

2.9.2 Impact specimens. The impact test specimens are to be of the Charpy V-notch type cut with their edge within 2 mm from the "as rolled" surface with their longitudinal axes either parallel (indicated "Long" in Table 3.3.6 and Table 3.3.7) or transverse (indicated "Trans" in Table 3.3.6 and Table 3.3.7) to the final direction of rolling of the material. The notch is to be cut in a face of the test specimen which was originally perpendicular to the rolled surface. The position of the notch is not to be nearer than 25 mm to a flame cut or sheared edge (see also 3.6.3). Where the product thickness exceeds 40 mm, the impact test specimens are to be taken with their longitudinal axis at a quarter thickness position.

2.10. Number of test specimens

2.10.1 Number of tensile tests. For each batch presented, except where specially agreed by LHR, one tensile test is to be made from one piece, unless the weight of the finished material is greater than 50 tonnes in which case one extra test is to be made from a different piece from each 50 tonnes or fraction thereof. Additionally, tests are to be made for every variation of 10 mm in the thickness or diameter of products from the same cast.

2.10.2 Number of Impact Tests (except for Grades LHR-E, LHR-EH32, LHR-EH36, LHR-EH40, LHR-FH32, LHR-FH36 and LHR-FH40) see Table 3.2.1 and Table 3.2.2.

i. Except where otherwise specified or specially agreed by LHR, for each batch presented, at least one set of three Charpy V-notch test specimens is to be made from one piece unless the weight of finished material is greater than 50 tonnes, in which case one extra set of three test specimens is to be made from a different piece from each 50 tonnes or fraction thereof. When steel plates except for Grade LHR-A steel over 50 mm in thickness is supplied in the controlled rolled condition, the frequency of impact test is to be made from a different piece from each 25 tonnes or fraction thereof.
ii. For steel plates of Grades LHR-AH40 and LHR-DH40 with thickness over 50 mm in normalized or TM condition, one set of impact test specimens is to be taken from each batch of 50 tonnes or fraction thereof. For those in QT condition, one set of impact test specimens is to be taken from each length as heat-treated.
iii. When, subject to the special approval of LHR, material is supplied in the as rolled condition, the frequency of impact tests is to be increased to one set from each batch of 25 tonnes or fraction thereof. Similarly Grade LHR-A steel over 50mm in thickness may be supplied in the as rolled condition. In such case one set of three Charpy V-notch test specimens is to be taken from each batch of 50 tonnes or fraction thereof.

iv. The piece selected for the preparation of the test specimens is to be the thickest in each batch.

2.10.3 Number of Impact Tests (Grades LHR-E, LHR-EH32, LHR-EH36, LHR-EH40, LHR-FH32, LHR-FH36 and LHR-FH40)

i. For steel plates supplied in the normalized or TM condition one set of impact test specimens is to be taken from each piece. For quenched and tempered steel plates one set of impact test specimens is to be taken from each length as heat-treated.

ii. For sections one set of impact tests is to be taken from each batch of 25 tonnes or fraction thereof.

iii. When, subject to the special approval of LHR, sections other than Grades LHR-EH40 and LHR-FH40 are supplied in the as rolled or controlled rolled condition, one set of impact tests is to be taken from each batch of 15 tonnes or fraction thereof.

iv. For (ii) and (iii) above the piece selected for the preparation of the test specimens is to be the thickest in each batch.

Table 3.2.1: Required condition of supply and number of impact tests for normal strength steels

<table>
<tr><th rowspan="3">Grade</th><th rowspan="3">Deoxidation Practice</th><th rowspan="3">Products</th><th colspan="5">Condition of Supply (Batch for Impact Tests) (1)(2)</th></tr>
<tr><th colspan="5">Thickness (mm)</th></tr>
<tr><th>10 12,5</th><th>20 25</th><th>30 35</th><th>40 50</th><th>100</th></tr>
<tr><td rowspan="3">LHR-A</td><td>Rimmed</td><td>Sections</td><td>A (-)</td><td colspan="4">Not Applicable</td></tr>
<tr><td rowspan="2">For t≤ 50 mm
Any method
except rimmed
For t > 50 mm
Killed</td><td>Plates</td><td colspan="4">A (-)</td><td>N (-)
TM (-) (3)
CR (50), AR* (50)</td></tr>
<tr><td>Sections</td><td colspan="4">A (-)</td><td>Not applicable</td></tr>
<tr><td rowspan="2">LHR-B</td><td rowspan="2">For t≤ 50 mm
Any method
except rimmed
For t > 50 mm
Killed</td><td>Plates</td><td colspan="2">A (-)</td><td colspan="2">A (50)</td><td>N (50)
TM (50)
CR (25), AR* (25)</td></tr>
<tr><td>Sections</td><td colspan="2">A (-)</td><td colspan="2">A (50)</td><td>Not applicable</td></tr>
<tr><td rowspan="2">LHR-D</td><td>Killed</td><td>Plates
Sections</td><td colspan="2">A (50)</td><td colspan="3">Not Applicable</td></tr>
<tr><td>Plates</td><td>Plates</td><td colspan="3">A (50)</td><td>N(50)
CR (50)
TM(50)</td><td>N(50)
CR (50)
TM(50)</td></tr>
</table>

	Killed and fine Grain treated	Sections	A (50)	N(50) CR (50) TM(50) AR* (25)	Not applicable
LHR-E	Killed and fine grain treated	Plates	N (Each piece) TM (Each piece)		
		Sections	TM (25) TM (25) AR* (15), CR* (15)		Not applicable

NOTES:

1. Conditions of Supply

   A - Any
   N - Normalized Condition
   CR - Controlled Rolled Condition
   TM - Thermo-Mechanical rolling
   AR* - As Rolled Condition subject to special approval of LHR
   CR* - Controlled Rolled Condition subject to special approval of LHR

2. Number of Impact Tests

   One set of impact tests is to be taken from each batch of the "specified weight" in ( ) or fraction thereof.

3. See Note (5) of Table 3.3.6.

Table 3.2.2: Required condition of supply and number of impact tests for higher strength steels (see continuation)

Grade	Deoxidation Practice	Grain Refining Elements	Products	Condition of Supply (Batch for Impact Tests) (1)(2)		
				Thickness (mm) 10 12,5 20 25 30 35 40 50100		
LHR-AH32 LHR-AH36	Killed and fine Grain treated	Nb and/or V	Plates	A(50)	N(50) CR(50),TM(50)	N(50),CR(25), TM(50)
			Sections	A(50)	N(50) CR(50),TM(50) AR*(25)	Not applicable
					AR*(25)	Not applicable

		Al alone Or with Ti	Plates	A(50)		N(50), CR(50), TM(50)	N(50),CR(25), TM(50)
			Sections	A(50)		N (50) CR(50) TM(50) AR*(25)	Not applicable
LHR-AH40	Killed and fine Grain treated	Any	Plates Sections	A(50)		N(50) CR(50) TM(50)	Not applicable
LHR-DH32 LHR-DH36	Killed and fine Grain treated	Nb and/or V	Plates	A(50)		N(50) CR(50), TM(50)	N(50),CR(25), TM(50)
			Sections	A(50)		N(50) CR(50),TM(50) AR*(25)	Not applicable
		Al alone or with Ti	Plates	A(50)		AR* (25)	Not applicable
						N(50),CR(50)TM(50)	N(50),CR(25), TM(50)
			Sections	A(50)		N (50) CR(50),TM(50) AR*(25)	Not applicable
LHR-DH40	Killed and fine Grain treated	Any	Plates Sections	N(50) CR(50) TM(50)			Not applicable
	Killed and fine grain		Plates	N(Each piece) TM(Each piece)			

LHR-EH32 LHR-EH36	treated	Any			
			Sections	N(25) TM(25) AR*(15), CR*(15)	Not applicable
LHR-EH40	Killed and fine grain treated	Any	Plates	N(Each piece) TM(Each piece) QT(Each length as heat-treated)	Not applicable
			Sections	N(25) TM(25) QT(25)	Not applicable

Table 3.2.2: **Required condition of supply and number of impact tests for higher strength steels (continuation)**

Grade	Deoxidation Practice	Grain Refining Elements	Products	Condition of Supply (Batch for Impact Tests) (1)(2) Thickness (mm) 10 12,5 20 25 30 35 40 50 100	
LHR-FH32 LHR-FH36	Killed and fine Grain treated	Any	Plates	N (Each piece) TM (Each piece) QT (Each length as heat-treated)	N (Each piece) TM (Each piece) QT (Each length as heat-treated)
			Sections	N(25) TM (25) QT (25) CR* (15)	Not applicable
LHR-FH40	Killed and fine Grain treated	Any	Plates	N (Each piece) TM (Each piece) QT (Each length as heat-treated)	Not applicable
			Sections	N (25) TM (25) QT (25)	Not applicable

NOTES:

1. Conditions of Supply

A	- Any
N	- Normalized Condition
CR	- Controlled Rolled Condition
TM	- Thermo-Mechanical rolling
QT	- Quenched and Tempered Condition
AR*	- As Rolled Condition subject to special approval of LHR
CR*	- Controlled Rolled Condition subject to special approval of LHR

2. Number of Impact Tests
   One set of impact tests is to be taken from each batch of the "specified weight" in ( ) or fraction thereof. For grades LHR-AH32 and LHR-AH36 steels a relaxation in the number of impact tests may be permitted. (See Note (3) of Table 3.3.7.

2.11. Retest Procedures

2.11.1 When the tensile test from the first piece selected in accordance with 2.10.1 fails to meet the requirements, re-test requirements for tensile tests are to be in accordance with Part 2, Chapter 2 two further tensile tests may be made from the same piece. If both of these additional tests are satisfactory, this piece and the remaining pieces from the same batch may be accepted. Re-test requirements for Charpy impact tests are to be in accordance with Part 2, Chapter 2.

2.11.2 If one or both of the additional tests referred to above are unsatisfactory, the piece is to be rejected, but the remaining material from the same batch may be accepted provided that two of the remaining pieces in the batch selected in the same way, are tested with satisfactory results. If unsatisfactory results are obtained from either of these two pieces, then the batch of material is to be rejected.

2.11.3 When the average value of the three initial Charpy V-notch impact specimens fails to meet the stated requirement, or the value for more than one specimen is below the required average value, or when the value of any one specimen is below 70% of the specified average value, three additional specimens from the same material may be tested and the results added to those previously obtained to form a new average. If this new average complies with the requirements and if not more than two individual results are lower than the required average and of these, not more than one result is below 70% of the specified average value the piece or batch may be accepted.

2.11.4 When the initial piece, representing a batch, gives unsatisfactory results from the additional Charpy V-notch impact tests referred to above, this piece is to be rejected but the remaining material in the batch may be accepted provided that two of the remaining pieces in the batch are tested with satisfactory results. If unsatisfactory results are obtained from either of these two pieces, then the batch of material is to be rejected. The pieces selected for these additional tests are to be the thickest remaining in the batch.

2.11.5 If any test specimen fails because of faulty preparation, visible defects or (in the case of tensile test) because of fracturing outside the range permitted for the appropriate gauge length, the defective test piece may, at the Surveyors discretion, be disregarded and replayed by an additional test piece of the same type.

2.11.6 At the option of the steelmaker, when a batch of material is rejected, the remaining pieces in the batch may be resubmitted individually for test and those pieces which give satisfactory results may be accepted.

2.11.7 At the option of the steelmaker, rejected material may be resubmitted after heat treatment or re-heat treatment, or may be resubmitted as another grade of steel and may then be accepted provided the required tests are satisfactory.

2.11.8 In the event of any material proving unsatisfactory during subsequent working or fabrication, such material may be rejected, notwithstanding any previous satisfactory testing and/or certification.

2.12. Marking

2.12.1 Every finished piece is to be clearly marked by the steelmaker in at least one place with the LHR certification mark and the following particulars:

1. Unified identification mark for the grade steel (e.g. A, A36)
2. Steels which have been specially approved by LHR and which differ from these requirements are to have the letter “S” after the above identification mark.
3. Material supplied in the thermo-mechanically controlled processed condition is to have the letters TM added after the identification mark.
4. Name or initials to identify the steelworks.
5. Cast or other number to identify the piece.
6. If required by the purchaser, his order number or other identification mark.

2.12.2 The above particulars, but excluding the steelmaker’s name or trade mark where this is embossed on finished products, are to be encircled with paint or otherwise marked so as to be easily recognizable.

2.12.3 In the event of any material bearing the MRS mark failing to comply with the test requirements, the mark is to be unmistakably defaced by the manufacturer.

2.12.4 Additional data may be required to be entered to the above-mentioned list of particulars, if so specified in the following Sections.

2.12.5 Where a number of light materials are securely fastened together in bundles the manufacturer may, subject to the agreement of LHR, brand only the top piece of each bundle, or alternatively, a firmly fastened durable label containing the brand may be attached to each bundle.

2.13. Certification

2.13.1 The Surveyor is to be supplied with the number of copies, as required by LHR, of the test certificates or the shipping statements for all accepted materials. LHR may require separate documents for each grade of steel. These documents are to contain, in addition to the description, dimensions, etc., of the material, at least the following particulars:

1. Purchaser's order number and, if known, the hull number for which the material is intended.
2. Identification of the cast and piece including, where appropriate, the test specimen number.
3. Identification of steelworks.
4. Identification of the grade of steel.
5. Ladle analysis.

6. Condition of supply when other than as rolled, i.e. normalized, controlled rolled or thermo-mechanically rolled.

2.13.2 Before the test certificates or shipping statements are signed by the Surveyor, the manufacturer is required to furnish him with a written declaration stating that the material has been made by an approved process and that it has been subjected to and has withstood satisfactorily the required tests in the presence of the Surveyor or his authorized deputy. The name of LHR is to appear on the test certificate. The following form of declaration will be accepted if stamped or printed on each test certificate or shipping statement with the name of the steelworks and signed by an authorized official of the manufacturer:

"We hereby certify that the material has been made by an approved process and has been satisfactorily tested in accordance with the Rules of Libero Hellenic Register."

2.13.3 Additional data may be required to be entered to the above-mentioned list of particulars, if so specified in the following Sections.

SECTION 3 Normal and higher strength hull structural steels (IACS UR W11 Rev.9 (2017))

3.1. Scope

3.1.1 These requirements apply to weldable normal and higher strength hot-rolled steel plates, wide flats, strips, sections and bars intended for use in hull construction.

3.1.2 The requirements are primarily intended to apply to steel products with a thickness as follows:

For steel plates and wide flats;

- Grades LHR-A, LHR-B, LHR-D, LHR-E, LHR-AH32, LHR-DH32, LHR-EH32, LHR-AH36, LHR-DH36 and LHR-EH36: Up to 100 mm in thickness
- Grades LHR-A40, D40, E40, F32, F36 and F40: Up to 50 mm in thickness

For sections and bars;

- All Grades: Up to 50 mm in thickness

For greater thickness certain variations in the requirements may be allowed or required in particular cases after consideration of the technical circumstances involved.

3.1.3 Provision is made for four grades of normal strength steel based on the impact test requirements. For higher strength steels provision is made for three strength levels (315, 355 and 390 N/mm^2), each subdivided into four grades based on the impact test temperature.

3.1.4 Steels differing in chemical composition, deoxidation practice, conditions of supply and mechanical properties may be accepted, subject to the special approval of LHR. Such steels are to be given a special designation.

3.1.5 These requirements also apply to normal and higher strength Corrosion Resistant steels when such steel is used as the alternative means of corrosion protection for cargo oil tanks as specified in the performance standard MSC.289 (87) of Regulation 3-11, Part A-1, Chapter II-1 of the SOLAS Convention (Corrosion protection of cargo oil tanks of crude oil tankers). Corrosion Resistant steels as defined within this SECTION, are steels whose corrosion resistance performance in the bottom or top of the internal cargo oil tank is tested and approved to satisfy the requirements in MSC.289 (87) in addition to other relevant requirements for hull structural steels, structural strength and construction. It is not intended that such steels be used for corrosion resistant applications in other areas of a vessel that are outside of those specified in the performance standard MSC.289 (87) of Regulation 3-11, Part A-1, Chapter II-1 of the SOLAS Convention. These requirements apply to plates, wide flats, sections and bars in all grades up to a maximum thickness of 50 mm.

3.2. Approval

3.2.1 All materials are to be manufactured at works which have been approved by LHR for the type and grade of steel which is being supplied. The suitability of each grade of steel for forming and welding is to be demonstrated during the initial approval tests at the steelworks. Approval of the steel works is to follow a scheme given in the ANNEX B. For the steels intended for high heat input welding over 50 kJ/cm, the approval of the manufacturer is to follow a scheme given in the ANNEX C. For steels intended for a corrosion resistant designation, the approval of the manufacturer is to additionally follow the scheme given in ANNEX E.

3.2.2 It is the manufacturer's responsibility to assure that effective process and production controls in operation are adhered to within the manufacturing specifications. Where control imperfection inducing possible inferior quality of product occurs, the manufacturer is to identify the cause and establish a countermeasure to prevent its recurrence. Also, the complete investigation report is to be submitted to the Surveyor. For further use, each affected piece is to be tested to the Surveyor's satisfaction.

The frequency of testing for the subsequent products offered may be increased to gain confidence in the quality at the discretion of LHR.

3.2.3 When steel is not produced at the works at which it is rolled, a certificate is to be supplied to the Surveyor at the rolling mill stating the process by which it was manufactured, the name of the manufacturer who supplied it, the number of the cast from which it was made and the ladle analysis. The Surveyor is to have access to the works at which the steel was produced.

Note:

1. The attention of the users must be drawn to the fact that when fatigue loading is present, the effective fatigue strength of a welded joint of higher strength steel may not be greater than that of a welded joint in normal strength steels.
2. Before subjecting steels produced by thermo-mechanical rolling to further heating for forming or stress relieving, or using high heat-input welding, special consideration must be given to the possibility of a consequent reduction in mechanical properties.

3.3. Method of manufacture

3.3.1 Steel is to be manufactured by the basic oxygen, electric furnace or open-hearth processes or by other processes specially approved by LHR.

3.3.2 The deoxidation practice used for each grade is to comply with the appropriate requirements of Table 3.3.1 and Table 3.3.2.

3.3.3 The rolling practice applied for each grade is to comply with the appropriate condition of supply of Table 3.3.4 and Table 3.3.5. The applicable rolling procedures are defined as follows and the schematic diagrams are given in the ANNEX D.

1. As Rolled, AR

This procedure involves steel being cooled as it is rolled with no further heat treatment. The rolling and finishing temperatures are typically in the austenite recrystallization region and above the normalizing temperature. The strength and toughness properties of steel produced by this process are generally less than steel heat-treated after rolling or than steel produced by advanced processes.

2. Normalizing, N

Normalizing involves heating rolled steel above the critical temperature, Ac3, and in the lower end of the austenite recrystallization region for a specific period of time, followed by air cooling. The process improves the mechanical properties of as rolled steel by refining the grain size and homogenizing the microstructure.

3. Controlled Rolling, CR (Normalizing Rolling, NR):

A rolling procedure in which the final deformation is carried out in the normalizing temperature range, allowed to cool in air, resulting in a material condition generally equivalent to that obtained by normalizing.

4. Quenching and Tempering, QT

Quenching involves a heat treatment process in which steel is heated to an appropriate temperature above the Ac3, held for a specific period of time, and then cooled with an appropriate coolant for the purpose of hardening the microstructure. Tempering subsequent to quenching is a process in which the steel is reheated to an appropriate temperature not higher than the Ac1, maintained at that temperature for a specific period of time to restore toughness properties by improving the microstructure and reduce the residual stress caused by the quenching process.

5. Thermo-Mechanical Rolling, TM (Thermo-Mechanical Controlled Processing, TMCP)

This is a procedure which involves the strict control of both the steel temperature and the rolling reduction. Generally, a high proportion of the rolling reduction is carried out close to the Ar3 temperature and may involve the rolling in the dual phase temperature region. Unlike controlled rolled (normalized rolling) the properties conferred by TM (TMCP) cannot be reproduced by subsequent normalizing or other heat treatment. The use of accelerated cooling on completion of TM-rolling may also be accepted subject to the special approval of LHR. The same applies for the use of tempering after completion of the TM-rolling.

6. Accelerated Cooling, AcC

Accelerated cooling is a process, which aims to improve mechanical properties by controlled cooling with rates higher than air cooling immediately after the final TM-rolling operation. Direct quenching is excluded from accelerated cooling.

The material properties conferred by TM and AcC cannot be reproduced by subsequent normalizing or other heat treatment.

Where NR (CR) and TM with/without AcC are applied, the programmed rolling schedules are to be verified by LHR at the time of the steel works approval, and are to be made available when required by the attending Surveyor. On the manufacturer’s responsibility, the programmed rolling schedules are to be adhered to during the rolling operation. Refer to the above 3.2.2. To this effect, the actual rolling records are to be reviewed by the manufacturer and occasionally by the Surveyor.

When deviation from the programmed rolling schedules or normalizing or quenching and tempering procedures occurs, the manufacturer shall take further measures to the Surveyor's satisfaction, in accordance with the requirements of the above 3.2.2.

3.4. Chemical composition

3.4.1 The chemical composition of samples taken from each ladle of each cast is to be determined by the manufacturer in an adequately equipped and competently staffed laboratory and is to comply with the appropriate requirements of Table 3.3.1 and Table 3.3.2. For steel plates and wide flats over 50mm thick, slight deviations in the chemical composition may be allowed as approved by LHR.

3.4.2 The manufacturer's declared analysis will be accepted subject to occasional checks if required by the Surveyor.

3.4.3 For TM (TMCP) steels the following special requirements apply:

- The carbon equivalent value is to be calculated from the ladle analysis using the following formula and to comply with the requirements of Table 3.3.3;

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15} \quad (\%)$$

- The following formula (cold cracking susceptibility) may be used for evaluating weldability instead of the carbon equivalent at the discretion of LHR;

$$P_{cm} = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B \quad (\%)$$

In such cases the cold cracking susceptibility value required may be specified by LHR.

3.5. Condition of supply

3.5.1 All materials are to be supplied in a condition complying with the appropriate requirements of Table 3.3.4 and Table 3.3.5.

3.6. Mechanical properties

3.6.1 For tensile test either the upper yield stress (R_eH) or where R_eH cannot be determined, the 0,2% proof stress (R_p 0,2) is to be determined and the material is considered to comply with the requirements if either value meets or exceeds the specified minimum value for yield strength (R_e).

3.6.2 The results obtained from tensile tests are to comply with the appropriate requirements of Table 3.3.6 and Table 3.3.7.

3.6.3 Minimum average energy values are specified for Charpy V-notch impact test specimens taken in either the longitudinal or transverse directions (see 2.9.2). Generally, only longitudinal test specimens need to be prepared and tested except for special applications where transverse test specimens may be required by the purchaser or LHR. Transverse test results are to be guaranteed by the supplier.

The tabulated values are for standard specimens 10 mm x 10 mm. For plate thicknesses less than 10 mm, impact test may be waived at the discretion of LHR or subsize specimens, as specified in Part 2, Chapter 2, may be used.

3.6.4 The average value obtained from one set of three impact tests is to comply with the requirements given in Table 3.3.6 and Table 3.3.7. One individual value only may be below the specified average value provided it is not less than 70% of that value.

3.6.5 Generally, impact tests are not required when the nominal plate thickness is less than 6 mm.

Table 3.3.1: Chemical composition and deoxidation practice for normal strength steels

Grade	LHR-A	LHR-B	LHR-D	LHR-E
Deoxidation practice	For t≤50 mm Any method except rimmed steel (1) For t>50 mm killed	For t≤50 mm Any method except rimmed For t>50 mm killed	For t≤25 mm killed For t>25 mm killed and fine grain treated	Killed and fine grain treated
Chemical composition (%) (4) (7) (8) (ladle samples)	CARBON PLUS 1/6 OF THE MANGANESE CONTENT IS NOT TO EXCEED 0,40%			
C max	0,21 (2)	0,21	0,21	0,18
Mn min	2,5 x C	0,80 (3)	0,60	0,70
Si max	0,50	0,35	0,35	0,35
P max	0,035	0,035	0,035	0,035
S max	0,035	0,035	0,035	0,035
Al (acid soluble min)	-	-	0,015 (5) (6)	0,015 (6)

t: thickness, mm

Notes:

1. Grade LHR-A sections up to a thickness of 12,5 mm may be accepted in rimmed steel, provided that it is stated on the test certificates or shipping statements to be rimmed steel and it is not excluded by the purchaser's order. Subject to the special approval of LHR.
2. For sections max. 0,23%.
3. When Grade LHR-B is impact tested the minimum manganese content may be reduced to 0,60%.
4. When any grade of steel is supplied in the thermo-mechanically rolled condition variations in the specified chemical composition may be allowed or required by LHR after special consideration.
5. For Grade LHR-D steel over 25 mm thick. Only applicable to thicknesses of > 25 mm.
6. For Grade LHR-D steel over 25 mm thick and Grade LHR-E steel the total aluminum content may be determined instead of the acid soluble content. In such cases the total aluminum content is to be not less than 0,020%. A maximum aluminum content may also be specified by LHR. Other suitable grain refining

elements may be used subject to the special approval of LHR. Aluminum may be wholly or partly replaced by niobium or vanadium provided that the following contents are not exceeded: niobium 0,05%; vanadium: 0,10%, sum of niobium and vanadium 0,12%. The titanium content may not exceed 0,02%.

7. LHR may limit the amount of residual elements which may have an adverse effect on the working and use of the steel, e.g. copper and tin.
8. Where additions of any other element have been made as part of the steelmaking practice, the content is to be indicated.

Table 3.3.2: Chemical composition and deoxidation practice for higher strength steels

Grade [1]	LHR-AH32 LHR-DH32 LHR-EH32 LHR-AH36 LHR-DH36 LHR-EH36 LHR-AH40 LHR-DH40 LHR-EH40		LHR-FH32 LHR-FH36 LHR-FH40	
Deoxidation practice	Killed and fine grain treated			
Chemical composition % [5] [7] (ladle samples)				
C max.	0,18		0,16	
Mn	0,90 – 1,60 [2]		0,90 – 1,60	
Si max.	0,50		0,50	
P max.	0,035		0,025	
S max.	0,035		0,025	
Al (acid soluble min)	0,015 [3] [4]		0,015 [3] [4]	
Nb	0,02 – 0,05 [4]	total:	0,02 - 0,05 [4]	total
V	0,05 – 0,10 [4]	0.12	0,05 - 0,10 [4]	0.12
Ti max.	0,02	max.	0,02	max.
Cu max.	0,35		0,35	
Cr max.	0,20		0,20	
Ni max.	0,40		0,80	
Mo max.	0,08		0,08	
N max.	-		0,009 (0,012 if Al is present)	
Carbon Equivalent [6]				

Notes:

1. The letter "H" may be added either in front or behind the grade mark e.g. HA32 or AH32.
2. Up to a thickness of 12,5 mm the minimum manganese content may be reduced to 0,70%.
3. The total aluminum content may be determined instead of the acid soluble content. In such cases the total aluminum content is to be not less than 0,020%.
4. The steel is to contain aluminum, niobium, vanadium or other suitable grain refining elements either singly, or in any combination. When used singly the steel is to contain the specified minimum content of the grain refining element. When used in combination, the specified minimum content of a fine graining element is not applicable.
5. When any grade of higher strength steel is supplied in the thermo-mechanically rolled condition, variations in the specified chemical composition may be allowed or required by LHR.
6. When required, the carbon equivalent value is to be calculated from the ladle analysis using the following formula:

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad (\%)$$

   This formula is applicable only to steels which are basically of the carbon-manganese type and gives a general indication of the weldability of the steel.

7. Where additions of any other element have been made as part of the steelmaking practice, the content is to be indicated.

Table 3.3.3: Carbon equivalent for higher strength steels up to 100mm in thickness produced by TM

Grade	Carbon Equivalent, max (%) [1]	
	t ≤ 50	50 < t ≤ 100
LHR-AH32, LHR-DH32, LHR-EH32, LHR-FH32	0,36	0,38
LHR-AH36, LHR-DH36, LHR-EH36, LHR-FH36	0,38	0,40
LHR-AH40, LHR-DH40, LHR-EH40, LHR-FH40	0,40	0,42
t: thickness, mm		

Notes:
1. It is a matter for the manufacturer and shipbuilder to mutually agree in individual cases as to whether they wish to specify a more stringent carbon equivalent

Table 3.3.4: Condition of supply for normal strength steels [1]

Grades	Thickness	Condition of Supply
LHR-A	≤50 mm 50mm< t ≤ 100mm	Any Normalized, controlled rolled or thermo-mechanically rolled [2]
LHR-B	≤50 mm 50mm< t ≤ 100mm	Any Normalized, controlled rolled or thermo-mechanically rolled [2]
LHR-D	≤35 mm 35mm< t ≤ 100mm	Any Normalized, controlled rolled or thermo-mechanically controlled processed [3]
LHR-E	≤ 100 mm	Normalized or thermo-mechanically controlled processed [3]

Notes:
1. These conditions of supply and the impact test requirements are summarized in Table 3.2.1.
2. Subject to the special approval LHR, grades LHR-A and LHR-B steel plates may be supplied in the as rolled condition (see 2.10.2 (ii)).
3. Subject to the special approval of LHR, sections in grade LHR-D steel may be supplied in the as rolled condition provided satisfactory results are consistently obtained from Charpy-V notch impact tests. Similarly sections in Grade LHR-E steel may be supplied in the as rolled or controlled rolled condition. The frequency of impact tests is to be in accordance with 2.10.2 (ii) and 2.10.3 (iii) respectively.

Table 3.3.5: Condition of supply for higher strength steel

Grade	Grain refining Elements used	Thickness	Condition of Supply
LHR-AH32 LHR-AH36	Nb and/or V	≤ 12,5 mm	Any
		12,5mm < t ≤ 100mm	Normalized, controlled rolled or thermo-mechanically rolled [(3)]
	Al alone or with Ti	≤ 20 mm	Any
		20 mm < t ≤ 35 mm	Any, as rolled subject to special approval of LHR [(2)]
		35 mm < t ≤ 100 mm	Normalized, controlled rolled or thermo-mechanically rolled [(3)]
LHR-AH40	Any	≤ 12,5 mm	Any
		12,5 mm< t ≤ 50 mm	Normalized, controlled rolled or thermo-mechanically rolled
		50 mm < t ≤ 100 mm	Normalized, thermo-mechanically rolled or quenched and tempered
LHR-DH32 LHR-DH36	Nb and/or V	≤ 12,5 mm	Any
		12,5 mm < t ≤ 100 mm	Normalized, controlled rolled or thermo- mechanically rolled
	Al alone or with Ti	≤ 20 mm	Any
		20 mm < t ≤ 25 mm	Any, as rolled subject to special approval of LHR [(2)]
		25 mm < t ≤ 100 mm	Normalized, controlled rolled or thermo-mechanically rolled [(3)]
LHR-DH40	Any	≤ 50 mm	Normalized, controlled rolled or thermo-mechanically rolled
		25 mm < t ≤ 100 mm	Normalized, thermo-mechanically rolled or quenched and tempered
LHR-EH32 LHR-EH36	Any	≤ 50 mm	Normalized or thermo-mechanically rolled [(3)]
		50 mm < t ≤ 100 mm	Normalized, thermo-mechanically rolled
LHR-EH40	Any	≤ 50 mm	Normalized, thermo-mechanically rolled or quenched and tempered
		50 mm< t ≤ 100 mm	Normalized, thermo-mechanically rolled or quenched and tempered
LHR-FH32 LHR-FH36 LHR-FH40	Any	≤ 50 mm	Normalized, thermo-mechanically rolled or quenched and tempered [(4)]
		50 mm < t ≤ 100 mm	Normalized, thermo-mechanically rolled or quenched and tempered

Notes:

1. These conditions of supply and the requirements for impact tests are summarised in Table 3.2.2.
2. The frequency of impact test is to be in accordance with 2.10.2 (ii).
3. Subject to the special approval of LHR, sections in Grade LHR-AH32, LHR-AH36, LHR-DH32 and LHR-DH36 steels may be supplied in the as rolled condition, provided satisfactory results are consistently obtained from Charpy V-notch impact tests. Similarly, sections in Grade LHR-EH32 and Grade LHR-EH36 steels may be supplied in the as rolled or controlled rolled condition. The frequency of impact tests is to be in accordance with 2.10.2 (ii) and 2.10.2 (iii), respectively.
4. Subject to the special approval of LHR, sections in Grade LHR-FH32 and LHR-FH36 steels may be supplied in the controlled rolled condition. The frequency of impact tests is to be in accordance with 2.10. (iii).

Table 3.3.6: Mechanical properties for normal strength steels

Grade	Yield Strength ReH (N/mm^2) min	Tensile Strength Rm (N/mm^2)	Elongation ($5.65\sqrt{S_0}$) A_5 (%)	Impact Test						
				Test Temp. °C	Average Impact Energy (J) min					
					t ≤ 50		50 < t ≤ 70		70 < t ≤ 100	
					Long [3]	Trans [3]	Long [3]	Trans [3]	Long [3]	Trans [3]
LHR-A	235	400/520 [1]	22 [2]	+20	-	-	34 [5]	24 [5]	41 [5]	27 [5]
LHR-B				0	27 [4]	20 [4]	34	24	41	27
LHR-D				-20	27	20	34	24	41	27
LHR-E				-40	27	20	34	24	41	27

t= thickness (mm)

Notes:

1. For all thicknesses of Grade LHR-A sections the upper limit for the specified tensile strength range may be exceeded at the discretion of LHR.
2. For full thickness flat tensile test specimens with a width of 25 mm and a gauge length of 200mm the elongation is to comply with the following minimum values:

Thickness (mm)	≤ 5	> 5 ≤ 10	> 10 ≤ 15	> 15 ≤ 20	> 20 ≤ 25	> 25 ≤ 30	> 30 ≤ 40	> 40 ≤ 50
Elongation %	14	16	17	18	19	20	21	22

3. See paragraph 3.6.3 of this Chapter.
4. Charpy V-notch impact tests are generally not required for Grade LHR-B steel with thickness of 25 mm or less.
5. Impact tests for Grade LHR-A over 50 mm thick are not required when the material is produced using fine grain practice and furnished normalised. TM rolling may be accepted without impact testing at the discretion of LHR.

Table 3.3.7: Mechanical properties for higher strength steels

Grade	Yield Strength R_{eH} (N/mm^2) min	Tensile Strength Rm (N/mm^2)	Elongation ($5.65\sqrt{S_0}$) A_5 (%)	Impact Test						
				Test Temp. °C	Average Impact Energy (J) min					
					t ≤ 50		50 < t ≤ 70		70 < t ≤ 100	
					Long [2]	Trans [2]	Long [2]	Trans [2]	Long [2]	Trans [2]
LHR-A32	315	440/570	22 [1]	0	31 [3]	22 [3]	38	26	46	31
LHR-D32				-20	31	22	38	26	46	31
LHR-E32				-40	31	22	38	26	46	31
LHR-F32				-60	31	22	38	26	46	31
LHR-A32	355	490/630	21 [1]	0	34 [3]	24 [3]	41	27	50	34
LHR-D32				-20	34	24	41	27	50	34
LHR-E32				-40	34	24	41	27	50	34
LHR-F32				-60	34	24	41	27	50	34
LHR-A32	390	510/660	20 [1]	0	39	26	46	31	55	37
LHR-D32				-20	39	26	46	31	55	37
LHR-E32				-40	39	26	46	31	55	37
LHR-F32				-60	39	26	46	31	55	37

t=thickness (mm)

Notes:

1. For full thickness flat tensile test specimens with a width of 25mm and a gauge length of 200 mm the elongation is to comply with the following minimum values:

Thickness (mm)	Grade	≤ 5	> 5 ≤ 10	> 10 ≤ 15	> 15 ≤ 20	> 20 ≤ 25	> 25 ≤ 30	> 30 ≤ 40	> 40 ≤ 50
Elongation %	LHR-A32, -D32, -E32, -F32	14	16	17	18	19	20	21	22
	LHR-A36, -D36, -E36, -F36	13	15	16	17	18	19	20	21
	LHR-A40, -D40, -E40, F40	12	14	15	16	17	18	19	20

2. See paragraph 3.6.3 of this chapter.
3. For Grades LHR-AH32 and LHR-AH36 steels a relaxation in the number of impact tests for acceptance purposes may be permitted by special agreement with LHR provided that satisfactory results are obtained from occasional check tests.

3.7. Surface quality

3.7.1 The steel is to be free from surface defects prejudicial to the use of the material for the intended application. The finished material is to have a surface quality in accordance with a recognized standard such as EN 10163 parts 1, 2 and 3, or an equivalent standard accepted by LHR, unless otherwise specified in this SECTION.

3.7.2 The responsibility for meeting the surface finish requirements rests with the manufacturer of the material, who is to take the necessary manufacturing precautions and is to inspect the products prior to delivery. At that stage, however, rolling or heat treatment scale may conceal surface discontinuities and defects. If, during the subsequent descaling or working operations, the material is found to be defective, LHR may require materials to be repaired or rejected.

3.7.2.1 The surface quality inspection method shall be in accordance with recognized national or international standards agreed between purchaser and manufacturer, accepted by LHR.

3.7.2.2 If agreed by the manufacturer and purchaser, steel may be ordered with improved surface finish over and above these requirements.

3.7.3 Acceptance Criteria

3.7.3.1 Imperfections.

Imperfections of a harmless nature, for example pitting, rolled-in scale, indentations, roll marks, scratches and grooves, regarded as being inherent of the manufacturing process, are permissible irrespective of their number, provided the maximum permissible limits of Class A of EN 10163-2 or limits specified in a recognized equivalent standard accepted by LHR, are not exceeded and the remaining plate or wide flat thickness remains within the average allowable minus thickness tolerance specified in ANNEX A. Total affected area with imperfection not exceeding the specified limits are not to exceed 15 % of the total surface in question.

3.7.3.2 Defects.

Affected areas with imperfections with a depth exceeding the limits of Class A of EN 10163-2 or the maximum permissible limits specified in a recognized equivalent standard accepted by LHR, shall be repaired irrespective of their number. Cracks, injurious surface flaws, shells (over lapping material with non-metallic inclusion), sand patches, laminations and sharp-edged seams (elongated defects) visually evident on surface and/or edge of plate are considered defects, which would impair the end use of the product and which require rejection or repair, irrespective of their size and number.

3.7.4 Repair

3.7.4.1 Grinding repair

Grinding may be applied provided all the conditions below are adhered to:

i. The nominal product thickness will not be reduced by more than 7% or 3 mm, whichever is the less.
ii. Each single ground area does not exceed 0,25 m^2.
iii. All ground areas do not exceed 2% of the total surface in question.
iv. Ground areas lying in a distance less than their average breadth to each other are to be regarded as one single area.
v. Ground areas lying opposite each other on both surfaces shall not decrease the product thickness by values exceeding the limits as stated under (i).

Defects or unacceptable imperfections are to be completely removed by grinding and the remaining plate or wide flat thickness shall remain within the average allowable minus thickness tolerance specified in ANNEX A. The ground areas shall be a smooth transition to the surrounding surface of the product. Complete elimination of the defect is to be verified by magnetic particle or by liquid penetrant testing.

3.7.4.2 Welding repair

Weld repair procedures and the method are to be reported and be approved by LHR. Repair of defects such as unacceptable imperfections, cracks, shells or seams shall be followed by magnetic particle or liquid penetrant testing. Local defects which cannot be repaired by grinding as stated in 3.7.4.1 may be repaired by welding with the agreement of LHR subject to the following conditions:

i. Any single welded area shall not exceed 0,125 m^2 and the sum of all areas shall not exceed 2% of the surface side in question.
ii. The distance between two welded areas shall not be less than their average width.
iii. The weld preparation shall not reduce the thickness of the product below 80% of the nominal thickness. For occasional defects with depths exceeding the 80% limit, special consideration at the Surveyor’s discretion will be necessary.
iv. If weld repair depth exceeds 3 mm, UT may be requested by LHR.
v. If required, UT shall be carried out in accordance with an approved procedure.
vi. The repair shall be carried out by qualified welders using an approved procedure for the appropriate steel grade. The electrodes shall be of low hydrogen type and shall be dried in accordance with the manufacturer’s requirements and protected against rehumidification before and during welding.

3.7.5 The surface quality and condition requirement herein are not applied to products in forms of bars and tubulars, which will be subject to manufacturers’ conformance standards.

3.8. Internal soundness

3.8.1 If plates and wide flats are ordered with ultrasonic inspection, this is to be made in accordance with an accepted standard at the discretion of LHR.

3.8.2 Verification of internal soundness is the responsibility of the manufacturer. The acceptance of internal soundness by the LHR's surveyor shall not absolve the manufacturer from this responsibility.

3.9. Tolerances

3.9.1 The products are to comply with the requirements of ANNEX A, unless otherwise agreed or specially required. Thickness tolerances of steel plates and wide flats are applicable.

3.10. Identification of materials

3.10.1 The products are to comply with the requirements of 2.1.4.

3.11. Testing and Inspection

3.11.1 The products are to comply with the requirements of 2.7.

3.12. Test Material

3.12.1 Definitions

- Piece: the term "piece" is understood to mean the rolled product from a single slab, billet or ingot if this is rolled directly into plates, sections or bars.
- Batch: a number of similar pieces presented as a group for acceptance tests.

3.13. Test samples

3.13.1 The requirements of 2.8 should be complied with.

3.14. Mechanical test specimens

3.14.1 The requirements of 2.9 should be complied with.

3.15. Number of test specimen

3.15.1 The requirements of 2.10 should be complied with.

3.16. Re-test procedures

3.16.1 All items referred in 2.11 are applicable.

3.17. Branding

3.17.1 Every finished piece is to be clearly marked by the maker in at least one place with the LHR's brand and the following particulars:

- Unified identification mark for the grade steel (e.g. LHR-A, LHR-AH36).
- Steels which have been specially approved by LHR and which differ from these requirements (see 3.1.4 of this SECTION) are to have the letter "S" after the above identification mark (e.g. LHR-AH36S, LHR-ES).
- When required by LHR, material supplied in the thermo-mechanically controlled process condition is to have the letters TM added after the identification mark (e.g. LHR-EH36 TM).
- Name or initials to identify the steelworks.
- Cast or other number to identify the piece.
- If required by the purchaser, his order number or other identification mark.

3.17.2 Steel plates that have complied with the requirements for corrosion resistant steel will be identified by adding a corrosion designation to the unified identification mark for the grade of steel. The corrosion resistant steel is to be designated according to its area of application as follows:

- Lower surface of strength deck and surrounding structures: RCU
- Upper surface of inner bottom plating and surrounding structures: RCB
- For both strength deck and inner bottom plating: RCW

Example of designation: LHR-A36 TM RCB Z35

3.17.3 The above particulars, but excluding the manufacturer's name or trade mark where this is embossed on finished products are to be encircled with paint or otherwise marked so as to be easily recognizable.

3.17.4 Where a number of light materials are securely fastened together in bundles the manufacturer may, subject to the agreement of LHR, brand only the top piece of each bundle, or alternatively, a firmly fastened durable label containing the brand may be attached to each bundle.

3.17.5 In the event of any material bearing the LHR's brand failing to comply with the test requirements, the brand is to be unmistakably defaced by the manufacturer.

3.18. Documentation

3.18.1 The Surveyor is to be supplied with the number of copies as required by LHR, of the test certificates or shipping statements for all accepted materials. LHR may require separate documents of each grade of steel. These documents are to contain, in addition to the description, dimensions, etc., of the material, at least the following particulars:

1. Purchaser's order number and if known the hull number for which the material is intended.
2. Identification of the cast and piece including, where appropriate, the test specimen number.
3. Identification of the steelworks.
4. Identification of the grade of steel.
5. Ladle analysis (for elements specified in Table 3.3.1 and Table 3.3.2).
6. For steel with corrosion resistant steel designation the weight percentage of each element added or intentionally controlled for improving corrosion resistance.
7. Condition of supply when other than as rolled i.e. normalized, controlled rolled or thermo-mechanically rolled.
8. State if rimming steel has been supplied for Grade LHR-A sections, up to 12,5 mm thick.
9. Test Results.

3.18.2 Before the test certificates or shipping statements are signed by the Surveyor, the manufacturer is required to furnish him with a written declaration stating that the material has been made by an approved process and that it has been subjected to and has withstood satisfactory the required tests in the presence of the Surveyor or his authorized deputy. The name of LHR is to appear on the test certificate. The following form of declaration will be accepted if stamped or printed on each test certificate or shipping statement with the name of the steelworks and initialled for the makers by an authorized official:

"We hereby certify that the material has been made by an approved process and has been satisfactorily tested in accordance with the Rules of Libero Hellenic Register."

3.19. Marking

3.19.1 Products are to be marked in accordance with 2.12.

3.20. Certification

3.20.1 Each test certificate or shipping statement is to provide the information required in 2.13, stating if rimming steel has been supplied for grade LHR-A sections, up to 12,5 mm thick, together with general details of the heat treatment. The chemical composition is to include the content of all the elements in Table 3.3.1.

SECTION 4 Steels for boilers and pressure vessels

4.1. Scope

4.1.1 This Section gives the requirements for carbon, carbon-manganese and alloy steels used in the construction of boilers and pressure vessels. Materials intended for use in the construction of the cargo tanks and process pressure vessels storage tanks for liquefied gases and for other low temperature services are not to comply with this Section but with the requirements set up in SECTION 6 or SECTION 7.

4.1.2 In addition to specifying mechanical properties at ambient temperature for acceptance purposes, this Section provides appropriate mechanical properties at elevated temperatures which may be used for design purposes.

4.2. Deoxidation practice and chemical composition

4.2.1 The deoxidation practice and the chemical composition must conform to Table 3.4.1 (see, for example, the relevant standard: ISO 2604/IV-1975(E) Steel Products for Pressure Purposes - Quality Requirements - Part IV: Plates).

4.3. Condition of supply

4.3.1 The appropriate conditions of supply are depicted in Table 3.4.2.

Table 3.4.1: Chemical composition of rolled steels for boilers and pressure vessels

Type of steel	Grade	Deoxid. method	Chemical composition % (ladle sample)						
			C	Si	Mn	S	P	Al	Residual Elements
Carbon and Carbon Manganese	360	semi killed or killed	<0,17	<0,35	0,4-1 ,0	<0,05	<0,05	...	Cr <0,25 Cu <0,3 Mo <0,1 Ni <0,3 Total <0,7
	410		<0,20	<0,35	0,5-1,3	<0,05	<0,05	...	
	460		<0,20 (Motel)	<0,4	0,8-1 ,2	<0,05	<0,05	—	
	490	killed	<0,20 (Motel)	< 0,1 -0,5	0,9-1 ,6	<0,05	<0,05	(Note 2)	
	360 FG	Fully	<0,7	<0,35	0,4-1,0	<0,04	<0,04		
	410 FG		<0,20	<0,35	0,5-1 ,3	<0,04	<0,04		
			<0,20	<0,40	0,6-1 ,4	<0,04	<0,04		

			(Motel)									
			<0,20 (Motel)	0,1-0,5	0,9-1 ,6	<0,04	<0,04					
Alloy steel									Ni	Cr	Mo	Cu
1 Cr 0,5 Mo	470	Killed	0,1-0,18	0,15-0,35	0,4-0,8	<0,04	<0,04	(Note 3)	<0,3	0,7-1,3	0,4-0,6	<0,3
2,25 Cr 1 Mo	480		0,08-0,18	0,15-0,5	0,4-0,8	<0,04	<0,04	(Note 3)	<0,3	2,0-2,5	0,9-1,1	<0,3
0,3 Mo	440		0,2-0,2	0,1-0,35	0,4-0,9	< 0,035	0,035	(Note 4)		< 0,25	0,25-0,35	

NOTES:

1. For thicknesses > 30 mm but < 100 mm, carbon 0,22% max.
2. Aluminium (acid soluble) 0,015% minor
   Aluminium (total) 0,018% min
   Niobium, vanadium or other suitable grain refining elements may be used either in place of or in addition to aluminium
3. Aluminium (acid soluble or total) 0,020% max.
4. The Al content of the heat is to be determined and stated in the certificate.

Table 3.4.2: Condition of supply of rolled steels for boilers and pressure vessels

Type of steel	Grade	Condition of supply
Carbon and	360	Normalized or
	410	
	460	
	490	
	360 FG	
	410 FG	
	460 FG	
	490 FG	
Alloy steel	440	Normalized
0,3 Mo		
1 Cr 0,5 Mo	470	Normalized
2,25 CM Mo	480	

4.4. Mechanical properties

4.4.1 The required values of tensile strength R_m, yield stress R_e (i.e. minimum lower yield stress R_eL or 0,2% proof stress $R_{0,2}$) and elongation as prescribed in Table 3.4.3 and Table 3.4.4 must be achieved under tensile tests at ambient temperature.

4.5. Tensile tests

4.5.1 All products shall be tensile tested. Their results are to comply with Table 3.4.3 and Table 3.4.4.

4.5.2 For plates: one specimen must be taken from one end of each plate as rolled when the mass does not exceed 5 tonnes and the length does not exceed 15m. If one of these limits is exceeded, tensile test specimens are to be taken from both ends of each plate as rolled. In the case of ingot casting, it shall be taken from the end corresponding originally to the top of ingot.

4.5.3 For strip: Tensile tests shall be taken from both ends of each coil.

4.5.4 For sections and bars: To be presented in batches containing not more than 50 lengths, as supplied. The material in each batch is to be of the same section size, from the same cast and in the same condition of supply. One tensile test specimen must be taken from each batch. Additional test specimens are to be taken when the mass of a batch exceeds 10 tonnes.

4.5.5 Where plates are required for hot forming and it had been agreed that the heat treatment will be carried out by the fabricator, the tests at the steelworks are to be made on material which has been cut from the plates and given a normalizing or normalizing and tempering heat treatment in a manner simulating the treatment which will be applied to the plates.

4.6. Marking

4.6.1 The particulars detailed in 2.12 are to be marked on all materials which have been accepted.

4.7. Certification

4.7.1 Each test certificate or shipping statement is to provide the information required in 2.13, together with general details of the heat treatment. The chemical composition is to include the content of all the elements in Table 3.4.1.

4.8. Mechanical properties for design purposes

4.8.1 Nominal values for the minimum lower yield or 0,2 per cent proof stress at temperatures of 200°C and higher are given in Table 3.4.5 and Table 3.4.6. For temperatures below 200°C, the values corresponding to that temperature are to be used.

4.8.2 These values are intended for design purposes only, and verification is not required except for materials complying with national or proprietary specifications where the elevated temperature properties used for design purposes are higher than those given in Table 3.4.5 and Table 3.4.6.

4.8.3 In such cases, at least one tensile test at the proposed design or other agreed temperature is to be made on material from each cast. Where materials of more than one thickness are supplied from one cast, the thickest material is to be tested. The test specimens are to be prepared from material adjacent to that used for tests at ambient temperature. The axis of the test specimens is to be between mid and quarter thickness of the material and the test specimens are to be machined to dimensions in accordance with the requirements of Part 2, Chapter 2, SECTION 3, 3.1. The test procedure is as detailed in Part 2, Chapter 2, and the results are to comply with the requirements of the national or proprietary specifications.

4.8.4 As an alternative to 4.8.3, a manufacturer may carry out an agreed comprehensive test program for a stated grade of steel to demonstrate that the specified minimum mechanical properties at elevated temperatures can be consistently obtained. This test program is to be carried out under supervision of the Surveyors, and the results submitted for assessment and approval. When a manufacturer is approved on this basis, tensile tests at elevated temperatures are not required for acceptance purposes, but at the discretion of the Surveyors occasional check tests of this type may be requested.

4.8.5 Values for the estimated average stress to rupture in 100000 hours are given in Table 3.4.7 and may be used for design purposes.

Table 3.4.3: Mechanical properties at ambient temperature for acceptance purposes: carbon and carbon - manganese steels normalized or controlled rolled

Grade	Thickness (mm)	Yield Stress, Re (N/mm^2) minimum	Tensile strength, Rm (N/mm^2)	Elongation A_5(%) minimum
360	3< ... ≤ 16	205	360-480	26
	16< ... ≤ 40	195		26
	40< ... ≤ 63	185		25
	63< ... ≤100	175		24
410	3< ... ≤ 16	235	410-530	24
	16< ... ≤ 40	225		24
	40< ... ≤ 63	215		23
	63< ... ≤100	205		22
460	3< ... ≤ 16	285	460-580	22
	16< ... ≤ 40	255		22
	40< ... ≤ 63	245		21
	63< ... ≤100	235		20
490	3< ... ≤ 16	305	490-610	21
	16< ... ≤ 40	275		21
	40< ... ≤ 63	265		20

	63< ... ≤100	255		19
360 FG	3< ... ≤ 16	235	360-480	26
	16< ... ≤ 40	215		26
	40< ... ≤ 63	195		25
	63< ... ≤100	(Note 1)		24
410 FG	3< ... ≤ 16	265	410-530	24
	16< ... ≤ 40	245		24
	40< ... ≤ 63	235		23
	63< ... ≤100	(Note 1)		22
460 FG	3< ... ≤ 16	295	460-580	22
	16< ... ≤ 40	285		22
	40< ... ≤ 63	275		21
	63< ... ≤100	(Note 1)		20
490 FG	3< ... ≤ 16	315	490-610	21
	16< ... ≤ 40	315		21
	40< ... ≤ 63	305		20
	63< ...≤100	(Note 1)		19

NOTE:

1. For thickness >63 mm but ≤100 mm, the values specified for the thickness range >40 mm but ≤63 mm are lowered by 1 % for each 5 mm of thickness over 63 mm.

Table 3.4.4: **Mechanical properties at ambient temperature for acceptance purposes: alloy steels**

Type of steel	Grade		Thickness (mm) (Note 1)	Tensile strength (N/mm²)	Elongation A_5(%) min
0,3 Mo	440	3< … ≤ 16	275	440 - 600	20
		16< … ≤ 40	270		20
		40< … ≤ 63	260		20
		63< … ≤ 100	240		19
1 Cr 0,5Mo	470	3< … ≤ 16	305	470 - 620	20
		16< … ≤ 40	305		20
		40< … ≤ 63	305		19
		63< … ≤ 100	(Note 1)		18
2,25 Cr 1 Mo	480	3< … ≤ 16	275	480 - 630	18
		16< … ≤ 40	265		18
		40< … ≤ 63	265		17
		63< … ≤ 100	(Note 1)		16

NOTE:

1. For thicknesses greater than 63 mm, the minimum values for yield stress may be reduced by 1 % for each 5 mm increment in thickness over 63 mm.

Table 3.4.5: Mechanical properties for design purposes: carbon and carbon-manganese steels

Grade	Thickness (mm)	Design temperature (°C)					
		200	250	300	350	400	450
		Nominal minimum yield or 0,2% proof stress N/mm²					
360	3< ... ≤ 16	168	150	124	117	115	113
	16< ... ≤ 40	162	144	124	117	115	113
	40< ... ≤ 63	152	141	124	117	115	113
410	3< ... ≤ 16	201	180	150	142	138	136
	16< ... ≤ 40	191	171	150	142	138	136
	40< ... ≤ 63	181	168	150	142	138	136
460	3< ... ≤ 16	235	210	176	168	162	158
	16< ... ≤ 40	220	198	176	168	162	158
	40< ... ≤ 63	210	194	176	168	162	158
490	3< ... ≤ 16	255	228	192	183	177	172
	16< ... ≤ 40	237	214	192	183	177	172
	40< ... ≤ 63	227	210	192	183	177	172
360 FG	3< ... ≤ 16	165	145	127	116	110	106
	16< ... ≤ 40	164	145	127	116	110	106
	40< ... ≤ 63	159	145	127	116	110	106
410 FG	3< ... ≤ 16	194	171	152	141	134	130
	16< ... ≤ 40	192	171	152	141	134	130
	40< ... ≤ 63	188	171	152	141	134	130
460 FG	3< ... ≤ 16	223	198	177	167	158	153
	16< ... ≤ 40	220	198	177	167	158	153
	40< ... ≤ 63	217	198	177	167	158	153
490 FG	3< ... ≤ 16	240	213	192	182	173	168
	16< ... ≤ 40	237	213	192	182	173	168
	40< ... ≤ 63	234	213	192	182	173	168

Table 3.4.6: Mechanical properties for design purposes: alloy steels

			Nominal min. lower yield or 0,2% proof stress (N/mm²)				
Type of steel	Grade	Thickness (mm)	Design temperature (°C)				
			200	300	350	400	450
0,3 Mo	440	≤ 10	240	195	185	175	170
		10< … ≤40	225	180	170	160	155
		40< … ≤ 60	210	170	160	150	145
		40< … ≤ 100	200	160	155	145	140
1 Cr 0,5 Mo	470	3< … ≤63	248	216	203	199	194
2,25 Cr 1 Mo	480	3< … ≤63	233	219	212	207	194

Table 3.4.7: Mechanical properties for design purposes: estimated average stresses for rupture in 100000 hours

Temperature °C	Grades					
	360,410	460 FG 490 FG	360 FG 410 FG	460, 490	1 Cr 0,5 Mo	2,25 Cr 1 Mo
380	211	211	164	221		
390	186	182	145	198		
400	164	157	127	176		
410	141	135	110	154		
420	122	117	94	134		
430	103	100	79	117		
440	88	85	68	102		
450	75	73	56	87		221
460	63	62	46	75		204
470	51		39	63		186
480					210	170

490					177	153
500					146	137
510					121	122
520					99	107
530					81	93
540					67	79
550					54	69
560					43	59
570					35	51
580						44

SECTION 5 Steels for machinery structures

5.1. Scope

5.1.1 Rolled steels, such as plates, strips, sections or bars intended for use in the construction of welded machinery structures are to comply with one of the following alternatives:

1. Any grade of normal or higher tensile strength structural steel, as prescribed in SECTION 3.
2. Any grade of carbon or carbon-manganese boiler or pressure vessel steel, as detailed in SECTION 4, except that for this application batch testing is acceptable. The size of a batch and the number of tensile tests are to be as detailed in 2.10.

SECTION 6 Ferritic steels for low temperature service

6.1. Scope

6.1.1 This Section gives the requirements for rolled ferritic steels used in the construction of cargo tanks and cargo process pressure vessels of liquefied gases. It also depicts the requirements for plates and sections of hull structural steels which are subject to reduced temperature due to the cargo and which do not form part of secondary barrier.

6.1.2 These requirements are also applicable for other types of pressure vessels where the use of steels with guaranteed impact properties at low temperatures is required.

6.1.3 The steels applicable to low temperature services comprise of carbon-manganese steels and nickel alloy steels for products with thicknesses up to 40 mm.

6.2. Manufacture

6.2.1 All materials are to be manufactured according to 2.1.

6.3. Deoxidation practice and chemical composition

6.3.1 The deoxidation practice and the chemical composition must conform to Table 3.6.1.

6.4. Condition of supply

6.4.1 All materials are to be supplied in a condition complying with the appropriate requirements of Table 3.6.2.

6.4.2 Where the steels are used for cargo tanks and processing equipment for liquefied gases, the minimum design temperatures of the various steel grades are depicted in Table 3.6.2. The presentation of these data is necessary because of the influence of low temperature on the behavior of materials.

6.5. Mechanical properties

6.5.1 The required values of tensile strength, R_m, yield stress, R_e (i.e. upper yield stress R_6H or the 0,2

– proof stress, $R_{p0,2}$) and elongation A_5 prescribed in Table 3.6.3 must be achieved in tensile tests at ambient temperature.

6.5.2 The required impact energy values specified in Table 3.6.3 for the steel grade concerned must be achieved in tests on Charpy V-notch specimens at the prescribed test temperatures.

6.6. Tensile tests

6.6.1 Tensile tests are compulsory for the products. Specimens shall be taken transversely to the direction of rolling in the case of plate, hot-rolled wide strip and wide flats with a width > 600 mm. For all other products they may be taken transversely or parallel to the rolling direction

6.6.2 The number of specimens shall be determined as in 4.5.

6.6.3 Dimensions and tolerances of tensile test specimens shall be in accordance with Part 2, Chapter 2, SECTION 3, 3.1.

6.7. Impact tests

6.7.1 Impact Tests are compulsory for products with thicknesses ≥ 5 mm, at the test temperatures specified in Table 3.6.3. The requirements for impact test specimens of 2.9.2 are applicable.

6.7.2 The sampling of test specimens is to be made in accordance with 6.6.

6.7.3 The number of sets (each comprising 3 specimens) required shall be determined in the same way as the number of tensile test specimens prescribed in 6.6.2.

6.7.4 At the discretion of LHR depending on each case, other types of toughness tests, e.g.

dropweight test, may be used. These may be either in addition to or in lieu of the Charpy V-notch test.

Table 3.6.1: Chemical composition and deoxidation practice of ferritic steels for low temperature services

Type of steel	Grade	Deoxidation practice	Chemical composition (ladle samples) (%)						
			C_{max}	Si	Mn	P_{max}	S_{max}	Ni	Others
Carbon Manganese steels	490-LT	Fully killed And aluminum Fine Grain Teated (Note 1)	0,16 (Note 2)	0,10-0,50	0,90-1,65	0,03	0,025	20,30	
	500-LT			0,10-0,60	1,00-1,70	0,03	0,025	20,30	
Nickel Alloy Steels	0,5 Ni		0,15	0,15-0,35	0,85-1,65	0,03	0,025	0,30-0,80	Cr 0,25
	1.5 Ni		0,14	0,10-0,35	0,30-1,50	0,025	0,025	1,30-1,70	Cu 0,35
	3,5 Ni		0,12	0,10-0,35	0,30-0,70	0,025	0,025	3,25-3,75	Mo 0,08
	5 Ni		0,12	0,10-0,35	0,30-0,80	0,025	0,025	4,70-5,30	Total 0,45
	9 Ni		0,10	0,10-0,35	0,30-0,90	0,025	0,025	8,5-10,0	

NOTES:

1. Aluminum may be partly or wholly replaced by niobium or vanadium provided that the following figures are not exceeded: niobium content 0,05%, vanadium content 0,10%, sum of niobium + vanadium 0,12%. The titanium content may not exceed 0,02% (ladle and product analysis).

2. By special agreement with LHR the carbon content may be increased to 0,18% maximum provided the design temperature is not lower than -40°C

Table 3.6.2: Condition of supply and minimum design temperature of ferritic steels for low temperature services

Grade	Condition of supply	Minimum design temperature (°C)
490 - LT	Normalized (Note 1) or quenched and tempered	-45
500 - LT		-45
0,5 Ni		-55
1,5 Ni	Normalized or normalized and tempered or quenched and tempered	-60 (Note 2)
3,5 Ni		-90 (Note 2)
5 Ni		-105 (Note 2, 3)
9 Ni	Double normalized and tempered or quenched and tempered	-165

NOTES:

1. Subject to special approval by LHR, thermo mechanically control processed steels may be used instead of normalized steels.
2. A lower minimum design temperature for Quenched and Tempered steels may be specially agreed with LHR.
3. Steel grade 5 Ni may be approved for a minimum design temperature of -165°C provided, for example, that is alloyed with Cr and/or Mo and is subjected to triple heat treatment (see also Table 3.6.3, Note 4).

6.8. Marking

6.8.1 The particulars detailed in 2.12 are to be marked to all materials which have been accepted.

6.9. Certification

6.9.1 Each test certificate or shipping statement is to provide the information contained in 2.13, together with general details of the heat treatment. The chemical composition is to include the content of all the elements in Table 3.6.1.

Table 3.6.3: Mechanical properties of ferritic steels for low temperature services

Grade	Tensile strength Rm (N/mm^2)	Yield stress Re min (N/mm^2)	Elongation As (%) min		Product Thickness (mm)	Test Temperature °C	Average Energy (J) min	
			Long.	Trans.			Long.	Trans.
490 - LT	490 - 630	345	24	22	25 (Notes 1, 2)	5°C below minimum design temperature or -20°C whichever is lower	41	27
500 - LT	500 - 650	365	22	20				
0,5 Ni	490-610	345	25	23				
1,5 Ni	470 - 640	275	24	22	25 (Note 3)	-65	41	27
3,5 Ni	440 - 690	345	24	22		-95		
5 Mi	510-710	390	23	21		-110 (Note 4)		
9 Ni	640 - 840	490	21	19		-196		

NOTES:

1. 1. For material more than 25 mm thick, Charpy V-notch tests are to be conducted as follows:

Material Thickness		Test Temperature
25 < t	30 mm	10°C below minimum design temp, or -20°C whichever is lower
30 < t	35 mm	15°C minimum design temp, or -20°C whichever is lower
35 < t	40 mm	20°C below minimum design temp, or -20°C whichever is lower

The impact energy value shall be in accordance with the table for applicable type of test specimen. For material more than 40 mm thick, the Charpy V-notch values should be specially considered. Material for tanks and parks of tanks which are completely thermally stress relieved after welding may be tested at a temperature 5°C below design temperature or -20°C whichever is lower.

For thermally stress relieved reinforcements and other fittings, the test temperature is to be the same as that required for the adjacent tank shell thickness.

In no case should the test temperature be above that indicated in the table.

2. For materials exceeding 25 mm in thickness for which the test temperature is -60°C or lower, the use of a higher alloy steel may be necessary.

3. For materials 1,5% Ni, 3,5% Ni, and 5% Ni, with thickness greater than 25 mm, the test temperatures shall be determined in accordance with the data given in Note 1. They shall not, however, be higher than these shown in the Table.

   For 9% Ni over 25 mm thick, the requirements shall be specially agreed with LHR.

4. Where steel grade 5 Ni is tested and approved for a minimum design temperature of -165°C, the notched bar impact test shall be performed at a test temperature of -196°C.

SECTION 7 Austenitic stainless steels

7.1. Scope

7.1.1 This Section gives the requirements for rolled products in austenitic steels used in the construction of cargo tanks and cargo process pressure vessels for liquefied gases and chemicals up to a product thickness of 50 mm. These steels may also be used for the construction of other types of pressure vessels where the design temperature is not lower than -165°C.

7.1.2 Austenitic stainless steels contained in this Chapter are also heat resisting, appropriate for service at elevated temperatures. Approval for these applications may be given by LHR after submittance for consideration of details of the chemical composition, heat treatment and mechanical properties.

7.1.3 The steel grades shall be selected in such a way that following the manufacturing processes applied later, e.g. welding; the necessary chemical stability in relation to the cargo or operating fluid is assured.

7.2. Manufacture

7.2.1 All materials are to be manufactured according to 2.1.

7.3. Deoxidation practice and chemical composition

7.3.1 The deoxidation practice and the chemical composition must conform to Table 3.7.1.

7.4. Condition of supply

7.4.1 All materials are to be supplied in the solution treated condition.

7.5. Mechanical properties

7.5.1 The required values of tensile strength, 0,2% or 1% proof stress and elongation as prescribed in 7.5.2.

7.5.4 Table 3.7.2 must be achieved under tensile tests.

7.5.5 Unless otherwise agreed, impact tests are not required from the grades of steel given in this section.

7.6. Tensile test

7.6.1 Tensile test specimens are to be taken in accordance with the requirements of 6.6.

7.7. Intercrystalline corrosion test

7.7.1 A special bend test may be required for certain specific applications and, in particular, for materials intended for use in the construction of cargo or storage tanks for chemicals. The test is to be performed in accordance with a recognized standard (e.g. DIN 50914).

7.8. Cladding

7.8.1 The following requirements are applicable to steel plates, clad on one or both sides with austenitic stainless steels and intended for the manufacture of cargo or storage tanks for chemicals.

7.8.2 As base materials, use shall be made of suitable steels in accordance with SECTION 3, SECTION 4 or, where applicable, SECTION 5. The grades of austenitic steels specified in this section or other materials specially approved by LHR for the purpose may be used as cladding materials.

7.8.3 The process of manufacture is to be specially approved and may be either by roll cladding or by explosive cladding. Where the use of clad materials is proposed, the material specification is to be submitted for consideration, together with details of the extent, and the acceptance standards for non-destructive examination.

7.9. Marking

7.9.1 The particulars detailed in 2.12 are to be marked to all materials which have been accepted.

7.10. Certification

7.10.1 Each test certificate or shipping statement is to give the information contained in 2.13 together with general details of the heat treatment. The chemical composition is to include the content of all the elements in Table 3.7.1.

Table 3.7.1: Chemical composition of austenitic stainless steels

Grade	Chemical composition (%)								
	C_{max}	Si	Mn	max	S_{max}	Cr	Ni	Mo	Others
304L	0,35					18,0-20,0	8,0-13,0	-	
316L	0,35	≤ 1,0	≤ 2,0	0,040	0,030	16,0-18,0	10,0-15,0	2,0 - 3,0	
321	0,08					17,0-19,0	9,0-12,0	-	Ti > 5 x (% C) ≤ 0,70
347	0,08					17,0-19,0	9,0-13,0	-	Nb + Ta≥10x(%C) ≤ 1,10

Table 3.7.2: Mechanical properties of austenitic stainless steels

Grade	Tensile Strength R_m	0,2% proof stress $R_{p0,2}$	0,1% proof stress $R_{p1,0}$	Elongation A_5 (%) min	
				Long.	Trans.
304L	460-680	180	215	40	40
31 6L	490-690	190	225	40	40
321	500-730	205	240	35	35
347	510-740	205	240	30	30

SECTION 8 Steel plates and wide flats with specified minimum through thickness properties (“Z” quality) (IACS UR W14, Rev.3 (2021))

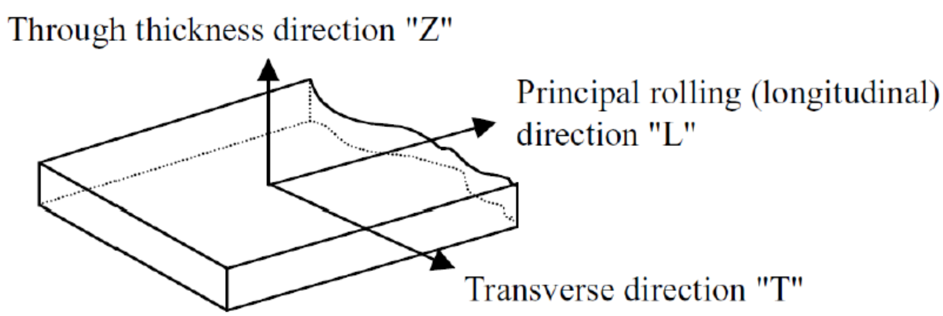
8.1. Scope

8.1.1 These requirements apply as a supplement to SECTION 3 and SECTION 9, of this Chapter, for plates and wide flats with thickness ≥ 15 mm, and intended to have a specified minimum ductility in the through thickness or “Z” direction (see Figure 3.8.1) where improved through thickness properties are specified. These requirements may also be applied for lower thickness at the discretion of LHR.

The use of such material, known as "Z" quality steel, is recommended for structural details subject to strains in the through thickness direction to minimize the possibility of lamellar tearing during fabrication. Two "Z" quality steels are specified, Z25 for normal ship applications and Z35 for more severe applications.

Through thickness properties are characterized by specified values for reduction of area in a through thickness tensile test.

Figure 3.8.1: Schematic of testing directions



8.2. Manufacture

8.2.1 All the materials are to be manufactured at works approved by LHR for "Z" quality steels.

8.2.2 The approval should follow the procedure given in ANNEX B, of this Chapter, but take into account the improved steelmaking techniques of calcium treatment, vacuum degassing and argon stirring as well as the control of centre-line segregation during continuous casting.

8.2.3 Chemical composition: In addition to the requirements of the appropriate steel specification SECTION 3 and SECTION 9, of this Chapter, the maximum sulphur content is to be 0,008% determined by the ladle analysis.

8.3. Test procedure

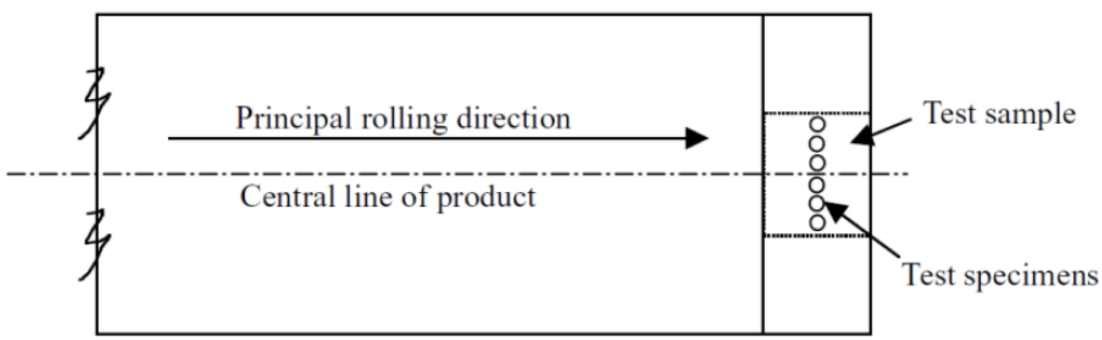
In addition to the requirements of the appropriate steel specification SECTION 3 and SECTION 9, of this Chapter, preparation of specimens and testing procedures are to be as follows:

8.3.1 Test sampling. For plates and wide flats, one test sample is to be taken close to the longitudinal centreline of one end of each rolled piece representing the batch. See Table 3.8.1 and Figure 3.8.2.

Table 3.8.1: Batch size dependent on product and sulphur content

Product	S > 0,005%	S ≤ 0,005%
Plates	Each piece (parent plate)	Maximum 50t of products of the same cast, thickness and heat treatment
Wide flats of normal thickness ≤ 25mm	Maximum 10t of products of the same cast, thickness and heat treatment	Maximum 50t of products of the same cast, thickness and heat treatment
Wide flats of nominal thickness > 25mm	Maximum 20t of products of the same cast, thickness and heat treatment	Maximum 50t of products of the same cast, thickness and heat treatment

Figure 3.8.2: Plate and wide flat sampling position



8.3.2 Number of tensile test specimens

The test sample must be large enough to accommodate the preparation of 6 specimens. 3 test specimens are to be prepared while the rest of the sample remains for possible retest.

8.3.3 Dimension of tensile test specimen

Round test specimens including built-up type by welding are to be prepared in accordance with a recognized national standard.

8.3.5 Tensile test results.

- The test is considered invalid and further replacement test is required if the fracture occurs in the weld or heat affected zone.
- The minimum average value for the reduction of area of at least 3 tensile test specimens taken in the through thickness direction must be that shown for the appropriate grade given in Table 3.8.2. Only one individual value may be below the minimum average but not less than minimum individual value shown for the appropriate grade. See Figure 3.8.3.
- A value less than the minimum individual value is a cause for rejection.

Table 3.8.2: Reduction of area acceptance values

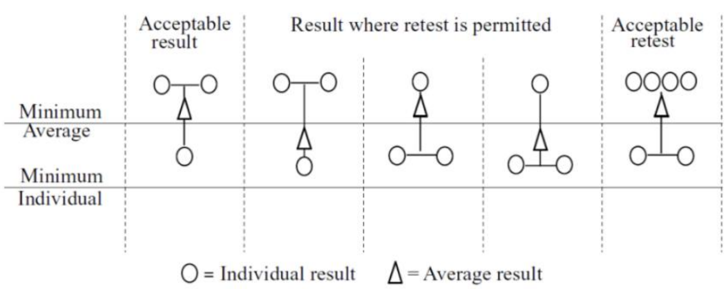
Grade	Z25	Z35
Minimum average	25%	35%
Minimum individual	15%	25%

8.4. Re-test procedure

8.4.1 Figure 3.8.3 shows the three cases where a retest situation is permitted. In these cases, three more tests are to be carried out on the remaining test pieces. The average of the results of the six tests shall be greater than the required minimum average with no greater than two results below the minimum average.

In the case of failure after retest, either the batch represented by the piece is rejected or each piece within the batch is required to be tested.

Figure 3.8.3: Diagram showing acceptance / rejection and retest criteria



8.5. Ultrasonic tests

8.5.1 Ultrasonic tests may be required if deemed necessary by LHR and is to be performed in accordance with either EN 10160:1999 Level S1/E1 or ASTM A 578:2017 Level C.

8.5.2 Ultrasonic testing should be carried out on each piece in the final supply condition and with a probe frequency of 4MHz.

8.6. Marking

8.6.1 Products complying with these requirements are to be marked in accordance with the appropriate steel requirement given in SECTION 3 and SECTION 9, of this Chapter, and in addition with the mark "Z" (“Z” 35 or "Z" 25) in addition to the material grade designation, e.g. LHR-EH36-Z25 or LHR-EH36-Z35.

8.7. Certification

The following information is required to be included on the certificate in addition to the appropriate steel requirement given in SECTION 3 and SECTION 9, of this Chapter:

a) Through thickness reduction in area (%).
b) Steel grade with Z25 or Z35 notation.

SECTION 9 High Strength Quenched and Tempered Steels for Welded Structures (IACS UR W16 Rev.3 (2016))

9.1. Scope

9.1.1 These requirements apply to hot-rolled, fine-grain, weldable high strength structural steels, intended for use in marine and offshore structural applications. These requirements do not apply to steels intended for hull structure of commercial ships whose requirements are specified in Part 2, Chapter 3, SECTION 3.

9.1.2 Steel covered by the scope of these requirements are specified in yield strength levels of 420, 460, 500, 550, 620, 690, 890 and 960 N/mm^2. For each yield strength level grades LHR-A, LHR-D, LHR-E and LHR-F are specified, based on the impact test temperature, Except for yield strength level of 890 and 960 N/mm^2 for which grade F is not applicable.

The full grades are:

AH420	DH420	EH420	FH420
AH460	DH460	EH460	FH460
AH500	DH500	EH500	FH500
AH550	DH550	EH550	FH550
AH620	DH620	EH620	FH620
AH690	DH690	EH690	FH690
AH890	DH890	EH890	
AH960	DH960	EH960	

9.1.3 Steels covered by the scope may be delivered in Normalized (N)/Normalised rolled (NR), Thermo-mechanical controlled rolled (TM), or Quenched and Tempered (QT) condition.

Note: TM is a generic delivery condition that may or may not include accelerated cooling, and may or may not include direct quenching followed by tempering after TM-rolling.

9.1.4 Product forms include plates, wide flats, sections, bars and seamless tubulars.

9.1.5 Steels with a thickness beyond the maximum thicknesses as given in Table 3.9.3 of paragraph 9.5.3 may be approved at the discretion of LHR.

9.1.6 Steels differing in chemical composition, deoxidation practice, delivery condition and mechanical properties may be accepted, subject to the special approval of LHR. Such steels are to be given a special designation.

9.2. Approval

9.2.1 For applications subjected to Classification, all steels are to be manufactured at steel works which have been approved by LHR for the type and grade of steel which is being supplied. The procedure for approval is shown in ANNEX B of this Chapter.

9.2.2 It is the steelmaker's responsibility to assure that effective quality, process and production controls during manufacturing are adhered to within the manufacturing specification. The manufacturing specification shall be submitted to LHR at the time of initial approval.

9.2.3 Where non-conformities arise, the manufacturer is to identify the root cause and establish countermeasures to prevent its recurrence. The non-conformities and the countermeasures are to be documented and reported to the LHR.

9.2.4 When the semi-finished products were not manufactured by the approved manufacturer of the finish rolled and heat treated products, the manufacturer of the semi-finished product shall also be subject to approval by LHR.

Notes:

1. The attention of the users must be drawn to the fact that when fatigue loading is present, the effective fatigue strength of a welded joint of high strength steel may not be greater than that of a welded joint in normal strength steels.
2. Before subjecting steels produced by both thermo-mechanical rolling or quenched and tempered after rolling to further heating for forming or stress relieving, or using high heat input welding, special consideration must be given to the possibility of a consequent reduction in mechanical properties.

9.3. Method of Manufacture

9.3.1 The steel is to be manufactured, by the basic oxygen, basic electric arc furnace or by processes specially approved by LHR.

9.3.2 Vacuum degassing shall be used for any of the following:

a) All steels with enhanced through-thickness properties
b) All steels of grade H690, H890 and H960.

9.3.3 The steel is to be fully killed.

9.3.4 The steel is to be fine grain treated, and is to have a fine grain structure. The fine grain practice is to be as detailed in the manufacturing specification.

Note: A fine grain structure has an equivalent index ≥ 6 determined by micrographic examination in accordance with ISO 643 or alternative test method.

9.3.5 The steels shall contain nitrogen binding elements as detailed in the manufacturing specification. Also see Note (4) in Table 3.9.1.

9.4. Chemical composition

9.4.1 The chemical composition is to be determined by the steelmaker in an adequately equipped and competently staffed laboratory. The method of sampling is to follow that carried out for the initial approval tests, either from the ladle, the tundish or the mould in the case of continuous casting. The aim analysis is to be in accordance with the manufacturing specification. All the elements listed in Table 3.9.1 are to be reported.

9.4.2 Elements used for alloying, nitrogen binding, and fine grain treatment, and as well as the residual elements are to be as detailed in the manufacturing specification, e.g. when boron is deliberately added for enhancement of hardenability of the steels, the maximum content of the boron content shall not be higher than 0,005% and the analysis result shall be reported.

9.4.3 The carbon equivalent value is to be calculated from the ladle analysis. Maximum values are specified in Table 3.9.2.

a. For all steel grades the following formula of IIW may be used:

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15} \quad (\%)$$

b. For steel grades H460 and higher, CET may be used instead of Ceq at the discretion of the manufacturer, and is to be calculated according to the following formula:

$$CET = C + \frac{(Mn + Mo)}{10} + \frac{(Cr + Cu)}{20} + \frac{Ni}{40} \quad (\%)$$

Note: The CET is included in the standard EN 1011-2:2001 used as one of the parameters for preheating temperature determination which is necessary for avoiding cold cracking.

c. For TM and QT steels with carbon content not more than 0,12%, the cold cracking susceptibility Pcm for evaluating weldability may be used instead of carbon equivalent of Ceq or CET at manufacturer's discretion and is to be calculated using the following formula:

$$Pcm = C + \frac{Si}{30} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Ni}{60} + \frac{Cr}{20} + \frac{Mo}{15} + \frac{V}{10} + 5B \quad (\%)$$

Table 3.9.1: Chemical Composition

Delivery condition (1)	N/NR		TM		QT	
Steel Grade Chemical composition (2)	AH420 DH420 AH460 AH460	EH420 EH460	AH420 DH420 AH460 DH460 AH500 DH500 AH550 DH550 AH620 DH620 AH690 DH690 AH890	EH420 FH420 EH460 FH460 EH500 FH500 EH550 FH550 EH620 FH620 EH690 FH690 DH890 EH890	AH420 DH420 AH460 DH460 AH500 DH500 AH550 DH550 AH620 DH620 AH690 DH690 AH890 AH960	EH420 FH420 EH460 FH460 EH500 FH500 EH550 FH550 EH620 FH620 EH690 FH690 DH890 EH890 DH960 EH960
Carbon % max	0,20	0,18	0,16	0,14	0,18	
Manganese %	1,0 ~ 1,70		1,0 ~ 1,70		1,70	
Silicon % max	0,60		0,60		0,80	
Phosphorus % max (3)	0,030	0,025	0,025	0,020	0,025	0,020
Sulphur % max (3)	0,025	0,020	0,015	0,010	0,015	0,010
$Aluminium_{total}$ % min (4)	0,02		0,02		0,018	
Niobium % max (5)	0,05		0,05		0,06	
Vanadium % max (5)	0,20		0,12		0,12	
Titanium % max (5)	0,05		0,05		0,05	
Nickel % max (5)	0,80		2,00 (6)		2.00 (6)	
Copper % max	0,55		0,55		0,50	
Chromium % max (5)	0,30		0,50		1,50	
Molybdenum % max (5)	0,10		0,50		0,70	
Nitrogen % max	0,025		0,025		0,015	
Oxygen ppm max (7)	Not applicable		Not applicable	50	Not applicable	30

Notes:

1. See 5.1 for definition of delivery conditions.
2. The chemical composition is to be determined by ladle analysis and shall meet the approved manufacturing specification at the time of approval.
3. For sections the P and S content can be 0,005% higher than the value specified in the table.
4. The total aluminium to nitrogen ratio shall be a minimum of 2:1. When other nitrogen binding elements are used, the minimum Al value and Al/N ratio do not apply.
5. Total Nb+V+Ti ≤ 0,26% and Mo+Cr ≤ 0,65%, not applicable for QT steels.
6. Higher Ni content may be approved at the discretion of LHR.
7. The requirement on maximum Oxygen content is only applicable to DH890, EH890, DH960 and EH960.

Table 3.9.2: Maximum Ceq, CET and Pcm values

Steel grade and delivery condition	Carbon Equivalent (%)							
	Ceq						CET	Pcm
	Plates			Sections	Bars	Tubulars	all	All
	t ≤ 50 (mm)	50 < t ≤ 100 (mm)	100 < t ≤ 250 (mm)	t ≤ 50 (mm)	t ≤ 250 or d ≤ 250 (mm)	t ≤ 65 (mm)	all	all
H420N/NR	0,46	0,48	0,52	0,47	0,53	0,47	N.A	N.A
H420TM	0,43	0,45	0,47	0,44	N.A	N.A	N.A	N.A
H420QT	0,45	0,47	0,49	N.A	N.A	0,46	N.A	N.A
H460N/NR	0,50	0,52	0,54	0,51	0,55	0,51	0,25	N.A
H460TM	0,45	0,47	0,48	0,46	N.A	N.A	0,30	0,23
H460QT	0,47	0,48	0,50	N.A	N.A	0,48	0,32	0,24
H500TM	0,46	0,48	0,50	N.A	N.A	N.A	0,32	0,24
H500QT	0,48	0,50	0,54	N.A	N.A	0,50	0,34	0,25
H550TM	0,48	0,50	0,54	N.A	N.A	N.A	0,34	0,25
H550QT	0,56	0,60	0,64	N.A	N.A	0,56	0,36	0,28
H620TM	0,50	0,52	N.A	N.A	N.A	N.A	0,34	0,26
H620QT	0,56	0,60	0,64	N.A	N.A	0,58	0,38	0,30
H690TM	0,56	N.A	N.A	N.A	N.A	N.A	0,36	0,30
H690QT	0,64	0,66	0,70	N.A	N.A	0,68	0,40	0,33
H890TM	0,60	N.A	N.A	N.A	N.A	N.A	0,38	0,28
H890QT	0,68	0,75	N.A	N.A	N.A	N.A	0,40	N.A
H960QT	0,75	N.A	N.A	N.A	N.A	N.A	0,40	N.A

Note: N.A= Not applicable

9.5. Delivery Condition - Rolling Process and Heat Treatment

9.5.1 Steel is to be delivered in accordance with the processes approved by LHR. These processes include:

- Normalized (N)/Normalised rolled (NR)
- Thermo-mechanical controlled rolled (TM)/with Accelerated cooling (TM+AcC)/with direct quenching followed by tempering (TM+DQ)
- Quenched and Tempered condition (QT)

The definition of these delivery conditions are defined in Part 2, Chapter 3, SECTION 3.

Note: Direct quenching after hot-rolling followed by tempering is considered equivalent to conventional quenching and tempering

9.5.2 The rolling reduction ratio of slab, billet, bloom or ingot should not be less than 3:1 unless agreed at the time of approval.

9.5.3 The maximum thickness of slab, billet or bloom from the continuous casting process shall be at the manufacturer's discretion.

9.5.4 Maximum thickness of plates, sections, bars and tubulars over which a specific delivery condition is applicable are shown in Table 3.9.3

Table 3.9.3: Maximum thickness limits

Delivery condition	Maximum thickness (mm)			
	Plates	Sections	Bars	Tubulars
N	250 (2)	50	250	65
NR	150	(1)		
TM	150	50	Not applicable	Not applicable
QT	150 (2)	50	Not applicable	50

Notes:

1. The maximum thickness limits of sections, bars and tubulars produced by NR process route are less than those manufactured by N route, and shall be at the discretion of LHR.
2. Approval for N steels with thickness larger than 250 mm and QT steels with thickness larger than 150 mm is subject to the special consideration of LHR.

9.6. Mechanical properties

Test specimens and test procedures for mechanical properties are in accordance with Part 2, Chapter 2 and Part 2, Chapter 3, SECTION 3.

9.6.1 Tensile test

9.6.1.1 Test specimens are to be cut with their longitudinal axes transverse to the final direction of rolling, except in the case of sections, bars, tubulars and rolled flats with a finished width of 600 m or less, where the tensile specimens may be taken in the longitudinal direction.

9.6.1.2 Full thickness flat tensile specimens are to be prepared. The specimens are to be prepared in such a manner as to maintain the rolling scale at least at one side. When the capacity of the test machine is exceeded by the use of a full thickness specimen, sub-sized flat tensile specimens representing either the full thickness or half of the product thickness retaining one rolled surface are to be used. Alternatively, machined round test specimens may be used. The specimens are to be located at a position lying at a distance of t/4 from the surface and additionally at t/2 for thickness above 100 mm or as near as possible to these positions.

9.6.1.3 The results of the tests are to comply with the appropriate requirements of Table 3.9.4. In the case of other product forms other than plates and wide flats where longitudinal tests are agreed, the elongation values are to be 2 percentage units above those listed in Table 3.9.4.

Table 3.9.4: Tensile properties at ambient temperature for all steel grades

Mechanical properties / Steel grade and delivery condition		Minimum yield strength R_{eH} [(1)] (N/mm^2) Nominal thickness (mm) [(4)]			Ultimate tensile strength R_m (N/mm^2) Nominal thickness (mm) [(4)]		Minimum percentage elongation after fracture (%) $L_0=5.65\sqrt{S_0}$ [(2)]		Charpy V-notch impact test: Test temp (^0C)	Charpy V-notch impact test: Minimum (Joules)	
		≥ 3 ≤ 50	> 50 ≤ 100	> 100 ≤ 250	≥ 3 ≤ 100	> 100 ≤ 250	T	L [(3)]		T	L
H420N/NR H420TM H420QT	A D E F	420	390	365	520~680	470~650	19	21	0 -20 -40 -60	28	42
H460N/NR H460TM H460QT	A D E F	460	430	390	540~720	500~710	17	19	0 -20 -40 -60	31	46
H500TM H500QT	A D E F	500	480	440	590~770	540~720	17	19	0 -20 -40 -60	33	50
H550TM H550QT	A D E F	550	530	490	640~820	590~770	16	18	0 -20 -40 -60	37	55
H620TM H620QT	A D E F	620	580	560	700~890	650~830	15	17	0 -20 -40 -60	41	62
H690TM H690QT	A D E F	690	650	630	770~940	710~900	14	16	0 -20 -40 -60	46	69
H890TM H890QT	A D E	890	830	Not applicable	940~1100	Not applicable	11	13	0 -20 -40	46	69
H960QT	A D E	960	Not applicable	Not applicable	980~1150	Not applicable	10	12	0 -20 -40	46	69

Notes:

1. For tensile test either the upper yield stress (R_{eH}) or where R_{eH} cannot be determined, the 0,2 percent proof stress (Rp0.2) is to be determined and the material is considered to comply with the requirement if either value meets or exceeds the specified minimum value of yield strength.

2. For full thickness flat test specimens with a width of 25 mm and a gauge length of 200 mm the elongation is to comply with the minimum values shown in Table 3.9.5.
3. In the case that the tensile specimen is parallel to the final rolling direction, the test result shall comply with the requirement of elongation for longitudinal (L) direction.
4. For plates and sections for applications, such as racks in offshore platforms etc., where the design requires that tensile properties are maintained through the thickness, a decrease in the minimum specified tensile properties is not permitted with an increase in the thickness.

Table 3.9.5: Elongation Minimum Values for a Width of 25 mm and a 200 mm Gauge Length [(1)]

Strength level	Thickness (mm)						
	≤ 10	> 10 ≤ 15	> 15 ≤ 20	> 20 ≤ 25	> 25 ≤ 40	> 40 ≤ 50	> 50 ≤ 70
H420	11	13	14	15	16	17	18
H460	11	12	13	14	15	16	17
H500	10	11	12	13	14	15	16
H550	10	11	12	13	14	15	16
H620	9	11	12	12	13	14	15
H690	9 [(2)]	10 [(2)]	11 [(2)]	11	12	13	14

Notes:

1. The tabulated elongation minimum values are the requirements for testing specimen in transverse direction. H890 and 960 specimens and specimens which are not included in this table shall be proportional specimens with a gauge length of $L_o=5{,}65\sqrt{S_o}$.
2. For H690 plates with thickness ≤ 20 mm, round specimen in accordance with Part 2, Chapter 2, may be used instead of the flat tensile specimen. The minimum elongation for testing specimen in transverse direction is 14%.

9.6.2 Impact test

9.6.2.1 The Charpy V-notch impact test specimens for plates and wide flats over 600 mm in width are to be taken with their axes transverse to the final rolling direction and the results should comply with the appropriate requirements for transverse direction of Table 3.9.4. For other product forms, the impact tests are to be in the longitudinal direction, the results of the tests are to comply with the appropriate requirements for longitudinal direction of Table 3.9.4.

9.6.2.2 Sub-surface test specimens will be taken in such a way that one side is not further away than 2 mm from a rolled surface, however, for material with a thickness in excess of 50 mm, impact tests shall be taken at the quarter thickness (t/4) location and mid-thickness (t/2).

9.6.2.3 Impact test for a nominal thickness less than 6 mm are normally not required.

9.6.3 Test frequency

9.6.3.1 Tensile test sample is to be randomly selected from each batch, as defined in Part 2, Chapter 3, SECTION 3, that is to be less than or equal to 25 tonnes, and to be from the same cast, in the same delivery condition and of the same thickness.

9.6.3.2 For steels plates in N/NR or TM condition test sample is to be taken from each piece.

9.6.3.3 For steels in QT condition test sample is to be taken from each individually heat treated part thereof.

9.6.3.4 For sections, bars and tubulars, test sample is to be taken from each batch of 25 tonnes or fraction thereof.

Notes:

1. If the mass of the finished material is greater than 25 tonnes, one set of tests from each 25 tonnes and/or fraction thereof is required. (e.g. for consignment of 60 tonnes would require 3 plates to be tested).
2. For continuous heat treated product special consideration may be given to the number and location of test specimens required by the manufacturer to be agreed by LHR.

9.6.4 Traceability

Traceability of test material, specimen sampling and test procedures including test equipment with respect to mechanical properties testing, is to be in accordance with Part 2, Chapter 3, SECTION 3.

9.6.5 Re-test procedures

Re-test procedures for tensile tests and Charpy impact tests are to be in accordance with Part 2, Chapter 2.

9.6.6 Through thickness tensile test

9.6.6.1 For steels designated with improved through thickness properties, through thickness tensile tests are to be performed in accordance with Part 2, Chapter 3, SECTION 8, “Steel plates and wide flats with specified minimum through thickness properties (“Z” quality)”.

9.6.6.2 Subject to the discretion of LHR, through thickness tensile strength may be required to be not less than 80% of the specified minimum tensile strength.

9.7. Tolerances

9.7.1 Unless otherwise agreed or specially required, the thickness tolerances in Part 2, Chapter 3, ANNEX A, “Allowable under thickness tolerances of steel plates and wide flats” are applicable.

9.8. Surface Quality

9.8.1 All materials are to be free from cracks, injurious surface flaws, injurious laminations and similar defects.

9.8.2 The surface quality inspection method shall be in accordance with recognised national or international standards agreed between purchaser and manufacturer.

a. Welding repair procedures and the method for reporting repairs are to be approved by LHR.
b. Where repair by grinding is carried out then the remaining plate thickness below the ground area must be within the allowable under thickness tolerance.

9.8.3 Surface finish requirement shall be in accordance with the relevant requirements in Part 2, Chapter 3, SECTION 3.

9.8.4 Surface inspection is the responsibility of the manufacturer. The acceptance by LHR's Surveyor of material later found to be defective shall not absolve the manufacturer of this responsibility.

9.9. Internal Soundness

9.9.1 Verification of internal soundness is the responsibility of the manufacturer. The acceptance by LHR's Surveyor shall not absolve the manufacturer of this responsibility.

9.9.2 Ultrasonic examination

9.9.2.1 If required by LHR, ultrasonic examination should be carried out in accordance with Part 2, Chapter 3, SECTION 3 for the requirement of internal soundness, and is to be performed in accordance with an approved standard.

9.10. Stress relieving heat treatment and other heat treatments

9.10.1 Steels approved by the procedures given in ANNEX B with respect to Heat Treatment are suitable for stress relieving heat treatment such as post-weld heat treatment and stress relieving heat treatment after cold forming for the purpose of reducing the risk of brittle fracture, increasing the fatigue lifetime and dimensional stability for machining.

Note: Products can be susceptible to deterioration in mechanical strength and toughness if they are subjected to incorrect post-weld heat treatment procedures or other processes involving heating such as flame straightening, rerolling, etc. where the heating temperature and the holding time exceed the limits given by the manufacturer.

9.11. Facilities for Inspection

9.11.1 Testing is to be carried out under the witness of the Surveyor, or an authorised deputy, in order to verify whether the test results meet the specified requirements.

9.11.2 The manufacturer is to afford the Surveyor all necessary facilities and access to all relevant parts of the steel works to enable him to verify the approved process is adhered to, for the selection of test materials, and the witnessing of tests, as required by this SECTION. Also for verifying the accuracy of the testing, calibration of inspection equipment and traceability of materials.

9.12. Identification of Materials

9.12.1 The manufacturer is to adopt a system for the identification of ingots, slabs, billet or bloom and finished products, which will enable the material to be traced to its original cast. The Surveyor is to be given full facilities for so tracing the material when required.

9.13. Branding

13.1 Each finished piece is to be clearly marked by the manufacturer with the following particulars:

a. LHR’s brand mark
b. Unified identification mark for the grade of steel (e.g. EH620)
c. Name or initials to identify the steelworks
d. Cast number/Heat number, plate number or equivalent identification mark
e. Delivery condition (N/NR, TM/TM+AcC/TM+DQ or Q&T)

The entire markings are to be encircled with paint or otherwise marked so as to be easily recognised. Steels which have been specially approved by LHR and which differ from these requirements (see 9.1.6) are to have the letter “S” after the identification mark (e.g. EH620S).

9.14. Documentation

9.14.1 The Surveyor is to be supplied with two copies of the test certificates or shipping statements for all accepted materials. In addition to the description, dimensions, etc., of the material, at least the following particulars are to be included:

1. Purchaser's order number
2. Identification of the cast and piece.
3. Manufacturer’s identification
4. Identification of the grade of steel.
5. Chemical analysis, Ceq, CET or Pcm value
6. Delivery condition with heat treatment temperatures.
7. Mechanical properties test results, including traceable test identification.
8. Surface quality and inspection results.
9. UT result, where applicable.

9.11.2 Before the test certificates are signed by the Surveyor, the steelmaker is required to provide a written declaration stating that the material has been made by an approved process and that it has been subjected to and has withstood satisfactorily the required tests in the presence of the Surveyor, or an authorised deputy. The following form of declaration will be accepted if stamped or printed on each test certificate with the name of the steelworks and signed by an authorized representative of the manufacturer:

"We hereby certify that the material has been made by an approved process and has been satisfactorily tested in accordance with Libero Hellenic Register Rules".

ANNEX A Allowable under thickness tolerances of steel plates and wide flats (IACS UR W13 Rev.7 (2021))

A1 Scope

A1.1 These requirements apply to the tolerance on thickness of steel plates and wide flats with widths of 600 mm or greater (hereinafter referred to as: product or products) with thicknesses of 5 mm and over, covering the following steel grades:

1. Normal and high strength hull structural steels according to SECTION 3, of this Chapter.
2. Steels for machinery structures according to SECTION 4, of this Chapter.

The thickness tolerances for products below 5 mm may be in accordance with national or international standards, e.g. Class B od ISO 7452:2013 as amended. However, the minus tolerance shall not exceed 0.3mm.

Note: Tolerances for length, width, flatness and over thickness may be taken from national or international standards.

A1.2 These requirements do not apply to products intended for the construction of lifting appliances, of boilers, pressure vessels and independent tanks, e.g. for the transportation of liquefied gases or chemicals.

A1.3 Class C of ISO 7452:2013 as amended or equivalent according to national or international standards may be applied in lieu of A3, in which case the requirements in A3.6, A3.7 and A4 need not be applied.

Additionally, if Class C of ISO 7452:2013 as amended is applied, it is required that the steel mill demonstrates to the satisfaction of LHR that the number of measurements and measurement distribution is appropriate to establish that the mother plates produced are at or above the specified nominal thickness.

A2 Responsibility

A2.1 The responsibility for verification and maintenance of production within the required tolerances rests with the manufacturer. Surveyor may require to witness some measurements.

A2.2 The responsibility for storage and maintenance of the delivered product(s) with acceptable level of surface conditions rests with the fabricator before the products are used in fabrication.

A3 Thickness tolerances

A3.1 The tolerances on thickness of a given product are defined as:

- Minus tolerance is the lower limit of the acceptable range below the nominal thickness.
- Plus tolerance is the upper limit of the acceptable range above the nominal thickness

NOTE: Nominal thickness is stated by the purchaser at the time of enquiry and order

A3.2 The minus tolerance on nominal thickness of products in accordance with SECTION 3 and SECTION 9 of this Chapter, is 0,3 mm irrespective of nominal thickness.

A3.3 The minus tolerances for products for machinery structures are to be in accordance with the following table:

Nominal Thickness (t) (mm)	Minus tolerance on nominal thickness(mm)
3 ≤ t < 5	-0,3
5 ≤ t < 8	-0,4
8 ≤ t < 15	-0,5
15 ≤ t < 25	-0,6
25 ≤ t < 40	-0,7
40 ≤ t < 80	-0,9
80 ≤ t < 150	-1,1
150 ≤ t < 2	-1,2
t ≥ 250	-1,3

A3.4 The tolerances on nominal thickness are not applicable to areas repaired by grinding. For areas repaired by grinding the 3.7.4.1 requirements of this Chapter, are to be applied, unless stricter requirements as per recognized standard are considered by LHR or purchaser.

A3.5 The plus tolerances on nominal thickness are to be in accordance with a recognized national or international standard unless required otherwise by LHR or purchaser.

A3.6 The average thickness of products is defined as the arithmetic mean of the measurements made in accordance with the requirements of A4.

A3.7 The average thickness of products in accordance with SECTION 3 or SECTION 9 of this Chapter, is not to be less than the nominal thickness.

A4 Thickness Measurements

A4.1 The thickness is to be measured at locations defined in A4.2. Automated method or manual method is applied to the thickness measurements. The procedure and the records of measurements are to be made available to the Surveyor and copies provided on request.

A4.2 Measuring locations

At least two lines among Line 1, Line 2 or Line 3 as shown in Figure A1, are to be selected for the thickness measurements and at least three points on each selected line as shown in Figure A1 are to be selected for thickness measurement. If more than three points are taken on each line the number of points shall be equal on each line.

Note:

The measurement locations apply to a product rolled directly from one slab or steel ingot even if the product is to be later cut by the manufacturer. Examples of the original measurements relative to later cut products are shown in Figure A2. It is to be noted that the examples shown are not representative of all possible cutting scenarios.

For automated methods, the measuring points at sides are to be located not less than 10 mm but not greater than 300 mm from the transverse or longitudinal edges of the product. For manual methods, the measuring points at sides are to be located not less than 10 mm but not greater than 100 mm from the transverse or longitudinal edges of the product.

Figure A1: Locations of Thickness Measuring Points for the Original Steel Plates

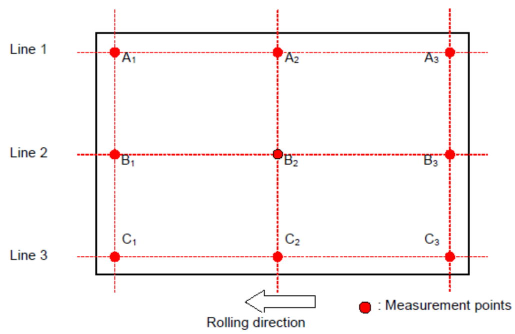
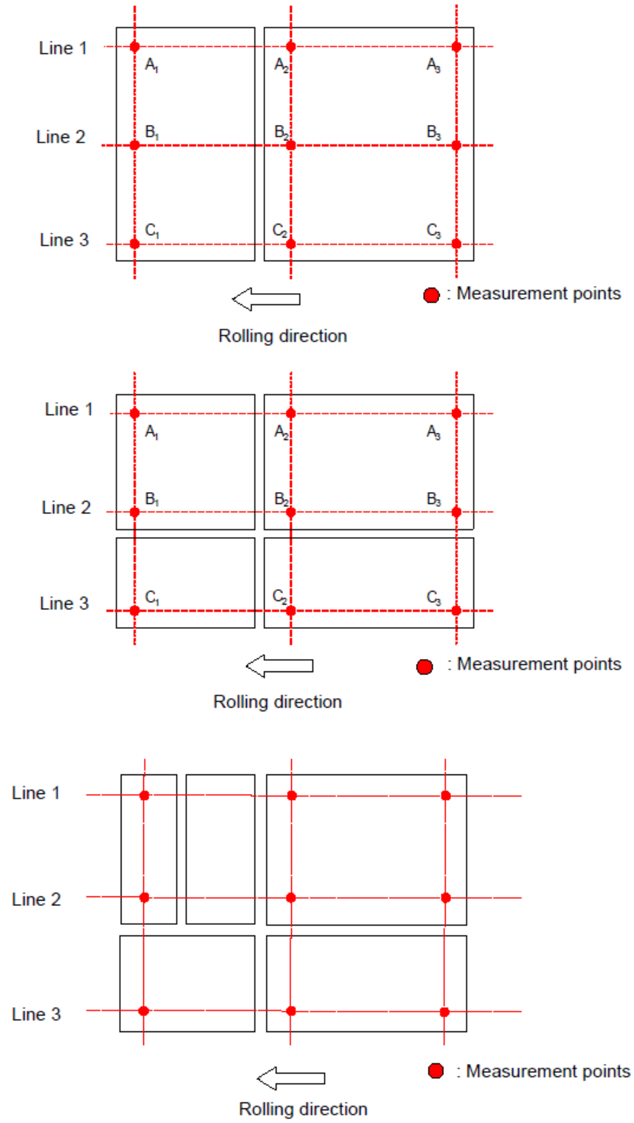


Figure A2: **Locations of Thickness Measuring Points for the Cut Steel Products**



ANNEX B Manufacturing Approval Scheme of Hull Structural Steels (IACS UR W11 Appendix A Rev.9 (2017))

B1 Manufacturing Approval Scheme of Semi Finished Products for Hull Structural Steels

B1.1 Scope of application

This document specifies, as given in 3.2.1, the scheme for the approval of the manufacturing process of semi-finished products such as ingots, slabs, blooms and billets for the structural steels. The manufacturing approval scheme is valid for verifying the manufacturer's capability to provide satisfactory products stably under effective process and production controls in which is required in 3.2.2.

B1.2 Approval application

B1.2.1 Documents to be submitted

The manufacturer has to submit to LHR, request of approval, proposed approval test program (see B1.3.1) and general information relevant to:

a) Name and site address of the manufacturer, location of the workshops, general indications relevant to the background, dimension of the works, estimated total annual production of finished products for shipbuilding and for other applications, as deemed useful.

b) Organization and quality:
   - organizational chart
   - staff employed
   - staff employed and organization of the quality control department
   - qualification of the personnel involved in activities related to the quality of the products
   - certification of compliance of the quality system with IS0 9001 or 9002, if any
   - approval certificates already granted by other Classification Societies, if any

c) Manufacturing facilities
   - flow chart of the manufacturing process
   - origin and storage of raw materials
   - storage of finished products
   - equipment for systematic control during fabrication

d) Details of inspections and quality control facilities
   - details of system used for identification of materials at the different stages of manufacturing
   - equipment of non-destructive examinations (NDE)
   - equipment for chemical analyses and relevant calibration procedures
   - list of quality control procedures

e) Type of products (ingots, slams, blooms, billets), types of steel (normal or higher), range of thickness and aim material properties as follows:

 - range of chemical composition and aim analyses, including grain refining, micro alloying and residual elements, for the various grades of steel; if the range of chemical composition depends on thickness and supply condition, the different ranges are to be specified, as appropriate.
 - aim maximum carbon equivalent according to IIW formula.
 - aim maximum Pcm content for higher strength grades with low carbon content C < 0,13 %.
 - production statistics of the chemical composition and, if available at rolling mills, mechanical properties (ReH, Rm, A% and KV). The statistics are intended to demonstrate the capability to manufacture the steel products in accordance with the requirements.

f) Steelmaking

- steel making process and capacity of furnace/s or converter/s
- raw material used
- deoxidation, grain refining, nitrogen binding and alloying practice
- desulphurization, dehydrogenation, sulphide treatment, ladle refining and vacuum degassing installations, if any
- casting methods: ingot or continuous casting. In the case of continuous casting, information relevant to type of casting machine, teeming practice, methods to prevent re-oxidation, inclusions and segregation control, presence of electromagnetic stirring, soft reduction, etc., is to be provided as appropriate.
- casting/solidification cooling rate control
- ingot or slab size and weight
- ingot or slab treatment: scarfing and discarding procedures

g) Approval granted already by other Classification Societies and documentation of approval tests performed.

B1.2.2 Documents to be submitted for changing the approval conditions

The manufacturer has to submit to LHR the documents required in B1.2.1 together with the request of changing the approval conditions, in the case of the following (a) through (c):

a) Change of the manufacturing process (steel making process, casting method, steel making plant, caster)

b) Change of the thickness range (dimension)

c) Change of the chemical composition, added element, etc.

However, where the documents are duplicated by the ones at the previous approval for the same type of product, part or all of the documents may be omitted except the approval test program (see B1.3.1)

B1.3 Approval tests

B1.3.1 Extent of the approval tests

The extent of the test program is specified in B1.3.6, it may be modified on the basis of the preliminary information submitted by the manufacturer. In particular, a reduction of the indicated number of casts, steel plate thicknesses and grades to be tested or complete suppression of the approval tests may be accepted by LHR taking into account:

a) Approval already granted by other Classification Societies and documentation of approval tests performed
b) Grades of steel to be approved and availability of long-term statistic results of chemical properties and of mechanical tests performed on rolled products
c) Change of the approval conditions

On the other hand, an increase of the number of casts and thicknesses to be tested may be required in the case of newly developed types of steel or manufacturing processes.

B1.3.2 Approval test program

Where the number of tests differs from those shown in B1.3.6, the program is to be confirmed by LHR before the tests are carried out.

B1.3.3 Approval survey

The approval tests are to be witnessed by the Surveyor at the manufacturer's plant and the execution of the plant inspection in operation may be required by the Surveyor during the visit for the approval. If the testing facilities are not available at the works, the tests are to be carried out at recognized laboratories.

B1.3.4 Selection of the test product

For each grade of steel and for each manufacturing process (e.g. steel making, casting), one test product with the maximum thickness and one test product with the minimum thickness to be approved are in general to be selected for each kind of product (ingots, slabs, blooms/billets).

The selection of the casts for the test product is to be based on the typical chemical composition, with particular regard to the specified Ceq or Pcm values and grain refining micro-alloying additions.

B1.3.5 Position of the test samples

The test samples are to be taken, unless otherwise agreed, from the product (slabs, blooms, billets) corresponding to the top of the ingot, or, in the case of continuous casting, a random sample.

B1.3.6 Tests on base material

3.6.1 Type of tests

The tests to be carried out for the approval of the manufacturing process of semi-finished products are:

- Chemical analysis. The analysis is to be complete and is to include micro alloying elements.
- Sulphur prints.

In addition, for initial approval and for any upgrade of the approval, LHR will require full tests indicated in B2.3 to be performed at rolling mill on the minimum thickness semi-finished product.

In case of a multi-caster work, full tests on finished products shall be carried out for one caster and reduced tests (chemical analysis and sulphur print) for the others. The selection of the caster shall be based on the technical characteristics of the casters to be evaluated on case-by-case basis to be performed at rolling mill on products manufactured from the minimum thickness semi-finished product.

3.6.2 Test specimens and testing procedure

The test specimens and testing procedures are to be, as a rule, in accordance with Part 2, Chapter 2. In particular, the following applies:

a) Chemical analyses

   Both the ladle and product analyses are to be reported. The material for the product analyses should be taken from the tensile test specimen. In general, the content of the following elements is to be checked: C, Mn, Si, P, S, Ni, Cr, Mo, Al, N, Nb, V, Cu, As, Sn, Ti and, for steel manufactured from electric or open-hearth furnace, Sb and B.

b) Sulphur prints are to be taken from plate edges which are perpendicular to the axis of the ingot or slab. These sulphur prints are to be approximately 600 mm long taken from the centre of the edge selected, i.e. on the ingot centerline, and are to include the full plate thickness.

B1.4 Results

All the results, which are in any case to comply with the requirements of the Rules, are evaluated for the approval; depending on the results, particular limitations or testing conditions, as deemed appropriate, may be specified in the approval document. All the information required under B2.2, applicable to the products submitted to the tests, is to be collected by the manufacturer and put in the dossier which will include all the results of the tests and operation records relevant to steel making, casting, and, when applicable, rolling and heat treatment of the test products.

B1.5 Certification

B1.5.1 Approval

Upon satisfactory completion of the survey, approval is granted by LHR.

On the approval certificate the following information is to be stated:

– Type of products (ingots, slabs, blooms, billets)
– Steelmaking and casting processes
– Thickness range of the semi-finished products

- Types of steel (normal or higher strength)

It is also to be indicated that the individual users of the semi finished products are to be approved for the manufacturing process of the specific grade of rolled steel products they are going to manufacture with those semi-finished products.

B1.5.2 List of approved manufacturers

The approved manufacturers are entered in a list containing the types of steel and the main conditions of approval.

B1.6 Renewal of approval

The validity of the approval is to be a maximum of five years. Renewal can be carried out by an audit and assessment on the result of satisfactory survey during the period. Where for operational reasons, the renewal audit falls outside the period of approval, the manufacturer will still be considered as approved if agreement to this audit date is made within the original period of approval, in this instance if successful, the extension of approval will be back dated to the original renewal date.

Manufacturers who have not produced the approved grades and products during the period between renewals may be required to either carry out approval tests or, on the basis of results of production of similar grades of products, at the discretion of LHR, be re-approved.

B1.7 Reconsideration of the approval

During the period of validity the approval may be reconsidered in the following cases:

a) in service failures, traceable to product quality
b) non conformity of the product revealed during fabrication and construction
c) discovered failure of the Manufacturer’s quality system
d) changes brought by the Manufacturer, without preliminary agreement of LHR, to the extent of the approval defined at the time of the approval
e) evidence of major non conformities during testing of the products.

B2 Manufacturing Approval Scheme of Hull Structural Steels

B2.1 Scope of application

This document specifies, as given in 3.2.1, the scheme for the approval of the manufacturing process of normal and higher strength hull structural steels.

The manufacturing approval scheme is valid for verifying the manufacturer's capability to provide satisfactory products stably under effective process and production controls in operation including programmed rolling, which is required in 3.2.2 and 3.3.3.

B2.2 Approval application

B2.2.1 Documents to be submitted

The manufacturer has to submit to LHR, request of approval, proposed approval test program (see B2.3.1) and general information relevant to:

a) Name and site address of the manufacturer, location of the workshops, general indications relevant to the background, dimension of the works, estimated total annual production of finished products for shipbuilding and for other applications, as deemed useful.

b) Organization and quality:
- organizational chart
- staff employed
- staff employed and organization of the quality control department
- qualification of the personnel involved in activities related to the quality of the products
- certification of compliance of the quality system with IS0 9001 or 9002, if any
- approval certificates already granted by other Classification Societies, if any

c) Manufacturing facilities
- flow chart of the manufacturing process
- origin and storage of raw materials
- storage of finished products
- equipment for systematic control during fabrication

d) Details of inspections and quality control facilities

- details of system used for identification of materials at the different stages of manufacturing
- equipment for mechanical tests, chemical analyses and metallography and relevant calibration procedures
- equipment for non destructive examinations
- list of quality control procedures

e) Type of products (plates, sections, coils), grades of steel, range of thickness and aim material properties as follows:

- range of chemical composition and aim analyses, including grain refining, micro alloying and residual elements, for the various grades of steel; if the range of chemical composition depends on thickness and supply condition, the different ranges are to be specified, as appropriate
- aim maximum carbon equivalent according to IIW formula
- aim maximum P_{cm} content for higher strength grades with low carbon content C < 0,13 %

- production statistics of the chemical composition and mechanical properties (R_{eH}, R_m, A% and KV). The statistics are intended to demonstrate the capability to manufacture the steel products in accordance with the requirements.

f) Steelmaking

- steel making process and capacity of furnace/s or converter/s
- raw material used
- deoxidation and alloying practice
- desulphurisation and vacuum degassing installations, if any
- casting methods: ingot or continuous casting. In the case of continuous casting, information relevant to type of casting machine, teeming practice, methods to prevent re-oxidation, inclusions and segregation control, presence of electromagnetic stirring, soft reduction, etc., is to be provided as appropriate.
- ingot or slab size and weight
- ingot or slab treatment: scarfing and discarding procedures

g) Reheating and rolling

- type of furnace and treatment parameters
- rolling: reduction ratio of slab/bloom/billet to finished product thickness, rolling and finishing temperatures
- descaling treatment during rolling
- capacity of the rolling stands

h) Heat treatment

- type of furnaces, heat treatment parameters and their relevant records
- accuracy and calibration of temperature control devices

i) Programmed rolling

- For products delivered in the controlled rolling (CR) or thermo-mechanical rolling (TM) condition, the following additional information on the programmed rolling schedules is to be given:
- description of the rolling process
- normalizing temperature, re-crystallization temperature and Ar3 temperature and the methods used to determine them
- control standards for typical rolling parameters used for the different thickness and grades of steel (temperature and thickness at the beginning and at the end of the passes, interval between passes, reduction ratio, temperature range and cooling speed of accelerated cooling, if any) and relevant method of control
- calibration of the control equipment

j) Recommendations for working and welding in particular for products delivered in the CR or TM condition

- cold and hot working recommendations if needed in addition to the normal practice used in the shipyards and workshops
- minimum and maximum heat input if different from the ones usually used in the shipyards and workshops (15 - 50 kJ/cm)

k) Where any part of the manufacturing process is assigned to other companies or other manufacturing plants, additional information required by LHR is to be included.

l) Approval already granted by other Classification Societies and documentation of approval tests performed.

B2.2.2 Documents to be submitted for changing the approval conditions

The manufacturer has to submit to LHR the documents required in B2.2.1 together with the request of changing the approval conditions, in the case of the following (a) through (e) as applicable:

a) Change of the manufacturing process (steel making, casting, rolling and heat treatment)
b) Change of the maximum thickness (dimension)
c) Change of the chemical composition, added element, etc.
d) Subcontracting the rolling, heat treatment, etc.
e) Use of the slabs, blooms and billets manufactured by companies other than the ones verified in the approval tests.

However, where the documents are duplicated by the ones at the previous approval for the same type of product, part or all of the documents may be omitted except the approval test program (see B2.3.1).

B2.3 Approval tests

B2.3.1 Extent of the approval tests

The extent of the test program is specified in B2.3.6 and B2.3.7; it may be modified on the basis of the preliminary information submitted by the manufacturer.

In particular, a reduction of the indicated number of casts, steel plate thicknesses and grades to be tested or complete suppression of the approval tests may be accepted by LHR taking into account:

a) Approval already granted by other Classification Societies and documentation of approval tests performed
b) Grades of steel to be approved and availability of long-term statistic results of chemical and mechanical properties
c) Approval for any grade of steel also covers approval for any lower grade in the same strength level, provided that the aim analyses, method of manufacture and condition of supply are similar.
d) For higher tensile steels, approval of one strength level covers the approval of the strength level immediately below, provided the steelmaking process, deoxidation and fine grain practice, casting method and condition of supply are the same.
e) Change of the approval conditions.

On the other hand, an increase of the number of casts and thicknesses to be tested may be required in the case of newly developed types of steel or manufacturing processes.

In case of multi-source slabs or changing of slab manufacturer, the rolled steel manufacturer is required to obtain the approval of the manufacturing process of rolled steels using the slabs from each slab manufacturer and to conduct approval tests in accordance with B2.3.6 and B2.3.7. A reduction or complete suppression of the approval tests may be considered by LHR taking into account previous approval as follows:

– the rolled steel manufacturer has already been approved for the manufacturing process using other semi finished products characterized by the same thickness, steel grade, grain refining and micro-alloying elements, steel making and casting process;
– the semi finished products manufacturer has been approved for the complete manufacturing process with the same conditions (steelmaking, casting, rolling and heat treatment) for the same steel types.

B2.3.2 Approval test program

Where the number of tests differs from those shown in B2.3.6 and B2.3.7, the program is to be confirmed by LHR before the tests are carried out.

B2.3.3 Approval survey

The approval tests are to be witnessed by the Surveyor at the manufacturer's plant and the execution of the plant inspection in operation may be required by the Surveyor during the visit for the approval. If the testing facilities are not available at the works, the tests are to be carried out at recognised laboratories.

B2.3.4 Selection of the test product

For each grade of steel and for each manufacturing process (e.g. steel making, casting, rolling and condition of supply), one test product with the maximum thickness (dimension) to be approved is in general to be selected for each kind of product.

In addition, for initial approval, LHR will require selection of one test product of average thickness.

The selection of the casts for the test product is to be based on the typical chemical composition, with particular regard to the specified Ceq or Pcm values and grain refining micro-alloying additions.

B2.3.5 Position of the test samples

The test samples are to be taken, unless otherwise agreed, from the product (plate, flat, section, bar) corresponding to the top of the ingot, or, in the case of continuous casting, a random sample.

The position of the samples to be taken in the length of the rolled product, "piece" defined in 3.11.1(a), (top and/or bottom of the piece) and the direction of the test specimens with respect to the final direction of rolling of the material are indicated in Table B1. The position of the samples in the width of the product is to be in compliance with 2.8.4.

B2.3.6 Tests on base material

3.6.1 Type of tests

The tests to be carried out are indicated in the following Table B1

Type of test	Position of the samples and direction of the test specimens (**1**)	Remarks			
Tensile test	Top and bottom transverse (**2**)	ReH, Rm, A_5 (%), RA (%) are to be reported			
Tensile test (stress relieved) only for TM steels	Top and bottom transverse (**2**)	Stress relieving at 600 C (2min/mm with min. 1 hour)			
Impact tests (**3**) on an aged specimens for grades:	Top and bottom – longitudinal	Testing temperature (C)			
LHR-A, LHR-B, LHR-AH32, LHR-AH36, LHR-AH40		+20	0	-20	
LHR-D, LHR-DH32, LHR-DH36, LHR-DH40		0	-20	-40	
LHR-E, LHR-EH32, LHR-EH36, LHR-EH40,		0	-20	-40	-60
LHR-FH32, LHR-FH36,LHR-FH40		-20	-40	-60	-80
LHR-A, LHR-B, LHR-AH32, LHR-AH36, LHR-AH40	Top –transverse (4)	+20	0	-20	
LHR-D, LHR-DH32, LHR-DH36, LHR-DH40		0	-20	-40	
LHR-E, LHR-EH32, LHR-EH36, LHR-EH40		-20	-40	-60	
LHR-FH32, LHR-FH36, LHR-FH40		-40	-60	-80	
Impact test (**3**) on strain aged specimens (**5**) for grades:	Top – longitudinal	Testing temperature (°C)			
LHR-AH32, LHR-AH36, LHR-AH40		+20	0	-20	

LHR-D, LHR-DH32, LHR-DH36, LHR-DH40		0	-20	-40	
LHR-E, LHR-EH32, LHR-EH36, LHR-EH40		-20	-40	-60	
LHR-FH32, LHR-FH36, LHR-FH40		-40	-60	-80	
Chemical analyses (**6**)	Top	Complete analyses including micro alloying elements			
Sulphur prints	Top				
Micro examination	Top				
Grain size determination	Top	Only for fine grain steels			
Drop weight test (**4**)	Top	Only for grades LHR-E, LHR-EH32, LHR-Eh36, LHR-EH40, LHR-FH32, LHR-FH36, LHR-FH40			
Through thickness tensile tests	Top and bottom	Only for grades with improved through thickness properties			
NOTES: 1. For hot rolled strips see 3.6.2 2. Longitudinal direction for sections and plates having width less than 600 mm. 3. One set of 3 Charpy V-notch impact specimens is required for each compact test. 4. Not required for sections and plates having width less than 600 mm. 5. Deformation 5% + 1 hour at 250°C. 6. Besides product analyses, ladle analyses are required.					

3.6.2 Test specimens and testing procedure

The test specimens and testing procedures are to be, as a rule, in accordance with Part 2, Chapter 2. In particular, the following applies:

a) Tensile test

- for plates made from hot rolled strip one additional tensile specimen is to be taken from the middle of the strip constituting the coil.
- for plates having thickness higher than 40 mm, when the capacity of the available testing machine is insufficient to allow the use of test specimens of full thickness, multiple flat specimens,

representing collectively the full thickness, can be used. Alternatively, two round specimens with the axis located at one quarter and at midthickness can be taken.

b) Impact test

- for plates made from hot rolled strip one additional set of impact specimens is to be taken from the middle of the strip constituting the coil.
- for plates having thickness higher than 40 mm one additional set of impact specimens is to be taken with the axis located at mid-thickness.
- in addition to the determination of the energy value, also the lateral expansion and the percentage crystallinity are to be reported.

c) Chemical analyses

Both the ladle and product analyses are to be reported. The material for the product analyses should be taken from the tensile test specimen. In general, the content of the following elements is to be checked: C, Mn, Si, P, S, Ni, Cr, Mo, Al, N, Nb, V, Cu, As, Sn, Ti and, for steel manufactured from electric or open-hearth furnace, Sb and B.

d) Sulphur prints are to be taken from plate edges which are perpendicular to the axis of the ingot or slab. These sulphur prints are to be approximately 600 mm long taken from the centre of the edge selected, i.e. on the ingot centerline, and are to include the full plate thickness.

e) Micrographic examination: the micrographs are to be representative of the full thickness. For thick products in general at least three examinations are to be made at surface, one quarter and mid-thickness of the product.
All photomicrographs are to be taken at x100 magnification and where ferrite grain size exceeds ASTM 10, additionally at x500 magnification. Ferrite grain size should be determined for each photomicrograph.

f) Drop weight test: the test is to be performed in accordance with ASTM E208. The NDTT is to be determined and photographs of the tested specimens are to be taken and enclosed with the test report.

g) Through thickness tensile test: the test is to be performed in accordance with Part 2, Chapter 3, SECTION 8. The test results are to be in accordance, where applicable, with the requirements specified for the different steel grades in SECTION 3 of this Chapter.

3.6.3 Other tests

Additional tests such as CTOD test, large scale brittle fracture tests (Double Tension test, ESSO test, Deep Notch test, etc.) or other tests may be required in the case of newly developed type of steel, outside the scope of SECTION 3 of this Chapter, or when deemed necessary by LHR.

B2.3.7 Weldability tests

B3.7.1 General

Weldability tests are required for plates and are to be carried out on samples of the thickest plate.

Tests are required for normal strength grade E and for higher strength steels.

B3.7.2 Preparation and welding of the test assemblies

The following tests are in general required:

a) 1 butt weld test assembly welded with a heat input approximately 15 kJ/cm
b) 1 butt weld test assembly welded with a heat input approximately 50 kJ/cm.

The butt weld test assemblies are to be prepared with the weld seam transverse to the plate rolling direction, so that impact specimens will result in the longitudinal direction. The bevel preparation should be preferably 1/2V or K.

The welding procedure should be as far as possible in accordance with the normal welding practice used at the yards for the type of steel in question.

The welding parameters including consumables designation and diameter, pre-heating temperatures, interpass temperatures, heat input, number of passes, etc. are to be reported.

B3.7.3 Type of tests

From the test assemblies the following test specimens are to be taken:

a) 1 cross weld tensile test
b) a set of 3 Charpy V-notch impact specimens transverse to the weld with the notch located at the fusion line and at a distance 2, 5 and minimum 20 mm from the fusion line. The fusion boundary is to be identified by etching the specimens with a suitable reagent. The test temperature is to be the one prescribed for the testing of the steel grade in question.
c) Hardness tests HV 5 across the weldment. The indentations are to be made along a 1 mm transverse line beneath the plate surface on both the face side and the root side of the weld as follows:

- Fusion line
- HAZ: at each 0.7 mm from fusion line into unaffected base material (6 to 7 minimum measurements for each HAZ)

The maximum hardness value should not be higher than 350 HV. A sketch of the weld joint depicting groove dimensions, number of passes, hardness indentations should be attached to the test report together with photomacrographs of the weld cross section.

B3.7.4 Other tests

Additional tests such as cold cracking tests (CTS, Cruciform, Implant, Tekken, Bead-on plate), CTOD, or other tests may be required in the case of newly developed type of steel, outside the scope of SECTION 3, or when deemed necessary by LHR.

B2.4 Results

All the results, which are in any case to comply with the requirements of the Rules, are evaluated for the approval; depending on the results, particular limitations or testing conditions, as deemed appropriate, may be specified in the approval document.

All the information required under B2.2.2, applicable to the products submitted to the tests, is to be collected by the manufacturer and put in the dossier which will include all the results of the tests and operation records relevant to steel making, casting, rolling and heat treatment of the test products.

B2.5 Certification

B2.5.1 Approval

Upon satisfactory completion of the survey, approval is granted by LHR.

B2.5.2 List of approved manufacturers

The approved manufacturers are entered in a list containing the types of steel and the main conditions of approval.

B2.6 Renewal of approval

The validity of the approval is to be a maximum of five years.

Renewal can be carried out by an audit and assessment on the result of satisfactory survey during the period. Where for operational reasons, the renewal audit falls outside the period of approval, the manufacturer will still be considered as approved if agreement to this audit date is made within the original period of approval, in this instance if successful, the extension of approval will be back dated to the original renewal date.

Manufacturers who have not produced the approved grades and products during the period between renewals may be required to either carry out approval tests or, on the basis of results of production of similar grades of products, at the discretion of LHR, be re-approved.

B2.7 Reconsideration of the approval

During the period of validity, the approval may be reconsidered in the following cases:

a) in service failures, traceable to product quality
b) non conformity of the product revealed during fabrication and construction
c) discovered failure of the Manufacturer’s quality system
d) changes brought by the Manufacturer, without preliminary agreement of LHR, to the extent of the approval defined at the time of the approval
e) evidence of major non conformities during testing of the products.

ANNEX C Approval scheme for manufacturer of hull structural steels intended for welding with high heat input (IACS UR W11 Appendix B Rev.9 (2017))

C1 Scope

This document specifies the weldability confirmation scheme of normal and higher strength hull structural steels stipulated in SECTION 3 of this Chapter, intended for welding with high heat input over 50kJ/cm.

The weldability confirmation scheme is to be generally applied by manufacturer's option and valid for certifying that the steel has satisfactory weldability for high heat input welding concerned under testing conditions. Demonstration of conformance to the requirements of this document approves a particular steel mill to manufacture grade of steel to the specific chemical composition range, melting practice, and processing practice for which conformance was established. The approval scheme does not apply to qualification of welding procedures to be undertaken by the shipyards.

C2 Application of certification

The manufacturer is to submit to LHR, request of certification, proposed weldability test program (see C3.2) and technical documents relevant to:

a) Outline of steel plate to be certified
- grade
- thickness range
- deoxidation practice
- fine grain practice
- aim range of chemical composition
- aim maximum Ceq and Pcm
- production statistics of mechanical properties (tensile and Charpy V-notch impact tests), if any

b) Manufacturing control points to prevent toughness deterioration in heat affected zone when welded with high heat input, relevant to chemical elements, steel making, casting, rolling, heat treatment etc.

c) Welding control points to improve joint properties on strength and toughness, if any.

C3 Confirmation tests

C3.1 Range of certification

Range of certification for steel grades is to be the following (a) through (e) unless otherwise agreed by LHR:

a) Approval tests on the lowest and highest toughness levels cover the intermediate toughness level.
b) Approval tests on normal strength level cover that strength level only.
c) For high tensile steels, approval tests on one strength level cover strength level immediately below.
d) Tests may be carried out separately subject to the same manufacturing process.

e) Certification and documentation of confirmation tests performed by other Classification Societies may be accepted at the discretion of LHR.

C3.2 Weldability test program

Extent of the test program is specified in C3.5 but it may be modified according to the contents of certification. In particular, additional test assemblies and/or test items may be required in the case of newly developed type of steel, welding consumable and welding method, or when deemed necessary by LHR. Where the content of tests differs from those specified in C3.5, the program is to be confirmed by LHR before the tests are carried out.

C3.3 Test plate

Test plate is to be manufactured by a process approved by LHR in accordance with the requirements of ANNEX B of this Chapter.

For each manufacturing process route, two test plates with different thickness are to be selected. The thicker plate (t) and thinner plate (less than or equal to t/2) are to be proposed by the manufacturer. Small changes in manufacturing processing (e.g. within the TMCP process) may be considered for acceptance without testing, at the discretion of LHR.

C3.4 Test assembly

One butt weld assembly welded with heat input over 50kJ/cm is to be generally prepared with the weld axis transverse to the plate rolling direction. Dimensions of the test assembly are to be amply sufficient to take all the required test specimens specified in C3.5. The welding procedures should be as far as possible in accordance with the normal practices applied at shipyards for the test plate concerned. Welding process, welding position, welding consumable (manufacturer, brand, grade, diameter and shield gas) and welding parameters including bevel preparation, heat input, preheating temperatures, interpass temperatures, number of passes, etc. are to be reported.

C3.5 Examinations and tests for the test assembly

The test assembly is to be examined and tested in accordance with the following (a) through (h) unless otherwise agreed by LHR.

a) Visual examination

Overall welded surface is to be uniform and free from injurious defects such as cracks, undercuts, overlaps, etc.

b) Macroscopic test

One macroscopic photograph is to be representative of transverse section of the welded joint and is to show absence of cracks, lack of penetration, lack of fusion and other injurious defects.

c) Microscopic test

Along mid-thickness line across transverse section of the weld, one micrograph with x100 magnification is to be taken at each position of the weld metal centerline, fusion line and at a distance 2, 5, 10 and minimum 20 mm from the fusion line. The test result is provided for information purpose only.

d) Hardness test

Along two lines across transverse weld section 1 mm beneath plate surface on both face and root side of the weld, indentations by HV5 are to be made at weld metal centerline, fusion line and each 0.7 mm position from fusion line to unaffected base metal (minimum 6 to 7 measurements for each heat affected zone). The maximum hardness value should not be higher than 350 HV.

e) Transverse tensile test

Two transverse (cross weld) tensile specimens are to be taken from the test assembly. Test specimens and testing procedures are to comply with the requirements of Part 2, Chapter 2. The tensile strength is to be not less than the minimum required value for the grade of base metal.

f) Bend test

Two transverse (cross weld) test specimens are to be taken from the test assembly and bent on a mandrel with diameter of quadruple specimen thickness. Bending angle is to be at least 120°. Test specimens are to comply with the requirements of Part 2, Chapter 2. For plate thickness up to 20 mm, one face-bend and one root-bend specimens or two side-bend specimens are to be taken. For plate thickness over 20 mm, two side-bend specimens are to be taken. After testing, the test specimens shall not reveal any crack nor other open defect in any direction greater than 3 mm.

g) Impact test

Charpy V-notch impact specimens (three specimens for one set) are to be taken within 2 mm below plate surface on face side of the weld with the notch perpendicular to the plate surface. One set of the specimens transverse to the weld is to be taken with the notch located at the fusion line and at a distance 2, 5 and minimum 20 mm from the fusion line. The fusion boundary is to be identified by etching the specimens with a suitable reagent. The test temperature is to be the one prescribed for the testing of the steel grade in question. For steel plate with thickness greater than 50 mm or one side welding for plate thickness greater than 20 mm, one additional set of the specimens is to be taken from the root side of the weld with the notch located at each the same position as for the face side.

The average impact energy at the specified test temperature is to comply with the Table 3.3.6 or Table 3.3.7 of SECTION 3, of this Chapter, depending on the steel grade and thickness. Only one individual value may be below the specified average value provided it is not less than 70% of that value. Additional tests at the different testing temperatures may be required for evaluating the transition temperature curve of absorbed energy and percentage crystallinity at the discretion of LHR.

h) Other test

Additional tests such as wide-width tensile test, HAZ tensile test, cold cracking tests (CTS, Cruciform, Implant, Tekken, and Bead-on plate), CTOD or other tests should be required at the discretion of LHR (see C3.2).

C4 Results

The manufacturer is to submit to LHR the complete test report including all the results and required information relevant to the confirmation tests specified in C3. The contents of the test report are to be reviewed and evaluated by LHR in accordance with this weldability confirmation scheme.

C5 Certification

LHR issues the certificate where the test report is found to be satisfactory.

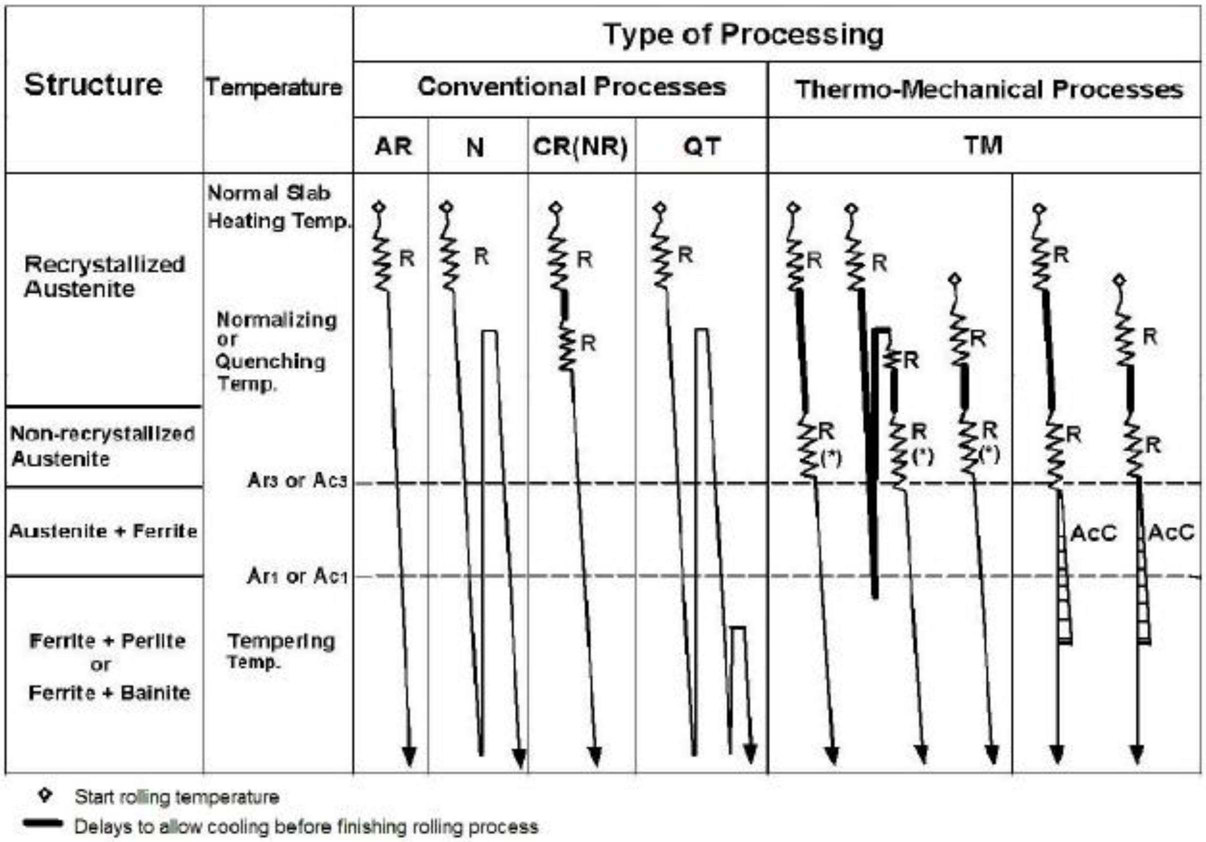
The following information is generally required to be included on the certificate:

- i) Manufacturer
- j) Grade designation with notation of heat input (see C6)
- k) Deoxidation practice
- l) Fine grain practice
- m) Condition of supply
- n) Plate thickness tested
- o) Welding process
- p) Welding consumable (manufacturer, brand, grade), if desired
- q) Actual heat input applied.

C6 Grade designation

Upon issuance of the certificate, the notation indicating the value of heat input applied in the confirmation test may be added to the grade designation of the test plate, e.g. "LHR-EH36-W300" (in the case of heat input 300 kJ/cm applied). The value of this notation is to be not less than 50 and every 10 added.

ANNEX D Schematic diagrams of thermo-mechanical and conventional processes



NOTE:

TM: Thermo-Mechanical Rolling (Thermo-Mechanical Controlled Process)

AcC: Accelerated Cooling

AR: As Rolled

(*): Sometimes rolling in the dual-phase temperature region of austenite and ferrite

N: Normalizing

CR (NR): Controlled Rolling (Normalizing Rolling)

R: Reduction

QT: Quenching and Tempering

ANNEX E Procedure for Approval of Corrosion resistant steels for cargo oil tanks (IACS UR W11 Appendix C Rev.9 (2017))

E1 Approval Procedure for Corrosion Resistant Steel

E1.1 This document specifies, as given in 3.2.1 of this Chapter, the scheme for the approval of corrosion resistant steels based upon corrosion testing.

E1.2 The corrosion testing is to be carried out in addition to the approval testing specified in ANNEX B, B1 and B2 for the approval of normal and higher strength hull structural steels.

E1.3 The corrosion tests and assessment criteria are to be in accordance with the Appendix of the Annex to Performance Standard for Alternative Means of Corrosion Protection for Cargo Oil Tanks of Crude Oil Tankers (MSC.289 (87)).

E2 Application for approval

E2.1 The manufacturer is to submit to LHR a request for approval, which is to include the following:

a) Corrosion test plan and details of equipment and test environments.
b) Technical data related to product assessment criteria for confirming corrosion resistance.
c) The technical background explaining how the variation in added and controlled elements improves corrosion resistance. The manufacturer will establish a relationship of all the chemical elements which affect the corrosion resistance. The chemical elements added or controlled to achieve the required level of corrosion resistance are to be specifically verified for acceptance. Verification is to be based on the ladle analysis of the steel.
d) The grades, the brand name and maximum thickness of corrosion resistant steel to be approved. Designations for corrosion resistant steels are given in Table E1.
e) The welding processes and the brand name of the welding consumables to be used for approval.

Table E1: Designations for Corrosion Resistant Steels

Type of steel	**Location where steel is effective**	**Corrosion Resistant Designation**
Rolled steel for hull	For lower surface of strength deck and surrounding structures (ullage space)	RCU
	For upper surface of inner bottom plating and surrounding structures	RCB
	For both strength deck and inner bottom plating	RCW

E3 Approval of test plan

E3.1 The test program submitted by the manufacturer is to be reviewed by LHR, if found satisfactory, it will be approved and returned to the manufacturer for acceptance prior to tests being carried out. Tests that need to be witnessed by the LHR's Surveyor will be identified.

E3.2 Method for selection of test samples is to satisfy the following:

E3.2.1 The numbers of test samples is to be in accordance with the requirements of the Appendix of the Annex to Performance Standard for Alternative Means of Corrosion Protection for Cargo Oil Tanks of Crude Oil Tankers (MSC.289 (87)).

E3.2.2 The number of casts and test samples selected are to be sufficient to make it possible to confirm the validity of interaction effects and/or the control range (upper limit, lower limit) of the elements which are added or intentionally controlled, for improving the corrosion resistance. Where agreed, this may be supported with data submitted by the manufacturer.

E3.2.3 Additional tests may be required by LHR when reviewing the test program against the paragraph E3.2.2.

Remarks: Considerations for additional tests may include but not be limited to:

a) When LHR determines that the control range is set by the theoretical analysis of each element based on existing data, the number of corrosion resistance tests conducted in accordance with the Appendix of the Annex to Performance Standard for Alternative Means of Corrosion Protection for Cargo Oil Tanks (MSC.289 (87)) is too few to adequately confirm the validity of the control range of chemical composition.
b) When LHR determines that the data of the corrosion resistance test result obtained for setting the control range of chemical composition varies too widely.
c) When LHR determines that the validity of the corrosion resistance test result for setting the control range of chemical composition is insufficient, or has some flaws.
d) When the LHR's surveyor has not attended the corrosion resistance tests for setting the control range of chemical composition, and LHR determines that additional testing is necessary in order to confirm the validity of the test result data.

Remarks: The chemical composition of the corrosion resistant steel is to be within the range specified for rolled steel for hull. Elements to be added for improving the corrosion resistance and for which content is not specified are to be generally within 1% in total.

E4 Carrying out the approval test

E4.1 The manufacturer is to carry out the approval test in accordance with the approved test plan.

E5 Attendance of the LHR's Surveyor for Test

E5.1 LHR's Surveyor is to be present, as a rule, when the test samples for the approval test are being identified and for approval tests, see also E3.1.

E6 Test Results

E6.1 After completion of the approval test, the manufacturer is to produce the report of the approval test and submit it to LHR.

E6.2 LHR will give approval for corrosion resistant steel where approval tests are considered by LHR to have given satisfactory results based on the data submitted in accordance with the provisions of this ANNEX E.

E6.3 The certificate is to contain the manufacturer's name, the period of validity of the certificate, the grades and thickness of the steel approved, welding methods and welding consumables approved.

E7 Assessment Criteria for Results of Corrosion Resistance Tests of Welded Joint

E7.1 The results will be assessed by LHR in accordance with the acceptance criteria specified in the Appendix of the Annex to Performance Standard for Alternative Means of Corrosion Protection for Cargo Oil Tanks (MSC.289 (87)).

CHAPTER 4 Castings

CONTENTS

SECTION 1 General requirements for steel castings

1.1 Scope

1.1.1 This Section provides the general requirements to be applied in the manufacture and testing of steel castings intended for use in the construction of ships, other marine structures, machinery, boilers, pressure vessels and piping systems.

1.1.2 The whole procedure of manufacture and testing is to be performed according to the requirements of Part 2, Chapter 1 and Chapter 2. This SECTION depicts the general requirement and SECTION 2 to SECTION 7 the more specific requirements corresponding to steel castings.

1.1.3 Specific requirements are given for carbon and carbon-manganese steel castings but, alternatively, steel castings which comply with national or proprietary specifications may be accepted provided such specifications give reasonable equivalence to these requirements or are otherwise specially approved or required by LHR.

1.1.4 Where small steel castings are manufactured in large quantities, quality control procedures may be adopted by the manufacturer other than those prescribed in these Rules after agreement with LHR.

1.1 Manufacture

1.2.1 Manufacturers wishing to supply products accepted by these Rules must be approved by LHR provided that they have demonstrated to its satisfaction that the necessary manufacturing and testing facilities are available and are supervised by qualified personnel.

1.2.2 The steels are to be manufactured by the basic oxygen, electric furnace or open-hearth process or by other methods approved by LHR.

1.2.3 Referring to the deoxidation method, all steels shall be killed.

1.2.4 All flame cutting, scarfing or arc-air gouging to remove surplus metal is to be undertaken in accordance with recognized good practice and is to be carried out before the final heat treatment. Preheating is to be employed when necessitated by the chemical composition and/or thickness of the castings. If necessary, the affected areas are to be either machined or ground smooth.

1.2.5 In order to remove surplus metal the manufacturer may use flame cutting, scarfing or arc-air gouging in accordance with recognized good practice, to be carried out definitely before the final heat treatment. Preheating is to be employed when necessitated by the chemical composition and/or thickness of the steel castings. If necessary, the affected areas are to be either machined or ground smooth.

1.2.6 Where steel castings are formed by joining of two or more components, the proposed welding procedure shall be submitted for approval. Welding approval procedure tests may be required.

1.2.7 Where steel castings of the same type are produced in regular quantities, the manufacturer is to make any tests necessary to prove the quality of the prototype castings, and is also to make periodical examinations to verify the continued efficiency of the manufacturing procedure. The Surveyor is to be given the opportunity to witness these tests.

1.2.8 For certain components, including steel castings subjected to surface hardening process, the proposed method of manufacture may require special approval by LHR.

1.2 Freedom from defects

1.3.1 Casting defects are undesirable. Defects liable to impair the use and workability of the material, e.g. non-metallic inclusions, shrinkage cavities, blow holes and cracks, are not allowed. Their removal is to be in accordance with 1.9, provided that LHR has given its consent to the repair. Minor casting defects such as small sand, slag marks, small cold shuts may be trimmed off within the negative tolerance on the wall thickness.

The surface finish must be in accordance with good practice and any specific requirements of the approved plan.

1.3 Chemical composition

1.4.1 The chemical composition of the ladle sample is to be within the limits given in the relevant Section of this Chapter. Where general overall limits are specified, the chemical composition shall be appropriate for the type of steel and the required mechanical properties of the particular castings.

1.4.2 Unless otherwise required, suitable grain refining elements such as aluminum may be used at the discretion of the manufacturer. The content of such elements is to be reported in the ladle analysis.

1.4.3 Where steel castings are intended for welded construction, the proposed chemical composition is subject to approval by LHR.

1.4 Condition of supply

1.5.1 All steel castings are to be heat-treated in a way appropriate to the material. The heat treatments are to be performed in suitable furnaces having efficient means for controlling and recording the temperature. The size of the furnace must enable the entire casting to be raised uniformly to the required heat treatment temperature. In the case of very large castings alternative methods for heat treatment will be specially considered by LHR.

1.5.2 When a steel casting is locally reheated or undergoes hot or cold straightening or alignment, after the final heat treatment, subsequent stress relief heat treatment may be required to avoid the possibility of harmful residual stresses.

1.5 Mechanical tests

1.6.1 Test material, sufficient for the required tests and for possible re-test purposes is to be provided for each steel casting or batch of steel castings.

1.6.2 At least one test sample is to be provided for each steel casting. Unless otherwise agreed these test samples are to be either integrally cast or gated to the castings and are to have a thickness of not less than 30 mm.

1.6.3 Where the steel casting is of complex design or where the finished mass exceeds 10 tonnes, two test samples are to be provided. Where large castings are made from two or more casts, which are not mixed in a ladle prior to pouring, two or more test samples are to be provided corresponding to the number of casts involved. These are to be integrally cast at locations as widely separated as possible.

1.6.4 For steel castings where the method of manufacture has been specially approved by LHR in accordance with 1.2.8, the number and position of test samples is to be agreed with LHR having regard to the method of manufacture employed.

1.6.5 As an alternative to 1.6.2, where a number of small castings of about the same size is made from one cast and heat-treated in the same furnace charge, a batch testing procedure may be adopted using separately cast test samples of suitable dimensions. At least one test sample is to be provided for each batch of castings.

1.6.6 All test samples are to be suitably marked to identify them with the steel castings which they represent.

1.6.7 The test samples are to be heat-treated together with the steel castings which they represent.

1.6.8 One tensile test specimen and, when required, one set of three impact test specimens are to be taken from each test sample. When impact tests are required Charpy V-notch impact test specimens may be used at the discretion of the manufacturer unless otherwise specified by LHR.

1.6.9 The test samples are not to be detached from the casting until the specified heat treatment has been completed and they have been properly identified.

1.6.10 Tensile and impact test specimens are to be machined to the dimensions given in Part 2, Chapter 2, SECTION 3 and SECTION 4 respectively.

1.6.11 All tensile tests are to be carried out at ambient temperature (generally 18-25°C) using test procedures in accordance with Part 2, Chapter 2, SECTION 3. Unless otherwise agreed, all tests are to be carried out in the presence of the Surveyors.

1.6 Mechanical properties

1.7.1 The results of the tensile tests are to comply with the requirements depicted on the tables of the appropriate SECTION. The average energy value from a set of three impact test specimens is to be not less than the appropriate value given in tables. One individual value may be less than the required average value provided that it is not less than 70% of this average value.

1.7.2 Where the result of a tensile test does not comply with the requirements, two additional tests may be taken. If satisfactory results are obtained from both of these additional tests the casting or batch of castings is acceptable. If one or both re-tests fail, the castings or batch of castings is to be rejected.

1.7.3 Where the results from a set of three impact test specimens do not comply with the requirements (see 1.7.1) an additional set of three impact test specimens may be taken provided that no more than two individual values are less than the required average value. The results obtained are to be combined with the original results to form a new average which for acceptance of the casting or batch of castings is to be not less than the required average value. Additionally, for these combined results not more than two individual values are to be less than the required average value and of these not more than one is to be less than 70% of this average value.

1.7.4 The additional tests detailed in 1.7.2 and 1.7.3 are to be taken, preferably from the same, but alternatively from another, test sample representative of the casting or batch of castings.

1.7.5 At the option of the manufacturer, when a casting or a batch of castings has failed to meet the test requirements, it may be re-heat-treated and re-submitted for acceptance tests.

1.7 Inspection and tests other than mechanical tests

1.8.1 All steel castings are to be cleaned and adequately prepared for examination; suitable methods include pickling, caustic cleaning, wire brushing, local grinding, shot or sand blasting. The surfaces are not to be hammered, peened or treated in any way which may obscure defects.

1.8.2 Before acceptance, all steel castings are to be presented to the Surveyors for visual examination. Where applicable, this is to include the examination of internal surfaces. Unless otherwise agreed, the verification of dimensions is the responsibility of the manufacturer.

1.8.3 When required by the relevant construction Rules, or by the approval procedure for welded composite components (see 1.2.6), appropriate non-destructive testing is also to be carried out before acceptance and the results are to be reported by the manufacturer. All such tests are to be carried out by competent operators, using reliable and efficiently maintained equipment. The testing procedures used are to be agreed with the Surveyors.

1.8.4 Magnetic particle or liquid penetrant testing is to be carried out for surface examination when the castings are in the finished condition. Where magnetic particle examination is specified, the dry powder method is not acceptable. Where current flow methods are used for magnetization, particular care is to be taken to avoid damaging finished machined surfaces by contact burns form the prods. Unless otherwise agreed these tests are to be carried out in the presence of the Surveyors.

Acceptance standards are to be to the satisfaction of LHR and in accordance with any requirements of the approved plan. Defects are liable to appear mostly in the following areas, therefore examination should be carried out:

1) At positions indicated on the approved plan.

2) At all accessible fillets and changes of sections.
3) At positions where surplus metal has been removed by flame cutting, scarfing or arc-air gouging.
4) At positions prepared for welding.
5) At other important areas which may be subject to high stress in service, after agreement with the Surveyor.

The magnetic particle method shall be used wherever possible, except in the case of austenitic steels. The liquid penetrant method shall be performed on those steels or others in lieu of the magnetic particle test. The manufacturer shall issue a test certificate stating the details of the test.

1.8.5 The radiographic examination of steel castings is to be carried out by the manufacturer at positions as indicated on the approved plan or as otherwise agreed with the Surveyors. All radiographs are to be submitted to the Surveyors for examination and acceptance. Acceptance standards are to be to the satisfaction of LHR and in accordance with any requirements of the approved plan.

1.8.6 The ultrasonic examination of steel castings is to be carried out at positions as indicated on the approved plan or as otherwise agreed with the Surveyors. This examination is to be carried out by the manufacturer but the Surveyor may request to be present in order to verify that the examination and the acceptance criteria are in accordance with the agreed procedure. The manufacturer shall issue a test certificate stating the details of the test.

1.8.7 When required by the relevant construction Rules, steel castings shall be submitted to a hydraulic pressure test. The test is to be performed in the presence of the Surveyor, wherever possible in the rough-machined casting. Where no other test pressure is specified, the test pressure shall be equal to 1,5 times the operating pressure.

1.8.8 In the event of any casting proving defective during subsequent machining or testing it is to be rejected notwithstanding any previous certification.

1.8 Rectification of defective steel castings

1.9.1 Defects may be repaired by machining, grinding, flame scarfing, arc-air gouging or by welding. The method depends on the base metal as well as on the size and position of the defect and is to be agreed with the Surveyor. Flame-scarfing or arc-air gouging may be used provided that preheating is employed when necessary (because cast steels are liable to hardening) and that the surfaces of the resulting depression are subsequently ground smooth. Complete elimination of the defective material is to be proved by adequate non-destructive testing.

Shallow grooves or depression resulting from the removal of defects may, at the discretion of the Surveyor, be accepted provided that they will cause no appreciable reduction in the strength of the castings and that they are suitably smoothed and contoured by grinding. Small surface irregularities sealed by welding are to be treated as weld repairs.

1.9.2 Proposals to repair a defective casting by welding are to be submitted to the Surveyors for approval before this work is commenced. Such proposals are to include details of the extent and position of all defects. The manufacturer may be required to carry out welding procedure tests to demonstrate that satisfactory mechanical properties can be obtained.

The manufacturer is to maintain full records detailing the extent and location of repairs made to each casting and details of weld procedures and heat treatments applied for repairs. These records are to be available to the Surveyor and copies provided on request.

1.9.3 When it has been agreed that the casting can be repaired this is to be carried out in accordance with an approved welding procedure which includes the following features:

1) Before welding is started, full details of the extent and location of the repair, the proposed welding procedure, heat treatment and subsequent inspection procedures are to be submitted for approval

2) Cast steel components for crankshafts and alloy steel castings are to be given a suitable preliminary heat treatment prior to carrying out weld repairs. A similar heat treatment may also be required for other types of castings where the repair of a major defect is proposed.

3) The excavations are to be suitably shaped to allow good access for welding and after final preparation for welding are to be re-examined by suitable nondestructive testing methods to ensure that all defective material has been eliminated.

4) All castings in alloy steels and castings in carbon and carbon-manganese steels are to be suitably pre-heated prior to welding depending on their chemical composition and the dimensions and position of the weld repairs.

5) Welding is to be done under cover in positions free from draughts and adverse weather conditions by qualified welders with adequate supervision. As far as possible, all welding is to be carried out in the downhand (flat) position.

6) The welding consumables used are to be of an appropriate composition and type, giving a weld deposit with mechanical properties similar to those of the parent castings. The use of low hydrogen type welding consumables is preferred. Consideration is to be given to the effect of post-weld heat treatment on the mechanical properties of the weld metal. Welding procedure tests are to be carried out by the manufacturer to demonstrate that satisfactory mechanical properties can be obtained after heat treatment as detailed in 2.3.1.

7) After welding has been completed the castings are to be given either a suitable heat treatment in accordance with the requirements of 2.3, or a stress relieving heat treatment at a temperature of not less than 550°C for the same kind of castings. The type of heat treatment employed will be dependent on the chemical composition of the casting and the dimensions, positions and nature of the defects.

8) Special consideration may be given to the omission of post-weld heat treatment or to the acceptance of a local stress-relieving heat treatment where the repaired area is small and machining of the casting has reached an advanced stage.

9) On completion of heat treatment, the weld repairs and adjacent material are to be ground smooth and examined by magnetic particle or liquid penetrant testing. Supplementary examination by ultrasonics or radiography may also be required depending on the dimensions and nature of the original defect. Satisfactory results are to be obtained from all forms of non-destructive testing used.

1.9 Marking

1.10.1 The manufacturer is to adopt a system of identification which will enable all finished castings to be traced to the original cast, and the Surveyor is to be given full facilities for so tracing the castings when required.

1.10.2 Before acceptance, all castings which have been tested and inspected with satisfactory results are to be clearly marked by the manufacturer. The following particulars are required:

1) Steel quality.
2) Identification number, cast number or other marking which will enable the full history of the casting to be traced.
3) Manufacturer's name or trade mark.
4) The LHR mark “LHR”.
5) Abbreviated name of the LHR's local office.
6) Personal stamp of Surveyors responsible for inspection.
7) Where applicable, test pressure.

8) Date of final inspection

1.10.3 Where small castings are manufactured in large numbers, modified arrangements for identification may be specially agreed with LHR.

1.10 Certification

1.11.1 The manufacturer is to provide the Surveyor with a test certificate or shipping statement giving the following particulars for each casting or batch of castings which has been accepted:

1. Purchaser's name and order number.
2. Description of castings and steel quality.
3. Identification number.
4. Steel making process, cast number and chemical analysis of ladle samples.
5. Results of mechanical tests.
6. General details of heat treatment.
7. Where applicable, test pressure.

SECTION 2 Hull and machinery steel castings (IACS UR W8, Rev.3 (2022))

2.1 Scope

2.1.1 These requirements are applicable to C, C-Mn and alloy steel castings intended for hull and machinery applications for ships and offshore units for worldwide services as specified in the relevant Rules of this Section. These Rules also make consideration for grades that are intended for fabrication by welding, as well as grades not intended for welding.

2.1.2 Additional requirements will typically be required for castings for offshore units depending on applicable service temperature and environment. Additional requirements may be necessary, especially when the castings are intended for service at low or elevated temperatures, e.g. for ships with ice-class or for boilers.

2.1.3 Similarly, C and C-Mn steel castings and castings which comply with national or proprietary specifications may be accepted provided such specifications give reasonable equivalence to these requirements or are otherwise specially approved or required by LHR.

2.2 Manufacture

2.2.1 Castings are to be made at a manufacturer approved by LHR.

2.2.2 The steel is to be manufactured by a process approved by LHR.

2.2.3 All flame cutting, scarfing or arc-air gouging to remove surplus metal is to be undertaken in accordance with recognized good practice and is to be carried out before the final heat treatment. Preheating is to be employed when necessitated by the chemical composition and/or thickness of the castings. If necessary, the affected areas are to be either machined or ground smooth.

2.2.4 For certain components including steel castings subjected to surface hardening process, the proposed method of manufacture may require special approval by LHR.

2.2.5 Joining of two or more castings by welding to form a composite component:

Requirements for welding procedure qualification tests of steels for hull construction and marine structures are specified in Chapter 9, SECTION 2 of this Part. Welders for hull structural steel castings are to be qualified in accordance with IACS UR W32.

Requirements for other WPS and qualification thereof, for welder certification and for type approval of welding consumables are at the discretion of LHR.

2.2.6 Temporary welds made for operations such as lifting, handling, staging, etc., are to be in accordance with approved welding procedures and qualified welders, and are to be removed, ground and inspected using suitable NDT methods.

2.3 Quality of Castings - Freedom from defects

2.3.1 Castings are to be free from surface or internal defects which would be prejudicial to their proper application in service. The surface finish is to be in accordance with good practice and any specific requirements of the approved plan.

2.4 Chemical composition

2.4.1 All castings are to be made from killed steel and the chemical composition is to be appropriate for the type of steel and the mechanical properties specified for the castings. The chemical composition of each heat is to be determined by the manufacturer on a sample taken preferably during the pouring of the heat. When multiple heats are tapped into a common ladle, the ladle analysis shall apply.

2.4.2 The chemical composition is to comply with the overall limits given in Table 4.2.1 and Table 2, respectively, or, where applicable, the requirements of the approved specification.

2.4.3 Suitable grain refining elements such as aluminum may be used at the discretion of the manufacturer or as agreed with LHR.

Table 4.2.1: Chemical composition limits for hull and machinery steel castings (%):C, C-Mn steels

Steel type	Applications	C (max)	Si (max)	Mn	S (max)	P (max)	Residual elements (max)				Total residuals (max)
							Cu	Cr	Ni	Mo	
C, C-Mn	Castings for non-welded construction	0,40	0,60	0,50-1,60	0,035	0,035	0,30	0,30	0,40	0,15	0,80
	Castings for welded construction	0,23	0,60	0,50-1,60	0,035	0,035	0,30	0,30	0,40	0,15	0,80

Table 4.2.2: Chemical composition limits for hull and machinery steel castings (%): Alloy steels

Steel type	Applications	C (max.)	Si (max.)	Mn	S (max.)	P (max.)	Alloying elements [1] (min.)			
							Cu	Cr	Ni	Mo
Alloy	Castings for non-welded construction	0,45	0,60	0,50-1,60	0,030	0,035	0,30	0,40	0,40	0,15
	Castings for welded construction	alloying element values to be agreed with LHR								

Note:
1. At least one of the elements shall comply with the minimum content

2.5 Condition of supply

2.5.1 Castings are to be supplied in one of the following delivery conditions:

1. Carbon and carbon-manganese steels:
   - Fully annealed
   - Normalized
   - Normalized and tempered
   - Quenched and tempered
2. Alloy steels:
   - Normalized
   - Normalized and tempered
   - Quenched and tempered

For all types of steel the tempering temperature is to be not less than 550°C.

The delivery condition shall meet the design and application requirements. It is the manufacturers responsibility to select the appropriate heat treatment method to obtain the required mechanical properties.

2.5.2 Castings for components such as crankshafts and engine bedplates, where dimensional stability and freedom from internal stresses are important, are to be given a stress relief heat treatment. This is to be carried out at a temperature of not less than 550°C followed by furnace cooling to 300°C or lower.

2.5.3 Heat treatment is to be carried out in properly constructed furnaces which are efficiently maintained and have adequate means for control and recording of temperature. The furnace dimensions are to be such as to allow the whole casting to be uniformly heated to the necessary temperature. In the case of very large castings alternative methods for heat treatment will be specially considered by LHR. Sufficient thermocouples are to be connected to the furnace charge to measure and record that its temperature is adequately uniform unless the temperature uniformity of the furnace is verified at regular intervals.

2.5.4 If a casting is locally reheated or any straightening operation is performed after the final heat treatment, a subsequent stress relieving heat treatment may be required in order to avoid the possibility of harmful residual stresses. The manufacturer shall have strict control of this temperature in order to avoid any detrimental effects to the final heat treatment and resultant microstructure and mechanical properties of the casting.

2.5.5 The foundry is to maintain records of heat treatment identifying the furnace used, furnace charge, date, temperature and time at temperature. The records are to be presented to the Surveyor on request.

2.6 Mechanical tests

2.6.1 Test material, sufficient for the required tests and for possible retest purposes is to be provided for each casting or batch of castings.

2.6.2 At least one test block is to be provided for each casting. Unless otherwise agreed these test blocks are to be either integrally cast or gated to the castings.

2.6.3 The size of the test blocks for mechanical testing is to be such that the heat treatment and microstructure is representative for the section of the casting with the ruling section, i.e. the section for which the specified mechanical properties apply, see also ISO 683-1:2018 as amended and ISO 683-2:2018 as amended, respectively.

For C, C-Mn steel castings this is in general to be achieved as follows: The test block shall have a thickness (t_S) of not less than the ruling section of the casting, or 30 mm, whichever is larger.

2.6.4 For large thickness castings other than stern tube, stern frame, anchor and rudder horn, t_S normally need not to exceed 150 mm. Length and width of the test block is normally to be at least three times t_S, unless otherwise agreed with LHR, as shown in Figure 4.2.1.
(Note that longer or wider test blocks may be necessary in order to accommodate the required test specimens.)

For castings for stern tube, stern frame, anchor and rudder horn the test block thickness tS shall represent the ruling section.

--Guidance--

Shorter width or length may be accepted for test blocks where actual casting width or length (t_A) is in the range between t_S and $3t_S$.

Example 1: For a general casting with dimensions 140 x 160 x 1250 mm the required test block size would typically be 140 x 160 x 420 mm (that is: t_S x t_A x $3t_S$).

Example 2: For a stern tube casting with ruling section t_S = 170 mm and width/height/length

t_{A1}/t_{A2}/tA3 = 1000/600/1800 mm, the required test block size would typically be 170 x 510 x 510 mm (that is: t_S x $3t_S$ x $3t_S$) see Figure 4.2.2.

--End of guidance—

For alloy steel castings the manufacturer shall propose dimensions for the test block and demonstrate the representative nature of it.

2.6.5 For test blocks with thickness ≤ 56 mm, the longitudinal axis of the test specimens is to be located at ≥ 14 mm from the surface in the thickness direction. For test blocks with thickness > 56 mm, the longitudinal axis of the test specimens is to be located at ≥ ¼ t_S from the surface. Test specimens shall be taken in such a way that no part of the gauge length is machined from material closer than t_S to any of the other surfaces. For impact testing, this requirement shall apply to the complete test specimen - refer to Figure 4.2.1 for location of test specimens in relation to the test block.

2.6.6 Where the casting is of complex design or where the finished mass exceeds 10 tonnes, two cast on test blocks are to be provided from the heaviest section, located as far as practicable from each other.

6.6.7 Where large castings are made from two or more casts, which are not mixed in a ladle prior to pouring, two or more test blocks are to be provided corresponding to the number of casts involved. These are to be integrally cast at locations as widely separated as possible.

2.6.8 For castings where the method of manufacture has been specially approved by LHR in accordance with 2.2.4, the number and position of test blocks is to be agreed with LHR having regard to the method of manufacture employed.

Figure 4.2.1: Specimen positions relative to the test block in accordance with ISO 4990:2015 as amended

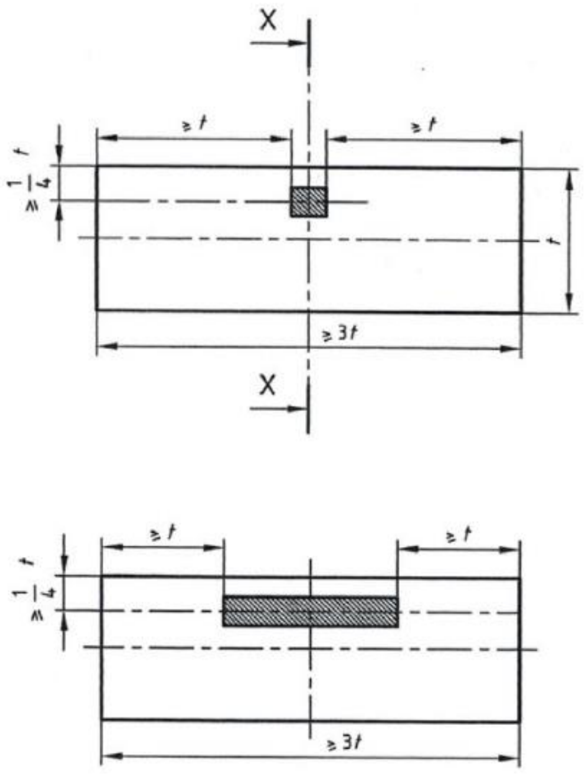
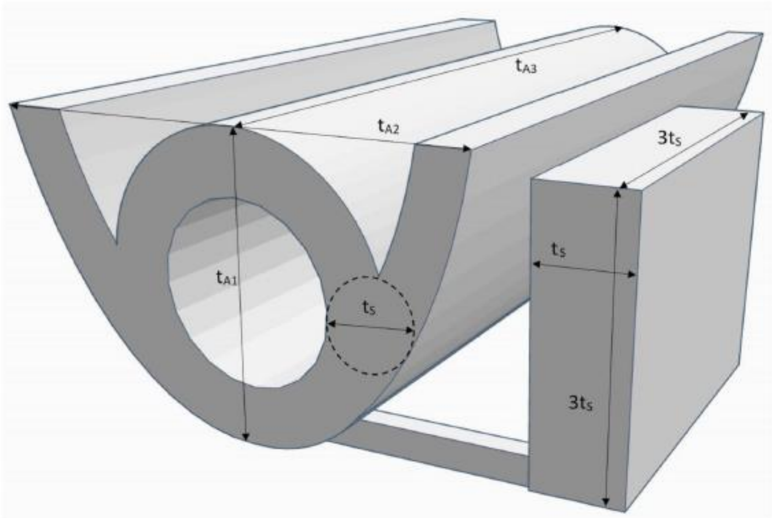


Figure 4.2.2: Example 2-Test block gated to stern tube casting



2.6.9 As an alternative to 2.6.2, where a number of small castings of about the same size, each of which is under 1000kg in mass, are made from one cast and heat treated in the same furnace charge, a batch testing procedure may be adopted using separately cast test blocks of suitable dimensions. At least one test block is to be provided for each batch of castings.

2.6.10 The test blocks are not to be detached from the casting until the specified heat treatment has been completed and they have been properly identified.

2.6.11 One tensile test specimen and one set of impact tests are to be taken from each test block.

2.6.12 The preparation of test specimens and the procedures used for mechanical testing are to comply with the relevant requirements of Part 2, Chapter 2, SECTIONS 1-6. Unless otherwise agreed all tests are to be carried out in the presence of the Surveyors.

2.7 Mechanical properties

2.7.1 Table 4.2.3 and Table 4.2.4 give the minimum requirements for yield stress, elongation, reduction of area and impact test energy values corresponding to steel types and different strength levels. Where it is proposed to use a steel with a specified minimum tensile strength intermediate to those given, corresponding minimum values for the other properties may be obtained by interpolation.

2.7.2 Castings may be supplied to any specified minimum tensile strength selected within the general limits detailed in Table 4.2.3 and Table 4.2.4, respectively, but subject to any additional requirements of the relevant construction Rules.

2.7.3 The mechanical properties are to comply with the requirements of Table 4.2.3 and Table 4.2.4, respectively, appropriate to the specified minimum tensile strength or, where applicable, the requirements of the approved specification.

2.7.4 Re-test requirements for tensile tests are to be in accordance with Part 2, Chapter 2, SECTIONS 1-6.

2.7.5 The additional tests detailed in 2.7.4 are to be taken, preferably from the same, but alternatively from another, test block representative of the casting or batch of castings.

2.7.6 At the option of the manufacturer, when a casting or batch of castings has failed to meet the test requirements, it may be reheat treated and re-submitted for acceptance tests.

Table 4.2.3: Mechanical properties for steel castings intended for welding

Steel type	Specified minimum tensile strength (1) [N/mm^2]	Yield stress [N/mm^2] min.	Elongation on 5,65 √So (%) min	Reduction area (%) min.	Charpy V-notch impact test (2)	
					Test temperature (°C)	Minimum average energy (J)
C, C-Mn	400	200	25	40	0	27
	440	220	22	30		
	480	240	20	27		
	520	260	18	25		
	560	300	15	20		
	600	320	13	20		
Alloy	550	355	18	30	0	27
	600	400	16	30		
	650	450	14	30		
	700	540	12	28		

Notes:
1. A tensile strength range of 150 N/mm^2 may additionally be specified.
2. Special consideration may be given to alternative requirements for Charpy V-notch impact test, depending on design and application, and subject to agreement by LHR.

Table 4.2.4: Mechanical properties for machinery steel castings not intended for welding

Steel type	Specified minimum tensile strength (1) [N/mm²]	Yield stress [N/mm²] min.	Elongation on 5,65 √So (%) min	Reduction area (%) min.	Charpy V-notch impact test (2)	
					Test temperature (°C)	Minimum average energy (J)
C, C-Mn	400	200	25	40		27
	440	220	22	30		
	480	240	20	27		
	520	260	18	25		
	560	300	15	20		
	600	320	13	20		
Alloy	550	340	16	35	AT (3)	27
	600	400	16	35		

Notes:
1. A tensile strength range of 150 N/mm² may additionally be specified.
2. Special consideration may be given to alternative requirements for Charpy V-notch impact test, depending on design and application, and subject to agreement by LHR.
3. AT refers to Ambient Temperature (i.e. 23°C±5°C), which is specified in ISO 148-1:2016 as amended.

2.8 Inspection

2.8.1 All castings are to be cleaned and adequately prepared for examination; suitable methods include pickling, caustic cleaning, wire brushing, local grinding, shot or sand blasting. The surfaces are not to be hammered, peened or treated in any way which may obscure defects.

2.8.2 Before acceptance all castings are to be presented to the Surveyors for visual examination. Where applicable, this is to include the examination of internal surfaces. Unless otherwise agreed, the verification of dimensions is the responsibility of the manufacturer.

2.8.3 When required by the relevant construction Rules, or by the approved procedure for welded composite components (see 2.6 of this SECTION), appropriate non-destructive testing is also to be carried out before acceptance and the results are to be reported by the manufacturer. The extent of testing and acceptance criteria are to be agreed with LHR.

IACS Recommendation No. 69 is regarded as an example of an acceptable standard specifying suitable minimum requirements.

2.8.4 When required by the relevant construction Rules castings are to be pressure tested before final acceptance. These tests are to be carried out in the presence of the Surveyor and are to be to their satisfaction.

2.8.5 In the event of any casting proving to be defective during subsequent machining or testing it is to be rejected notwithstanding any previous certification.

2.9 Rectification of defective castings

2.9.1 General

a) Where castings are to be repaired, the manufacturer shall exercise robust controls of all repair operations regarding the repair of castings, with respect to dimensions, heat treatment, inspection and quality control.

b) The approval of LHR is to be obtained where steel castings from which defects were removed are to be used with or without weld repair.

c) Defects and unacceptable indications must be repaired as indicated below:

Defective parts of material may be removed by grinding, or by chipping and grinding, or by arc air-gouging and grinding. Thermal methods of metal removal shall only be allowed before the final heat treatment. All grooves shall have a bottom radius of approximately three times the groove depth and should be smoothly blended to the surface area with a finish equal to that of the adjacent surface.

d) For NDT of steel castings after repair, see 2.8.3.

e) Where the defective area is to be repaired by welding, the excavations are to be suitably shaped to allow good access for welding. The resulting grooves are to be subsequently ground smooth and complete elimination of the defective material is to be verified by MT or PT.

f) Shallow grooves or depressions resulting from the removal of defects may be accepted provided that they will cause no appreciable reduction in the strength of the casting or affect the intended use, and the depth of defect removal is not over 15mm or 10% of wall thickness, whichever is less. The resulting grooves or depressions are to be subsequently ground smooth and complete elimination of the defective material is to be verified by MT or PT. Small surface irregularities sealed by welding are to be treated as weld repairs, see 2.9.2.

2.9.2 Weld Repairs

In addition to the requirements given in 2.9.1, the following apply for weld repairs:

a) For C and C-Mn steel castings weld repairs shall be suitably classified as major or minor. For alloy steel castings, repair requires approval from LHR.
   i. Major repairs are those where:
      - the depth is greater than 25% of the wall thickness or 25mm whichever is less, or
      - the total weld area on a casting exceeds 0.125m^2 of the casting surface noting that where a distance between two welds is less than their average width, they are to be considered as one weld.
   ii. Minor weld repairs: Weld repairs not classified as major are considered as minor and need to be carried out in accordance with a qualified welding procedure.

b) The following is required for major repairs:
   i. Shall be carried out before the final delivery heat treatment condition
   ii. Shall comply with the requirements in (d) below
   iii. Before welding is started, full details of the extent and location of the repair, the proposed welding procedure, heat treatment and subsequent inspection procedures are to be submitted for approval.

c) The following is required for minor repairs:
   i. Shall be carried out before the final delivery heat treatment condition
   ii. Shall comply with the requirements in (d) below (also with respect to records, see (d) vii) and viii).
   iii. With the exception of alloy steels, do not require prior approval by LHR, except as given in iv.
   iv. LHR may request minor repairs in critical areas to be treated as major repairs.

d) The following requirements apply for all weld repairs (major and minor):
   i. All castings in alloy steels and all castings for crankshafts are to be suitably preheated prior to welding. Castings in carbon or carbon-manganese steel may also require to be pre-heated depending on their chemical composition and the dimensions and position of the weld repairs.

ii. Welding procedures are to be qualified and shall match the delivery condition of the casting. Qualification of welding procedures shall follow the LHR rules, or subject to agreement with LHR, a recognized standard (e.g. IACS UR W28 or ISO 11970:2016 as amended).

iii. Welding is to be done under cover in positions free from draughts and adverse weather conditions by qualified welders with adequate supervision. As far as possible, all welding is to be carried out in the downhand (flat) position.

iv. The welding consumables used are to be of an appropriate composition, giving a weld deposit with mechanical properties similar and in no way inferior to those of the parent castings. Welding procedure tests are to be carried out by the manufacturer to demonstrate that satisfactory mechanical properties can be obtained after heat treatment as detailed in 2.5.1.

v. After welding has been completed the castings are to be given either a suitable heat treatment in accordance with the requirements of 2.5.1 or a stress relieving heat treatment at a temperature of not less than 550°C for C and C-Mn steel castings. For alloy steel castings, the heat treatment has to be agreed with LHR. The type of heat treatment employed will be dependent on the chemical composition of the casting and the dimensions, positions and nature of the repairs, and should not affect the properties of the casting.

vi. Subject to the prior agreement of LHR, special consideration may be given to the omission of post weld heat treatment or to the acceptance of local stress-relieving heat treatment where the repaired area is small and machining of the casting has reached an advanced stage.

vii. On completion of heat treatment the weld repairs and adjacent material are to be ground smooth and examined by magnetic particle or liquid penetrant testing. Supplementary examination by ultrasonics or radiography ultrasonic or radiographic testing may also be required depending on the dimensions and nature of the original defect. Satisfactory results are to be obtained from all forms of nondestructive testing used.

viii. The manufacturer is to maintain full records detailing the extent and location of repairs made to each casting and details of weld procedures and heat treatments applied for repairs. These records are to be available to the Surveyor and copies provided on request.

2.9.3 Recommendation for welding:

For steels with C ≥ 0,23 or Ceq ≥ 0,45, the WPQT on which the WPS is based, should be qualified on a base material having a Ceq as follows: the Ceq of the base material should not fall below more than 0,02 of the material to be welded.

(Example: WPQT for a material with actual Ceq = 0,50 may be qualified on a material with Ceq ≥ 0,48.)

2.10 Marking

2.10.1 The manufacturer is to adopt a system of identification which will enable all finished castings to be traced to the original cast and the Surveyors are to be given full facilities for so tracing the castings when required.

2.10.2 Before acceptance, all castings which have been tested and inspected with satisfactory results are to be clearly marked by the manufacturer. At the discretion of LHR any of the following particulars may be required:

- Steel quality.
- Identification number, cast number or other marking which will enable the full history of the casting to be traced.
- Manufacturer's name or trade mark.
- The LHR's name, initials or symbol.
- Abbreviated name of the LHR's local office.
- Personal stamp of Surveyors responsible for inspection.
- Where applicable, test pressure.

2.10.3 Where small castings are manufactured in large numbers, modified arrangements for identification may be specially agreed with LHR.

2.11 Certification

2.11.1 The manufacturer is to provide the required type of inspection certificate giving the following particulars for each casting or batch of castings which has been accepted:

- Purchaser's name and order number.
- Description of castings and steel quality.
- Identification number.
- Steel making process, cast number and chemical analysis of ladle samples.
- Results of mechanical tests.
- Results of non-destructive tests, where applicable.
- Details of heat treatment, including temperatures and holding times.
- Where applicable, test pressure.

SECTION 3 Steel castings for boilers, pressure vessels and piping equipment

3.1 Scope

3.1.1 These Rules are applicable for carbon, carbon - manganese and alloy steel castings for boilers, pressure vessels, piping equipment and turbines.

3.1.2 Steel castings in accordance with these Rules may be used for the cargo and processing equipment on gas tankers with design temperatures not lower than 0°C.

3.1.3 Where it is proposed to use alloy steels other than those given in this Section, specifications are to be submitted for approval.

3.1.4 If it is proposed to use a carbon or carbon-manganese steel with a specified minimum tensile strength intermediate to those given in this Section, corresponding minimum values for the yield stress, elongation and reduction of area may be obtained by interpolation.

3.2 Chemical composition

3.2.1 The chemical composition of ladle samples is to comply with Table 4.3.1.

3.3 Condition of supply

3.3.1 All castings must be supplied in a properly heat-treated condition appropriate to the grade of steel. The following treatments may be applied:

1) For carbon - manganese steel castings: Normalizing or
   Normalizing and tempering (air quenching and tempering) or
   Quenching and tempering.

2) For alloy-steel castings: Quenching and tempering

3.3.2 Steel castings subject to special requirements as regards their dimensional and geometrical stability and the absence of internal stresses must undergo additional stress relief heat treatment. Unless otherwise specified, the stress relief heat treatment temperature shall be 20°C below the tempering temperatures. The castings must be cooled in the furnace to below 300°C. The stress relief heat treatment may be dispensed with in the case of castings which have been quenched and tempered and which, after tempering, have been cooled to 300°C at a rate of less than 15°C.

3.4 Weldability

3.4.1 All grades should, where necessary, be capable of being welded by common industrial practice. The grades of cast steel shown in Table 4.3.1 are considered suitable for welding, provided that appropriate measures (e.g. preheating and post-weld heat treatment) are taken to safeguard the material characteristics. The manufacturer should demonstrate the weldability of the castings at the request of LHR.

3.5 Mechanical properties

3.5.1 The required values of tensile strength, yield strength (in this SECTION 0,2% proof stress is used), elongation and reduction in area specified in Table 4.3.2 must be met under tensile testing carried out at ambient temperature.

3.5.2 Where the design of the casting is based on mechanical properties at elevated temperatures, the values are to be specially agreed.

3.5.3 Where the lower yield, R_{eL}, or 0,2% proof stress, $R_{p0,2}$, at elevated temperature is the limiting design criterion, a tensile test is to be made at an agreed temperature within ±50°C of the design temperature. The above-mentioned stress is to be not less than the value agreed for the test temperature.

Table 4.3.1: Chemical composition of steel castings for steam boilers, pressure vessels and piping equipment

Type of steel	Grade	Chemical composition of ladle sample (%)							
		C	Si	Mn	Pmax	Smax	Cr	Mo	Residual elements
Carbon and carbon manganese	370 440	≤ 0,23	0,3-0,6	≤ 1,2	0,04	0,04	—	—	(Note 1)
0,5 Mo	450	0,15-0,23	0,3 - 0,6	0,5 - 1,2 (Note 2)	0,04	0,04	≤ 0,3	0.4-0,6	—
1,25 Cr 0,5 Mo	500	0,13-0,20	0,3 - 0,6	0,5 - 0,8 (Note 2)	0,04	0,04	1,0-1,5	0,45-0,65	—
2,5 Cr 1 Mo	580	0,13-0,20	0,3 - 0,6	0,5 - 0,8 (Note 2)	0,04	0,04	2,0 - 2,5	0,9-1,2	—
Cr Mo V	500	0,13-0,20	0,3-0,6	0,5 - 0,8 (Note 2)	0,035	0,035	1,2-1,5	0,9-1,2	V=0,15-0,35

NOTES:

1. For unalloyed steel castings the following limits shall be applied:

Cr ≤ 0,30Cu ≤ 0,30 the sum of (Cr + Mo + Cu + Ni) ≤ 0,80%

Mo ≤ 0,15 Ni ≤ 0,40

2. An upper limit of 1,10% for the manganese content is acceptable where this increase is necessary for the through quenching and tempering of large wall thicknesses.

Table 4.3.2: Mechanical properties of steel castings for steam boilers, pressure vessels and piping equipment

Type of steel	Grade	0,2% proof stress (N/mm²)	Tensile strength (N/mm²)	Elongation A_5 (%) min.	Reduction of area (%) min.
Carbon and Carbon manganese	370	185	370 - 520	25	35
	440	230	440 - 600	22	30
0,5 Mo	450	230	450 - 600	21	35
1,25 Cr 0,5 Mo	500	300	500 - 650	18	30
2,5 Cr 1 Mo	580	380	580 - 730	18	35
Cr Mo V	500	350	500 - 650	15	25

3.6 Tensile Test

3.6.1 From important castings and castings with a final weight of more than 300 kg, at least one tensile specimen shall be taken and tested.

3.6.2 In the case of castings of complicated shape, e.g. turbine casings, or where the weight of the finished component is greater than 2,5 tn, at least 2 test specimens shall be taken from sample bars which are to be integrally cast with the component as far away from each other as possible.

3.6.3 Small castings of the same type with unit weights of up to 300 kg which are heat-treated together may be grouped by heats into batches of not more than 2,5 tn. From each batch at least one tensile specimen shall be taken and tested.

3.6.4 Where steel castings are intended for operation at elevated temperatures, reference shall be made to 3.6.3. Unless otherwise specified, the test shall be on at least one specimen per heat.

With the consent of the Surveyor, the test may be dispensed with in the case of cast steels to recognized standards, the elevated temperature mechanical properties of which can be considered to be proven.

3.7 Non-destructive tests

3.7.1 Significant steel castings shall be subjected to magnetic particle and radiographic inspection in accordance with SECTION 1. Important castings include, for example, turbine casings and valve bodies as well as those castings for which corresponding requirements are specified in the order documents. Complementary tests such as ultrasonic inspection may be required. The non-destructive examination of castings is to be carried out in accordance with the requirements of the approved plan, or as otherwise agreed between the manufacturer, purchaser, and Surveyor.

3.7.2 Where castings are welded together, the welds shall be subjected to magnetic particle and ultrasonic or radiographic inspection.

3.8 Hydraulic test

3.8.1 Steel castings subjected to internal pressure shall be submitted to the hydraulic pressure test in accordance with 1.8.7.

3.9 Marking

3.9.1 The particulars detailed in 1.10 are to be marked to all materials which have been accepted.

3.10 Certification

3.10.1 Each test certificate or shipping statement is to give the information contained in 1.11.

SECTION 4 Ferritic steel castings for low temperature use

4.1 Scope

4.1.1 These Rules are applicable for carbon-manganese and nickel alloy steels intended for use in liquefied gas piping systems where the design temperature is lower than 0°C and for other applications where guaranteed impact properties at low temperatures are required.

4.1.2 Where it is proposed to use alternative steels, particulars of the specified chemical composition, mechanical properties and heat treatment are to be submitted for approval.

4.1.3 The lowest design temperatures permitted for the various grades of steel castings are in Table 4.4.2.

4.2 Chemical composition

4.2.1 The chemical composition of castings made of ferritic steel for low temperature use must comply with the content of Table 4.4.1. Carbon-manganese steel castings must contain a sufficient quantity of grain refining elements.

4.3 Condition of supply

4.3.1 All castings must be supplied in a properly heat-treated condition appropriate to the grade of cast steel. Table 4.4.2 depicts the heat treatments corresponding to the steel grade.

4.3.2 Any subsequent stress relief heat treatment which may be required shall not impair the characteristics of the material or its toughness at sub-zero temperatures.

4.4 Weldability

4.4.1 Where necessary, the grades of cast steel must be capable of being welded by established workshop methods. The welding and any heat treatment applied may not impair the characteristics of the material, including in particular its toughness at low temperatures. The manufacture of socket-welded fittings by machining off the flanges of flanged fittings is not permitted. On demand, the manufacturer must demonstrate the weldability of the material.

4.5 Mechanical properties

4.5.1 The required values of tensile strength, 0,2% proof stress, A_5 elongation and reduction in area specified in Table 4.4.3 must be met under tensile test carried out at ambient temperature.

Table 4.4.1: Chemical composition of ferritic steel castings for low temperature service

Type of steel	Grade	Chemical composition of ladle sample (%)								
		C	Si	Mn	Pmax	Smax	Cr	Mo	Ni	Residual elements
Carbon manganese	400 - LT 440 - LT 480 - LT	0,23	0,3-0,6	0,5-1,65	0,03	0,03	≤ 0,3	-	≤ 0,8	Note 1
2,25 Ni	490 - LT	0,16	0,3-0,6	0,5 - 0,8	0,03	0,03	0,3	-	2,0 - 3,0	Cu ≤ 0,3% Mo < 0,15%
3,5 Ni	490 - LT	0,14	0,3- 0,6	0,5 - 0,8	0,3	0,03	≤ 0,3	-	3,0 - 4,0	

NOTE:

– Carbon-manganese steel castings must be fully killed and fine grain treated.

Table 4.4.2: Condition of supply and minimum design temperatures of ferritic steel castings for low temperature service

Grade	Condition of supply	Minimum design temperature (°C)
400 - LT 440 - LT 480 - LT	Normalized or normalized and tempered, or quenched and tempered (Note 1)	- 55
2,25 Ni	Normalized or normalized and tempered, or quenched and tempered (Note 1)	- 65
3,5 Ni	Normalized or normalized and tempered, or quenched and tempered (Note 1)	- 90

NOTE:

1. A lower minimum design temperature may be specially agreed for quenched and tempered materials.

Table 4.4.3: Mechanical properties of ferritic steel castings for low temperature service

Type of steel	Grade	0,2% proof stress (N/mm²) min	Tensile strength (N/mm²)	Elongation A_5(%) min	Reduction of area (%) min.	Charpy V-notch impact test	
						Test temperature (°C)	Average energy (J) min
Carbon Manganese	400	200	400 - 550	25	40	(Note 1)	27
	440	220	440 - 590	22	35		
	480	240	480 - 630	20	30		
2,25 Ni	490	275	490 - 640	20	35	- 70	34
3,5 Ni	490	275	490 - 640	20	35	- 95	34

NOTE:

1. The test temperature should be 5°C below the design temperature or - 20°C whichever is lower.

4.6 Tensile test

4.6.1 Steel castings shall be subjected to tensile test. Small castings of the same type with a weight up to 300 kg which are heat-treated together may be grouped by heats into batches of up to 2500 kg. At least one tensile test shall be taken from each batch.

4.6.2 From each important casting and castings with a weight of more than 300 kg at least one specimen shall be taken and tested.

4.7 Impact test

4.7.1 Castings shall be subjected to the notched bar impact test performed on ISO V-notch specimens at the test temperature specified in Table 4.4.3. The number of sets of specimens (each comprising of 3 specimens) shall be determined in the same way as the number of tensile specimens in 4.6.

4.8 Non-destructive tests

4.8.1 Non-destructive tests are to be performed either when prescribed in the approved drawings or specifications or when required by the Surveyor in specially considered cases. Moreover, the manufacturer must inspect for external or internal defects any weldment intended for welded assemblies. The extension, the method and the scope of the tests shall be agreed with the Surveyor.

4.9 Hydraulic test

4.9.1 Steel castings subjected to internal pressure shall be submitted to the hydraulic pressure test in accordance with 1.8.7.

4.10 Marking

4.10.1 The particulars detailed in 1.10 are to be marked to all materials which have been accepted.

4.11 Certification

4.11.1 Each test certificate or shipping statement is to give the information contained in 1.11.

SECTION 5 Austenitic stainless-steel castings

5.1 Scope

5.1.1 These Rules are applicable on austenitic stainless-steel castings intended for use in the cargo and processing equipment in ships for liquefied gases where the design temperature is not lower than -165°C, in chemical tankers and wherever chemical stability is required.

5.1.2 Where it is proposed to use alternative steels, particulars of the specified chemical composition, mechanical properties and heat treatment are to be submitted for approval.

5.1.3 These Rules are also applicable to austenitic stainless-steel castings for the fabrication of propellers, propeller bosses and propeller blades.

5.2 Chemical composition

5.2.1 The chemical composition of ladle samples is to comply with the requirements given in Table 4.5.1.

5.3 Condition of supply

5.3.1 All castings must be supplied in a properly heat-treated condition. All castings are to be solution treated at a temperature of not less than 1000°C and cooled rapidly in air, oil or water.

Table 4.5.1: Chemical composition of austenitic stainless steel casting

Grade	Chemical composition of ladle sample (%)								
	Cmax	Si	Mn	S	P	Cr	Mo	Ni	Residual elements
304 L	0,03	0,2 - 1,5	0,5 – 2,0	0,04	Max	16,0 - 21,0	-	8,0 - 12,0	-
304	0,08						-	8,0 - 12,0	-
316 L	0,03						2,0 - 3,0	9,0 - 13,0	-
316	0,08						2,0 - 3,0	9,0 - 13,0	-
321	0,08						-	8,0 - 12,0	Ti ≥ 5 x C ≤ 0,7
347 (Note 1)	0,06						-	8,0 - 12,0	Nb ≥ 8 x C ≤ 0,9

NOTE:

1. When guaranteed impact values at low temperature are not required, the maximum carbon content may be 0,08% and the maximum niobium may be 1,00%.

5.4 Mechanical properties

5.4.1 The required values of tensile strength, 0,2% or 1% proof stress, elongation and reduction in area specified in Table 4.5.2 must be met under tensile test carried out at ambient temperature.

5.5 Tensile test

5.5.1 Steel castings shall be subjected to tensile test. Small castings of the same type with a weight up to 300 kg which are heat-treated together may be grouped by heats into batches of up to 2500 kg. At least one tensile test shall be taken from each batch.

5.5.2 From each important casting and castings with a weight of more than 300 kg at least one specimen shall be taken and tested.

5.6 Impact test

5.6.1 Castings shall be subjected to the notched bar impact test performed on ISO V-notch specimens at the test temperature specified in Table 4.5.2. The number of sets of specimens (each comprising of 3 specimens) shall be determined in the same way as the number of tensile specimens in 5.5.

Table 4.5.2: Mechanical properties of austenitic stainless steel castings

Grade	Tensile strength (N/mm²) min	1,0% proof stress (N/mm²) min	Elongation A_5 (%) min	Reduction of area (%) min	Charpy V-notch impact tests	
					Test temperature (°C)	Average energy (J) min
340 L	400	200	26	40	- 196	41
304	440	220	26	40		
316 L	430	215	26	40		
316	440	220	26	40		
321	480	240	22	35		
347	480	240	22	35		

5.7 Non-destructive tests

5.7.1 Non-destructive tests are to be performed either when are prescribed in the approved drawings or specifications or when required by the Surveyor in specially considered cases. Moreover, the manufacturer must inspect for external or internal defects any weldment intended for welded assemblies. The extension, the method and the scope of the tests shall be agreed with the Surveyor.

5.8 Hydraulic test

5.8.1 Steel castings subjected to internal pressure shall be submitted to the hydraulic pressure test in accordance with 1.8.7.

5.9 Resistance to intercrystalline corrosion

5.9.1 In the condition in which they are supplied, austenitic grades of cast steel must be resistant to intercrystalline corrosion. Where such castings are to be used for weldments without subsequent heat treatment, only those grades of casting shall be selected which are also resistant to intercrystalline corrosion in this condition, e.g. Nb stabilized grades of cast steel or grades with carbon contents of not more than 0,03%. The intercrystalline corrosion test is to be carried out in accordance with the procedure given in Part 2, Chapter 2.

5.10 Marking

5.10.1 The particulars detailed in 1.10 are to be marked to all materials which have been accepted.

5.11 Certification

5.11.1 Each test certificate or shipping statement is to give the information contained in 1.11.

SECTION 6 Grey iron castings (IACS UR W9, Rev.2 (2004))

6.1 Scope

6.1.1 All important grey iron castings, as defined in the relevant construction Rules, are to be manufactured and tested in accordance with the requirements of this SECTION.

6.1.2 Alternatively, castings which comply with national or proprietary specifications may be accepted provided such specifications give reasonable equivalence to these requirements or otherwise are specially approved or required by LHR.

6.1.3 Where small castings are produced in large quantities, the manufacturer may adopt alternative procedures for testing and inspection subject to the approval of LHR.

6.2 Manufacture

6.2.1 All major castings are to be made at foundries where the manufacturer has demonstrated to the satisfaction of LHR that the necessary manufacturing and testing facilities are available and are supervised by qualified personnel. A program of approval tests may be required in accordance with the procedures of LHR.

6.2.2 Suitable mechanical methods are to be employed for the removal of surplus material from castings. Thermal cutting processes are not acceptable, except as a preliminary operation to mechanical methods.

6.2.3 Where castings of the same type are regularly produced in quantity, the manufacturer is to make any tests necessary to prove the quality of the prototype castings and is also to make periodical examinations to verify the continued efficiency of the manufacturing technique. The Surveyor is to be given the opportunity to witness these tests.

6.3 Quality of Castings - Freedom from defects

6.3.1 Castings are to be free from surface or internal defects which would be prejudicial to their proper application in service. The surface finish is to be in accordance with good practice and any specific requirements of the approved plan.

6.4 Chemical composition

6.4.1 The chemical composition of the iron used is left to the discretion of the manufacturer, who is to ensure that it is suitable to obtain the mechanical properties specified for the castings. When required by LHR, the chemical composition of ladle samples is to be reported.

6.5 Condition of supply

6.5.1 Except as required by 6.5.2, castings may be supplied in either the as cast or heat-treated condition.

6.5.2 For some applications, such as high temperature service or where dimensional stability is important, castings may require to be given a suitable tempering or stress relieving heat treatment.

6.6 Mechanical tests

6.6.1 Test material sufficient for the required tests and for possible re-tests is to be provided for each casting or batch of castings.

6.6.2 The test samples may be separately cast (unless otherwise agreed between the manufacturer and purchaser) and generally are to be in the form of cylindrical bars, 30 mm diameter and of a suitable length. Test samples of other dimensions may be specially required for some components. The test samples are to be cast in moulds made from the same type of material as used for the castings and are not to be stripped from the moulds until the metal temperature is below 500°C. When two or more test samples are cast simultaneously in a single mould, the bars are to be at least 50 mm apart as given in Figure 4.6.1.

6.6.3 Integrally cast samples may be used when a casting is more than 20 mm thick and its mass exceeds 200 kg, subject to agreement between the manufacturer and the purchaser. The type and location of the sample are to be selected to provide approximately the same cooling conditions as for the casting it represents and also subject to agreement.

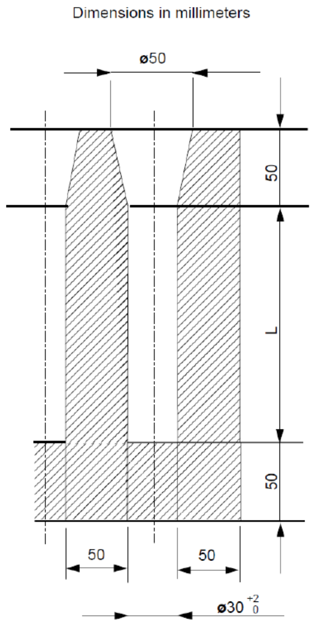
6.6.4 With the exception of 6.6.7, at least one test sample is to be cast with each batch. For large castings where more than one ladle of metal is used, additional test samples are to be provided so as to be representative of each ladle used.

6.6.5 With the exception of 6.6.6, a batch consists of the castings poured from a single ladle of metal, provided that they are all of similar type and dimensions. A batch should not normally exceed two tonnes of fettled castings and a single casting will constitute a batch is its mass is 2 tonnes or more.

6.6.6 For continuous melting of the same grade of cast iron in large tonnages the mass of a batch may be increased to the output of 2 hours of pouring.

6.6.7 If one grade of cast iron is melted in large quantities and if production is carefully monitored by systematic checking of the melting process, such as chill testing, chemical analysis or thermal analysis, test samples may be taken at longer intervals.

Figure 4.6.1: Test Sample for grey cast iron



6.6.9 As an alternative to 6.6.4 and with the exception of 6.6.6, a batch testing procedure may be adopted for castings with a fettled mass of 1 tonne or less. All castings in a batch are to be of similar type and dimensions, and cast from the same ladle of metal. One test sample is to be provided for each multiple of 2 tonnes of fettled castings in the batch.

6.6.11 All test samples are to be suitably marked to identify them with the castings which they represent.

6.6.12 Where castings are supplied in the heat-treated condition, the test samples are to be heat-treated together with the castings which they represent. For cast-on-test samples the sample shall not be cut off from the casting until after the heat treatment.

6.6.13 One tensile test specimen is to be prepared from each test sample and for 30 mm diameter samples is to be machined to the dimensions given in Part 2, Chapter 2, Section 3. Where test samples of other dimensions are specially required the tensile test specimens are to be machined to agreed dimensions.

6.6.14 All tensile tests are to be carried out using test procedures in accordance with Part 2, Chapter 2. Unless otherwise agreed all tests are to be carried out in the presence of the Surveyors.

6.7 Mechanical properties

6.7.1 Only the tensile strength is to be determined and the results obtained from tests are to comply with the minimum value specified for the castings being supplied. The value selected for the specified minimum tensile strength is to be not less than 200 N/mm² but subject to any additional requirements of the relevant Rules. The fractured surfaces of all tensile test specimens are to be granular and grey in appearance.

6.7.2 Where the result of a tensile test does not comply with the requirements, two additional tests may be taken from other test samples representative of the casting or batch of castings. If satisfactory results are obtained from both of these additional tests the casting or batch of castings is acceptable. If one or both re-tests fail the casting or batch of castings is to be rejected.

6.8 Inspection

6.8.1 All castings are to be cleaned and adequately prepared for examination. The surfaces are not to be hammered, peened or treated in any way which may obscure defects.

6.8.2 Before acceptance, all castings are to be visually examined including, where applicable, the examination of internal surfaces. Unless otherwise agreed, the verification of dimensions is the responsibility of the manufacturer.

6.8.3 Supplementary examination of castings by suitable non-destructive testing procedures is generally not required except in circumstances where there is reason to suspect the soundness of the casting.

6.8.4 When required by the relevant construction Rules, castings are to be pressure tested before final acceptance.

6.8.5 In the event of any casting proving defective during subsequent machining or testing it is to be rejected notwithstanding any previous certification.

6.8.6 Cast crankshaft are to be subjected to a magnetic particle inspection. Crack like indications are not allowed.

6.9 Rectification of defective castings

6.9.1 At the discretion of the Surveyor, small surface blemishes may be removed by local grinding.

6.9.2 Subject to the prior approval of the Surveyor, castings containing local porosity may be rectified by impregnation with a suitable plastic filler, provided that the extent of the porosity is such that it does not adversely affect the strength of the casting.

6.9.3 Repairs by welding are generally not permitted.

6.10 Identification of castings

6.10.1 The manufacturer is to adopt a system of identification, which will enable all finished castings to be traced to the original ladle of metal. The Surveyor is to be given full facilities for so tracing the castings when required.

6.10.2 Before acceptance, all castings which have been tested and inspected with satisfactory results are to be clearly marked by the manufacturer. The following particulars are required:

1. Quality of cast iron.
2. Identification number or other marking which will enable the full history of the casting to be traced.
3. Manufacturer's name or trade mark.
4. The LHR mark “LHR”.
5. Abbreviated name of LHR's local office.
6. Personal stamp of Surveyor responsible for inspection.
7. Where applicable, test pressure.
8. Date of final inspection.

6.10.3 Where small castings are manufactured in large numbers, modified arrangements for identification may be specially agreed with LHR.

6.11 Certification

6.11.1 The manufacturer is to provide the Surveyor with a test certificate or shipping statement giving the following particulars for each casting or batch of castings which has been accepted:

1. Purchaser's name and order number.
2. Description of castings and quality of cast iron.
3. Identification number.
4. Results of mechanical tests.
5. Where applicable, general details of heat treatment.
6. When specially required, the chemical analysis of ladle samples.
7. Where applicable, test pressure.

SECTION 7 Spheroidal or nodular graphite iron castings (IACS UR W10 Rev.2 (2004))

7.1 Scope

7.1.1 All important spheroidal or nodular graphite iron castings, as defined in the relevant construction Rules, are to be manufactured and tested in accordance with the requirements of this SECTION.

7.1.2 These requirements are applicable only to castings where the design and acceptance tests are related to mechanical properties at ambient temperature. For other applications additional requirements may be necessary, especially when the castings are intended for service at low or elevated temperatures.

7.1.3 Alternatively, castings which comply with national or proprietary specifications may be accepted provided such specifications give reasonable equivalence to these requirements or otherwise are specially approved or required by LHR.

7.1.4 Where small castings are produced in large quantities the manufacturer may adopt alternative procedures for testing and inspection subject to the approval of LHR.

7.2 Manufacture

7.2.1 Manufacture of spheroidal or modular graphite iron castings is to be performed according to the requirements of 6.2.

7.3 Quality of Castings - Freedom from defects

7.3.1 The requirements of SECTION 6, 6.3 apply.

7.4 Chemical composition

7.4.1 Unless otherwise specially required, the chemical composition of the iron used is left to the discretion of the manufacturer, who is to ensure that it is suitable to obtain the mechanical properties specified for the castings. When required by LHR the chemical composition of ladle samples is to be reported.

7.5 Heat treatment

7.5.1 Except as required by 7.5.2 castings may be supplied in either the as cast or heat-treated condition.

7.5.2 For some applications, such as high temperature service or where dimensional stability is important, it may be required that castings be given a suitable tempering or stress relieving heat treatment. This is to be carried out after any refining heat treatment and before machining. The special qualities with 350 N/mm² and 400 N/mm² nominal tensile strength and impact test shall undergo a ferritizing heat treatment.

7.5.3 Where it is proposed to locally harden the surfaces of a casting full details of the proposed procedure and specification are to be submitted for approval by LHR.

7.6 Mechanical tests

7.6.1 The mechanical tests are generally to be performed in accordance with the requirements of 6.6, unless otherwise stated in the following paragraphs of this subsection.

7.6.2 The test samples are generally to be one of the standard types detailed in Figure 4.7.1, Figure 4.7.2, Figure 4.7.3 with a thickness of 25 mm. Test samples of other dimensions, as detailed in Figure 4.7.1, Figure 4.7.2 and Figure 4.7.3 may, however, be specially required for some components.

7.6.3 At least one test sample is to be provided for each casting and unless otherwise required may be either gated to the casting or separately cast. Alternatively test material of other suitable dimensions may be provided integral with the casting.

7.6.4 For large castings where more than one ladle of treated metal is used, additional test samples are to be provided so as to be representative of each ladle used.

7.6.5 As an alternative to 7.6.3, a batch testing procedure may be adopted for castings with a fettled mass of 1 tonne or less. All castings in a batch are to be of similar type and dimensions, cast from the same ladle of treated metal. One separately cast test sample is to be provided for each multiple of 2,0 tonnes of fettled castings in the batch.

7.6.6 Where separately cast test samples are used, they are to be cast in moulds made from the same type of material as used for the castings and are to be taken towards the end of pouring of the castings. The samples are not to be stripped from the moulds until the temperature is below 500°C.

7.6.7 All test samples are to be suitably marked to identify them with the castings which they represent.

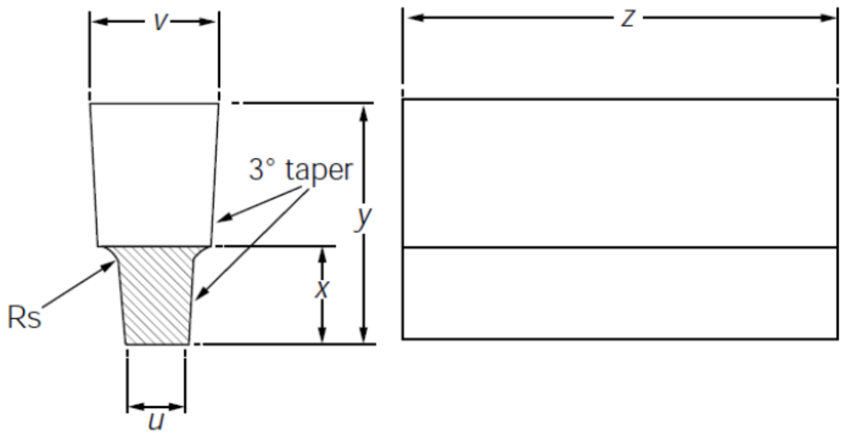
7.6.8 Where castings are supplied in the heat-treated condition, the test samples are to be heat-treated together with the castings which they represent.

7.6.9 One tensile test specimen is to be prepared from each test sample and is to be machined to the dimensions given in Part 2, Chapter 2.

7.6.10 All tensile tests are to be carried out using test procedures in accordance with Part 2, Chapter 2. Unless otherwise agreed all tests are to be carried out in the presence of the Surveyors.

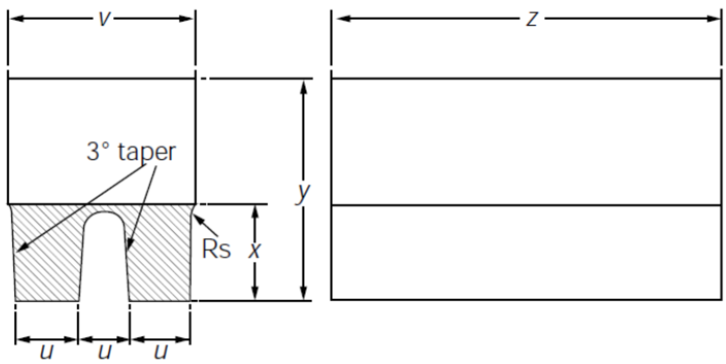
7.6.11 Impact tests may additionally be required and in such cases a set of three test specimens of agreed type is to be prepared form each sample. Where Charpy V-notch test specimens are used, the dimensions and testing procedures are to be in accordance with Part 2, Chapter 2.

Figure 4.7.1: **Type A test samples (U-type)**



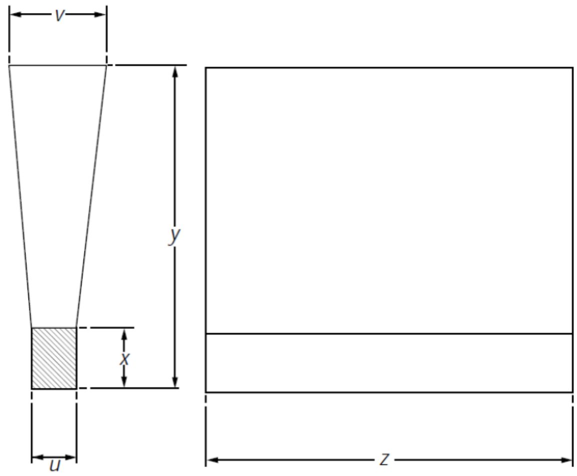
Dimensions	Standard sample	Alternative samples when specially required		
u (mm)	25	12	50	75
v (mm)	55	40	90	125
x (mm)	40	30	60	65
y (mm)	100	80	150	165
z	To suit testing machine			
Rs	Approximately 5 mm			

Figure 4.7.2: **Type B test samples (double U-type)**



Dimensions	Standard sample
u (mm)	25
v (mm)	90
x (mm)	40
y (mm)	100
z	To suit testing machine
Rs	Approximately 5 mm

Figure 4.7.3: Type C test samples (Y-type)



Dimensions	Standard sample	Alternative samples when specially required		
u (mm)	25	12	50	75
v (mm)	55	40	100	125
x (mm)	40	25	50	65
y (mm)	140	135	150	175
z	To suit testing machine			
Thickness of mould surrounding test sample	40 mm min.	40 mm min.	80 mm min.	80 mm min.

7.7 Mechanical properties

7.7.1 Table 4.7.1 gives the minimum requirements for the 0,2% proof stress and elongation corresponding to different strength levels. Typical Brinell hardness values are also given in Table 4.7.1 and are intended for information purposes only.

7.7.2 Castings may be supplied to any specified minimum tensile strength selected within the general limits detailed in Table 4.7.1 but subject to any additional requirements of the relevant construction Rules.

7.7.3 Unless otherwise agreed, only the tensile strength and elongation need be determined. The results of all tensile tests are to comply with the appropriate requirements of Table 4.7.1.

7.7.4 Re-test requirements for tensile tests are to be in accordance with Part 2, Chapter 2.

7.7.6 When impact tests are required, the results are to comply with the approved specification. It is recommended for castings with a specified minimum tensile strength not exceeding 400 N/mm² that, where Charpy V-notch test specimens are used, the average energy value should be not less than 13 J for tests at ambient temperature (18-25°C). One individual value may be less than 13 J provided that it is not less than 9 J. It is further recommended that the re-test procedure should be as detailed in 1.7 for steel castings.

7.8 Inspection

7.8.1 The requirements of SECTION 6, 6.8 apply.

7.9 Metallographic examination

7.9.1 For crankshafts, the metallographic examination will be mandatory.

7.9.2 When required, a representative sample from each ladle of treated metal is to be prepared for metallographic examination. These samples may conveniently be taken from the tensile test specimens but alternative arrangements for the provision of the samples may be adopted provided that they are taken from the ladle towards the end of the casting period.

7.9.3 Examination of the samples is to show that at least 90% of the graphite is in a dispersed spheroidal or nodular form. Details of typical matrix structures are given in Table 4.7.1 and are intended for information purposes only.

7.10 Rectification of defective castings

7.10.1 The requirements of SECTION 6, 6.9 apply.

7.11 Identification of castings

7.11.1 The particulars detailed in SECTION 6, 6.10 are to be marked to all materials which have been accepted.

7.12 Certification

7.12.1 Each test certificate or shipping statement is to give the information contained in SECTION 6, 6.11.

Table 4.7.1: Mechanical properties of spheroidal or nodular graphite iron castings (normal quality)

Specified minimum tensile strength (N/mm²)		0,2% proof stress (N/mm²) min.	Elongation on $5{,}65 \cdot \sqrt{S_o}$ (%) min.	Typical hardness values (Brinell) (see 7.7.1)	Impact energy		Typical structure of matrix (see 7.93)
					Test temp (°C)	KV (2) (J) min	
Ordinary quantities	370	230	17	120-180	-	-	Ferrite
	400	250	12	140-200	-	-	Ferrite
	500	320	7	170-240	-	-	Ferrite/Perlite
	600	370	3	190-270	-	-	Ferrite/Perlite
	700	420	2	230-300			Perlite
	800	480	2	250-350	-	-	Perlite or Tempered structure
Special quantities	350	220	22 (3)	110-170	+20	17 (14)	Ferrite
	400	250	18 (3)	140-200	+20	14 (11)	Ferrite

NOTES:

1. For intermediate values of specified minimum tensile strength, the maximum values for 0,2% proof and elongation may be obtained by interpolation.
2. The average value measured on three Charpy V-notch specimens. One result may be below the average value but not less than the minimum shown in brackets.
3. In the case of integrally cast samples, the elongation may be 2% less.

SECTION 8 Cast Steel Propellers (IACS UR W27 Corr.1 (2020))

8.1 Scope

8.1.1 These requirements are applicable to the manufacture of cast steel propellers, blades and bosses.

8.1.2 Where the use of alternative alloys is proposed, particulars of chemical composition, mechanical properties and heat treatment are to be submitted for approval.

8.1.3 These requirements may also be used for the repair of propellers damaged in service, subject to prior agreement with LHR.

8.2 Foundry approval

8.2.1 All propellers, blades and bosses are to be manufactured by foundries approved by LHR. The castings are to be manufactured and tested in accordance with the requirements of these rules.

8.2.2 It is the manufacturer's responsibility to assure that effective quality, process and production controls during manufacturing are adhered to within the manufacturing specification. The manufacturing specification shall be submitted to LHR at the time of initial approval, and shall at least include the following particulars: description of the foundry facilities, steel material specification, runner and feeder arrangements, manufacturing procedures, non-destructive testing and repair procedures.

8.2.3 The scope of the approval test is to be agreed with LHR. This should include the presentation of cast test coupons of the propeller materials in question for approval testing in order to verify that the chemical composition and the mechanical properties of these materials comply with these rules.

8.2.4 The foundry is to have an adequately equipped laboratory, manned by experienced personnel, for the testing of moulding materials chemical analyses, mechanical testing, microstructural testing of metallic materials and non-destructive testing. Where testing activities are assigned to other companies or other laboratory, additional information required by LHR is to be included.

8.3 Quality of castings

8.3.1 All castings are to have a workmanlike finish and are to be free from imperfections that could be considered to impair in-service performance.

8.3.2 Minor casting defects which may still be visible after machining such as small sand and slag inclusions, small cold shuts and scabs shall be trimmed off by the manufacturer in accordance with 8.11.

8.3.3 Casting defects which may impair the serviceability of the castings, e.g. major non-metallic inclusions, shrinkage cavities, blow holes and cracks, are not permitted. They may be removed by one of the methods described in 8.11 and repaired within the limits and restrictions for the severity zones. Full description and documentation must be available for the surveyor.

8.4 Chemical composition

8.4.1 Typical cast steel propeller alloys are grouped into four types depending on their chemical composition as given in Table 4.8.1. Cast steel whose chemical composition deviate from the typical values of Table 4.8.1 must be specially approved by LHR.

8.4.2 The manufacturer is to maintain records of the chemical analyses of the production casts, which are to be made available to the Surveyor so that he can satisfy himself that the chemical composition of each casting is within the specified limits.

8.5 Heat treatment

8.5.1 Martensitic castings are to be austenitized and tempered. Austenitic castings should be solution treated.

8.6 Mechanical properties

8.6.1 The mechanical properties are to meet the requirements in Table 4.8.2. These values refer to the test specimens machined from integrally cast test coupons attached to the hub or on the blade. The thickness of test coupon is to be in accordance with a recognized standard.

8.6.2 Where possible, the test bars attached on blades are to be located in an area between 0,5 to 0,6R, where R is the radius of the propeller.

8.6.3 The test bars are not to be detached from the casting until the final heat treatment has been carried out. Removal is to be by non-thermal procedures.

8.6.4 Separately cast test bars may be used subject to prior approval of LHR. The test bars are to be cast from the same heat as the castings represented and heat treated with the castings represented.

8.6.5 At least one set of mechanical tests is to be made on material representing each casting in accordance with Part 2, Chapter 2.

8.6.6 As an alternative to 8.6.5, where a number of small propellers of about the same size, and less than 1m in diameter, are made from one cast and heat treated in the same furnace charge, a batch testing procedure may be adopted using separately cast test samples of suitable dimensions. At least one set of mechanical tests is to be provided for each multiple of five castings in the batch.

8.7 Definition of skew, severity zones

8.7.1 In order to relate the degree of inspection to the criticality of imperfections in propeller blades and to help reduce the risk of failure by fatigue cracking after repair, propeller blades are divided into three severity zones designated A, B and C. Definition of skew, and, severity zones are given in Part 2, Chapter 7, SECTION 1.

8.8 Dimensions, dimensional and geometrical tolerances

8.8.1 The verification of dimensions, the dimensional and geometrical tolerances is the responsibility of the manufacturer. The report on the relevant examinations is to be submitted to the Surveyor, who may require checks to be made in his presence.

8.8.2 Static balancing is to be carried out on all propellers in accordance with the approved drawing. Dynamic balancing may be necessary for propellers running above 500 rpm.

8.9 Non-destructive testing

8.9.1 Qualification of personnel involved in NDT. Refer to IACS UR W35 Requirements for NDT Suppliers, sections 2.3, 2.4 and, 2.5.

8.9.2 All finished castings are to be 100% visually inspected by the manufacturer. Castings are to be free from cracks, hot tears or other imperfections which, due to their nature, degree or extent, will interfere with the use of the castings. A general visual examination is to be carried out by the Surveyor.

8.9.3 Liquid penetrant testing procedure is to be submitted to LHR and is to be in accordance with ISO 3452-1:2013 as amended or a recognized standard. The acceptance criteria are specified in 8.10.

8.9.4 For all propellers, separately cast blades and hubs, the surfaces covered by severity Zones A, B and C are to be liquid penetrant tested. Testing of Zone A is to be undertaken in the presence of the Surveyor, whilst testing of Zone B and C may be witnessed by the Surveyor upon his request.

8.9.5 If repairs have been made either by grinding or by welding, the repaired areas are additionally to be subjected to the liquid penetrant testing independent of their location and/or severity Zone. Weld repairs are, independent of their location, always to be assessed according to Zone A.

8.9.6 Magnetic particle testing may be used in lieu of liquid penetrant testing for examination of martensitic stainless steels castings. Magnetic particle testing procedure is to be submitted to LHR and is to be in accordance with ISO 9934-1:2016 as amended or a recognized standard.

8.9.7 When required by LHR or when deemed necessary by the manufacturer, further non-destructive testing (e.g. radiographic and/or ultrasonic testing) are to be carried out. The acceptance criteria or applied quality levels are then to be agreed between the manufacturer and LHR in accordance with a recognized standard.

Note: due to the attenuating effect of ultrasound within austenitic steel castings, ultrasonic testing may not be practical in some cases, depending on the shape/type/thickness, and grain-growth direction of the casting.

8.10 Acceptance criteria for liquid penetrant testing and magnetic particle testing

8.10.1 The following definitions relevant to liquid penetrant indications apply:

- Indication: the presence of detectable bleed-out of the penetrant liquid from the material discontinuities appearing at least 10 minutes after the developer has been applied.
- Relevant indication: only indications which have any dimension greater than 1,5mm shall be considered relevant for the categorization of indications.
- Linear indication: an indication with a largest dimension three or more times its smallest dimension (i.e. $l \geq 3w$).
- Nonlinear indication: an indication with a largest dimension less than three times its smallest dimension (i.e. $l < 3w$).
- Aligned indications:
  a. Non-linear indications form an alignment when the distance between indications is less than 2 mm and at least three indications are aligned. An alignment of indications is considered to be a unique indication and its length is equal to the overall length of the alignment
  b. Linear indications form an alignment when the distance between two indications is smaller than the length of the longest indication.

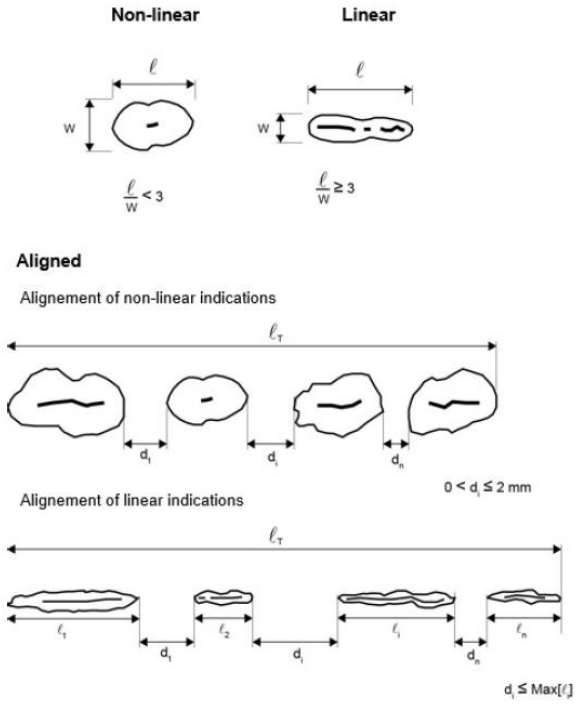
Illustration of liquid penetrant indications is given in Fig. 4.8.1.

8.10.2 For the purpose of evaluating indications, the surface is to be divided into reference areas of 100 cm², which may be square or rectangular with the major dimension not exceeding 250 mm. The area shall be taken in the most unfavorable location relative to the indication being evaluated.

8.10.3 The relevant indications detected may, with respect to their size and number, not exceed the values given in the Table 4.8.3.

8.10.4 Areas which are prepared for welding are independent of their location always to be assessed according to zone A. The same applies to the welded areas after being finished machined and/or grinded.

Figure 4.8.1: Shape of indications



8.11 Repair of defects

8.11.1 Defective castings are to be repaired in accordance with the requirements given in 8.11.2 to 8.11.7 and, where applicable, the requirements of 8.12.

8.11.2 In general the repairs are to be carried out by mechanical means, e.g. by grinding or milling. The resulting grooves are to be blended into the surrounding surface so as to avoid any sharp contours. Complete elimination of the defective material is to be verified by liquid penetrant testing, or magnetic particle testing if applicable.

8.11.3 Weld repairs are to be undertaken only when they are considered to be necessary and have prior approval of the Surveyor.

8.11.4 The excavations are to be suitably shaped to allow good access for welding. The resulting grooves are to be subsequently ground smooth and complete elimination of the defective material is to be verified by liquid penetrant testing. Welds having an area less than 5 cm² are to be avoided.

8.11.5 Grinding in severity Zone A may be carried out to an extent that maintains the blade thickness. Repair welding is generally not permitted in severity Zone A and will only be allowed after special consideration by LHR. In some cases the propeller designer may submit technical documentation to propose a modified zone A based on detailed hydrodynamic load and stress analysis for consideration by LHR.

8.11.6 Defects in severity Zone B that are not deeper than t/40 mm ("t" is the minimum local thickness according to the Rules) or 2 mm, whichever is greatest, are to be removed by grinding. Those defects that are deeper may be repaired by welding subject to prior approval from LHR.

8.11.7 Repair welding is generally permitted in severity Zone C.

8.11.8 The foundry is to maintain records of inspections, welding, and any subsequent heat treatment, traceable to each casting. Before welding is started, full details of the extent and location of the repair, the proposed welding procedure, heat treatment and subsequent inspection procedures are to be submitted to LHR for approval.

8.12 Welding repair procedure

8.12.1 Before welding is started, a detailed welding procedure specification is to be submitted to LHR, covering the weld preparation, welding parameters, preheating and post weld heat treatment and inspection procedures.

8.12.2 All weld repairs are to carried out in accordance with qualified procedures, and, by welders who are qualified to a recognized standard. Welding Procedure Qualification Tests are to be carried out in accordance with Appendix A of this Chapter and witnessed by the Surveyor.

Defects to be repaired by welding are to be ground to sound material according to 8.1 of this SECTION.

The welding grooves are to be prepared in such a manner which will allow a good fusion of the groove bottom.

The resulting ground areas are to be examined in the presence of the Surveyor by liquid penetrant testing in order to verify the complete elimination of defective material.

8.12.3 Welding is to be done under controlled conditions free from draughts and adverse weather.

8.12.4 Metal arc welding with electrodes or filler wire used in the procedure tests is to be used. The welding consumables are to be stored and handled in accordance with the manufacturer’s recommendations.

8.12.5 Slag, undercuts and other imperfections are to be removed before depositing the next run.

8.12.6 The martensitic steels are to be furnace re-tempered after weld repair. Subject to prior approval, however, local stress relieving may be considered for minor repairs.

8.12.7 On completion of heat treatment the weld repairs and adjacent material are to be ground smooth. All weld repairs are to be liquid penetrant tested.

8.13 Identification

8.13.1 The manufacturer is to adopt a system for the identification of all castings, which enable the material to be traced to its original cast. The Surveyor is to be given full facilities for so tracing the castings when required. Each finished casting propeller shall be marked by the manufacturer at least with the following particulars:

a) Heat number or other marking which will enable the full history of the casting to be traced

b) Grade of cast material or corresponding abbreviated designation

c) The LHR’s certificate number

d) Ice class symbol, where applicable

e) Skew angle for high skew propellers

f) Date of final inspection

8.13.2 The LHR’s stamp is to be put on when the casting has been accepted.

8.14 Certification

8.14.1 The manufacturer is to provide the Surveyor with an inspection certificate giving the following particulars for each casting which has been accepted:

1. Purchaser’s name and order number
2. Vessel identification, where known
3. Description of the casting with drawing number
4. Diameter, number of blades, pitch, direction of turning
5. Skew angle for high skew propellers
6. Final weight
7. Alloy type, heat number and chemical composition
8. Casting identification number
9. Details of time and temperature of heat treatment
10. Results of the mechanical tests
11. Results of non-destructive tests and details of test procedure where applicable

Table 4.8.1: Typical chemical composition for steel propeller castings

Alloy type	C Max. (%)	Mn Max. (%)	Cr (%)	Mo (1) Max. (%)	Ni (%)
Martensitic (12 Cr Ni)	0,15	2,0	11,5-17,0	0,5	Max. 2,0
Martensitic (13 Cr 4 Ni)	0,06	2,0	11,5-17,0	1,0	3,5-5,0
Martensitic (16 Cr 5 Ni)	0,06	2,0	15,0-17,5	1,5	3,5-6,0
Austenitic (19 Cr 11 Ni)	0,12	1,6	16,0-21,0	4,0	8,0-13,0
NOTE: 1. Minimum values are to be in accordance with recognized national or international standards					

Table 4.8.2: Mechanical Properties for steel propeller castings

Alloy type	Proof stress $R_{p0,2}$ min. (N/mm)	Tensile strength R_m min. (N/mm²)	Elongation A_5 min. (%)	Red. of area Zmin. (%)	Charpy V-notch (1) Energy min. (J)
12Cr1Ni	440	590	15	30	20
13Cr4Ni	550	750	15	35	30
16Cr5Ni	540	760	15	35	30
19Cr11Ni	180 (2)	440	30	40	-

NOTES:

1. Not required for general service and the lowest Ice class notations.
   For other Ice class notations, tests are to be made -10°C.
2. $R_{p1,0}$ value is 205 N/mm².

Table 4.8.3: Allowable number and size of indications depending on severity zones

Severity zone	Max. total number of indications	Indication type	Max. number for each type (0, 2)	Max. dimension of indication (mm)
A	7	Non-linear	5	4
		Linear	2	3
		Aligned	2	3
B	14	Non-linear	10	6
		Linear	4	6
		Aligned	4	6
C	20	Non-linear	14	8
		Linear	6	6
		Aligned	6	6

NOTES:

1. Single non-linear indications less than 2mm in Zone A and less than 3mm in other zones may be disregarded.

2. The total number of non-linear indications may be increased to the maximum total number, or part thereof, represented by the absence of linear or aligned indications.

SECTION 9 Guidelines for non-destructive testing of marine steel castings

9.1 General

9.1.1 This document is intended to give general guidance on the extent, methods and recommended quality levels applicable to the non-destructive testing (NDT), of marine steel castings, except in those cases where alternative criteria have been otherwise approved or specified.

9.1.2 Although no detailed guidelines are given for machinery components, the requirements in these guidelines may apply correspondingly considering their materials, kinds, shapes and stress conditions being subjected.

9.1.3 Castings intending to be examined by NDT methods are identified in 9.9 to this SECTION. The list of castings is not definitive. Criteria for the inspection of other castings not listed in 9.9 will be subject to agreement.

9.1.4 Part 2 Chapter 4 SECTIONS 1 and 2 or this SECTION do not include every cast component type that may be subject to LHR. In such cases where the particular component or type is not included, appropriate national/international standards, or other LHR requirements may be applied, to determine the appropriate testing regime and defect acceptance criteria.

9.1.5 These guidelines complement and reference the requirements of the following SECTIONS- Part 2 Chapter 4 SECTIONS 1 and 2, Part 2 Chapter 8 SECTION 1 and Part 3 Chapter 17 SECTIONS 1-4, and contain general guidance for the non-destructive testing methods, the extent of testing and the minimum recommended quality levels that should be complied with unless otherwise approved or specified.

9.1.6 Castings should be examined in the final delivery condition.

9.1.7 Where intermediate inspections have been performed the manufacturer should provide reports of the results upon the request of the Surveyor.

9.1.8 Where a casting is supplied in semi-finished condition, the manufacturer should take into account the quality level of final finished machined components.

9.1.9 Where advanced ultrasonic testing methods are applied, e.g. PAUT or TOFD, reference is made to IACS UR W34, for general approach in adopting and application of these advanced methods. Acceptance levels regarding accept/reject criteria are specified in the applicable paragraph in this SECTION.

9.2 Qualification of Personnel involved in NDT

9.2.1 Qualifications

9.2.1.1 Personnel engaged in visual examination are to have sufficient knowledge and experience, however, may be exempted from formal qualifications specified in this SECTION.

9.2.1.2 Personnel carrying out NDT should be certified to a recognized national or international certification scheme, e.g. ISO 9712:2012 as emended, or an employer based scheme such as SNT-TC-1A: 2016 as amended, or ANSI/ASNT CP-189:2016 as amended. Where employer based schemes are applied, personnel qualification to these schemes may be accepted if the written practice is reviewed and found acceptable by LHR. The written practice should align with the main requirements with those of ISO 9712 as amended (apart from the impartiality requirements of a certification body).

9.2.1.3 Personnel responsible for the NDT activity including approval of procedures should be qualified and certified to Level III.

9.2.1.4 The NDT personnel's certificates and competence should comprise all industrial sectors and techniques being applied by the manufacturer or its subcontractors. Certificates should be made available to LHR for verification, when requested.

9.2.1.5 The operator carrying out the NDT and interpreting indications, should, as a minimum, be qualified and certified to Level II in the NDT method(s) concerned. However, operators only undertaking the gathering of data using any NDT method and not performing data interpretation or data analysis may be qualified and certified as appropriate, at level I.

The operator should have adequate knowledge of materials, weld, structures or components, NDT equipment and limitations that are sufficient to apply the relevant NDT method for each application appropriately.

9.3 Casting Condition

9.3.1 Heat Treatment

Non-destructive testing applied for acceptance purposes to support final casting certification should be made after the final heat treatment of the casting. Where intermediate inspections have been performed the manufacturer should provide reports of the results upon request of the Surveyor.

9.3.2 Surface Condition

9.3.2.1 Castings should be examined in the final delivery condition free from any material such as scale, dirt, grease or paint that might affect the effectiveness of the inspection. A thin coating of contrast paint is permissible when using magnetic particle techniques. For surface inspection NDT methods, the surface quality should be a minimum value of $R_a \leq 6,3$ µm.

9.3.2.2 Ultrasonic testing should be carried out after the castings have been ground, machined or shot blasted to a suitable condition, with a minimum value surface quality of $R_a \leq 12,5$ µm. The surfaces of castings to be examined should be such that adequate coupling can be established between the probe and the casting and that excessive wear of the probe is avoided.

9.4 Extent of Inspection

9.4.1 Zones to be examined

9.4.1.1 Zones to be examined in nominated castings are identified in 9.9. Testing should be made in accordance with an inspection plan approved by LHR. The plan should specify the extent of the testing, the testing procedure, the quality level or, if necessary, level for different locations of the castings.

9.4.1.2 In addition to the areas identified in 9.9, surface inspections should be carried out in the following locations:

- at all accessible fillets and changes of section
- in way of fabrication weld preparation, for a band width of 30mm
- in way of chaplets
- in way of weld repairs
- at positions where surplus metal has been removed by flame cutting, scarifying or arc-air gouging

9.4.1.3 Ultrasonic testing should be carried out in the zones indicated in 9.9 and also at the following locations:

- in way of all accessible fillets and at pronounced changes of section
- in way of fabrication weld preparations for a distance of 50mm from the edge
- in way of weld repairs where the original defect was detected by ultrasonic testing
- in way of riser positions
- in way of machined areas particularly those subject to further machining such as bolt hole positions.

9.4.1.4 In the case of castings such as rudder horns, which may have a large surface area still untested after the above inspections have been applied, an additional ultrasonic inspection of the untested areas should be made along continuous perpendicular grid lines on nominal 225 mm centres, scanning from one surface only.

9.5 Examination Procedures

9.5.1 Visual Inspection

9.5.1.1 Steel castings nominated for NDT should be subjected to a 100% visual examination of all accessible surfaces by the manufacturer and made available to the Surveyor. Viewing conditions at the inspected surfaces should be in accordance with a nationally or internationally recognised standard. Unless otherwise agreed, the visual and surface inspections should be carried out in the presence of the Surveyor.

9.5.2 Surface Inspection

9.5.2.1 The testing procedures, apparatus and conditions of magnetic particle testing and penetrant testing should comply with recognised national or international standards. Magnetic particle testing is preferable to penetrant testing except in the following cases:

- austenitic stainless steels
- interpretation of open visual or magnetic particle indications
- at the instruction of the Surveyor, where a particular need for penetrant testing has been identified.

9.5.2.2 For magnetic particle testing, attention is to be paid to the contact between the casting and the clamping devices of stationary magnetisation benches in order to avoid local overheating or burning damage in its surface. Prods should not be permitted on finished machined items. Note that the use of solid copper at the prod tips must be avoided due to the risk of copper contamination into the casting. The pole of the magnets should have close contact with the component.

9.5.2.3 AC magnetisation method should normally be used, as it is more sensitive for detecting surface indications. Where DC magnetisation method is used, this should be in agreement with LHR, and the reason for use clearly stated.

9.5.2.4 When indications have been detected as a result of the surface inspection, acceptance or rejection should be decided in accordance with 9.6 of this SECTION.

9.5.3 Volumetric Inspection

9.5.3.1 Volumetric inspection in accordance with these guidelines is normally to be carried out by ultrasonic testing using the contact method with normal (0°) beam and/or angle beam technique. The testing procedures, apparatus and conditions of ultrasonic testing should comply with the recognised national or international standards.

9.5.3.2 In some cases, due to the shape, nature, complexity of casting, or defect type or orientation, there may be a need for radiographic testing. In such cases, radiographic testing may be carried out on the basis of prior agreement with LHR. Where radiographic testing is to be applied, national or international standards for both the testing method, and the quality or severity level to be applied, should be agreed with LHR.

Guidance on standards:

- ASTM E446 – 15
- ASTM E186 – 15 (2019) e1
- ASTM E280 – 15 (2019) e1
- ISO 4993:2015 as amended

These examples are suitable national or international standards as appropriate to the radiographic testing of castings, and casting thickness.

A suitable quality level for marine castings would normally be severity level 2 or 3 (of the above standards), depending on the location zone and type of casting. Other severity levels may be applied, and should be agreed with LHR.

9.5.3.3 Only those areas shown in the agreed inspection plan should be tested, however, the inspections may reveal indications that require further evaluation or an extension of testing. In such cases, this should be agreed with LHR. The plan should include those locations nominated in paragraph 9.4.1.3 together with the scanning zones identified for the relevant casting in 9.9 to this SECTION.

9.5.3.4 Ultrasonic scans should be made using a 0° probe of 1 - 4MHz (usually 2MHz) frequency, and angle probes, where required. Whenever possible scanning is to be performed from both surfaces of the casting and from surfaces perpendicular to each other.

9.5.3.5 The backwall echo obtained on parallel sections should be used to monitor variations in probe coupling and material attenuation. Any reduction in the amplitude of the back wall echo due to material properties should be corrected. Attenuation in excess of 30dB/m could be indicative of an unsatisfactory annealing heat treatment and may render the effectiveness of the testing as unsuitable. In such cases of excessive attenuation, this should be investigated, and suitable mitigation measures carried out for effective ultrasonic testing to continue, where possible.

9.5.3.6 Machined surfaces, especially those in the vicinity of riser locations and in the bores of stern boss castings, should also be subject to a near surface (approximately 25mm) scan using a twin crystal 0° probe.

Additional scans on machined surfaces are of particular importance in cases where boltholes are to be drilled or where surplus material such as 'padding' has been removed by machining thus moving the scanning surface closer to possible areas of shrinkage.

Additionally, it is good practice to examine the machined bores of castings using circumferential scans with 70° probes in order that axial radial planar flaws such as hot tears can be detected. Fillet radii should be examined using 45°, 60°, or 70° probes scanning from the surfaces/direction likely to give the best reflection, primarily to determine the presence of any cracks within the radiused areas, and as an additional scan to confirm any indications that may have been detected with 0° probe(s) within this area.

9.5.3.7 In the examinations of those zones nominated for ultrasonic examination the reference sensitivity for the 0° probe should be established against a 6mm reflector. Sensitivity can be calibrated either against 6mm diameter flat bottomed hole(s) in a reference block (or series of blocks) corresponding to the thickness of the casting provided that a transfer correction is made, using the DAC (distance-amplitude-correction) method, or by using the DGS (distance-gain-size) method.

9.5.3.8 The reference sensitivity of angle probes (where required for testing) should be established against an appropriate 6mm reflector (e.g. reference reflectors angled perpendicular to the sound beam) for the DAC method, or equivalent using the DGS method.

9.5.3.9 The DGS diagrams issued by a probe manufacturer identify the difference in dB between the amplitude of a back wall echo and that expected from a 6mm diameter disk reflector. By adding this difference to the sensitivity level initially set by adjusting a back wall echo to a reference height e.g. 80%, the amended reference level will be representative of a 6mm diameter disk reflector. Similar calculations can be used for evaluation purposes to establish the difference in dB between a back wall reflector and disk reflectors of other diameters such as 12 or 15 mm.

9.5.3.10 Having made any necessary corrections for differences in attenuation or surface condition between the reference block and the casting, any indications received from the nominated zones in the casting that exceed the 6mm reference level should be marked for evaluation against the criteria given in 9.6.3 below. Evaluation should include additional scans with angle probes in order that the full extent of the discontinuity can be plotted.

9.6 Acceptance Criteria

9.6.1 Visual Inspection

9.6.1.1 All castings should be free of cracks, crack-like indications, hot tears, cold shuts or other detrimental indications. Thickness of the remains of sprues or risers should be within the casting dimensional tolerance.

9.6.1.2 Additional magnetic particle, penetrant or ultrasonic testing may be required for a more detailed evaluation of surface irregularities at the request of the Surveyor.

9.6.2 Surface Inspection

9.6.2.1 The following definitions relevant to indications apply:

- Linear indication	=	an indication with a largest dimension three or more times its smallest dimension (i.e. $l \geq 3w$).
- Non-linear indication	=	an indication with a largest dimension less than three times its smallest dimension (i.e. $l < 3w$).
- Aligned indication	=	three or more indications in a line, separated by 2mm or less edge-to-edge, which results in a unique indication, defined as follows: a) Non-linear indications form an alignment when the distance between indications is less than 2mm and at least three indications are aligned. An alignment of indications is considered to be a unique indication and its length is equal to the overall length of the alignment. b) Linear indications form an alignment when the distance between two indications is smaller than the length of the longest indication.
- Open indication	=	an indication visible after removal of the magnetic particles or that can be detected by the use of penetrant testing.
- Non-open indication	=	an indication that is not visually detectable after removal of the magnetic particles or that cannot be detected by the use of penetrant testing.
- Relevant indication	=	an indication that is caused by a condition or type of discontinuity that requires evaluation. Only the indications which have any dimension greater than 1,5mm should be considered relevant for the categorization of indications.

9.6.2.2 For the purpose of evaluating indications, the surface should be divided into reference band length of 150 mm for level MT1/PT1 and into reference areas of 22500mm^2 for level MT2/PT2. The band length and/or area should be taken in the most unfavourable location relative to the indications being evaluated.

9.6.2.3 The following quality levels recommended for magnetic particle testing (MT) and/or penetrant testing (PT) are;

Level MT1/PT1 - fabrication weld preparation and weld repairs

Level MT2/PT2 - other locations nominated for surface inspection in 9.9

The allowable numbers and sizes of indications in the reference band length and/or area are given in Table 4.9.1. The required quality level should be shown on the manufacturer’s inspection plan. Cracks and hot tears should not be accepted.

Table 4.9.1: Allowable number and size of indications in a reference band length/area

Quality Level	Total maximum number of all indications	Type of indication	Maximum number of each type of indication	Maximum dimension, (e.g. width, length, diameter) of single indication, mm (2)
MT1/PT1	4 in 150 mm length	Non-linear	4 (1)	5
		Linear	4 (1)	3
		Aligned	4 (1)	3
MT2/PT2	20 in 22500 mm^2 area	Non-linear	10	7
		Linear	6	5
		Aligned	6	5
Notes: 1) 30 mm minimum (measured in any direction) between relevant indications 2) In weld repairs, the maximum dimension is 2mm.				

9.6.3 Volumetric Inspection

9.6.3.1 Acceptance criteria for ultrasonic testing are identified in Table 4.9.2 as UT1 and UT2. As stated in 4.1.1 the quality levels applicable to the zones to be examined should be identified on an inspection plan. The following quality levels are nominated for the castings identified in 9.9.

Level UT1 is applicable to:

- fabrication weld preparations for a distance of 50mm
- 50mm depth from the final machined surface including boltholes
- fillet radii to a depth of 50mm and within distance of 50mm from the radius end
- castings subject to cyclic bending stresses e.g. rudder horn, rudder castings and rudder stocks - the outer one third of thickness in the zones nominated for volumetric inspection by 9.9
- discontinuities within the examined zones interpreted to be cracks or hot tears.

Level UT2 is applicable to:

- other locations nominated for ultrasonic testing in 9.9 or on the inspection plan.
- positions outside locations nominated for level UT1 inspection where feeders and gates have been removed.
- castings subject to cyclic bending stresses - at the central one third of thickness in the zones of nominated for volumetric inspection by 9.9.

9.6.3.2 For near surface testing (to an approximate depth of 25 mm) twin crystal 0° (normal beam) probe should be used, plus a 0o probe (usually single crystal beyond a depth of 25 mm) for the remaining volume.

9.6.3.3 Ultrasonic acceptance criteria for other casting areas not nominated in 9.9 should be subject to special consideration based on the anticipated stress levels and the type, size and position of the discontinuity.

9.6.3.4 Table 4.9.2 describes the acceptance criteria for both methods of applied sensitivity (DGS and DAC)

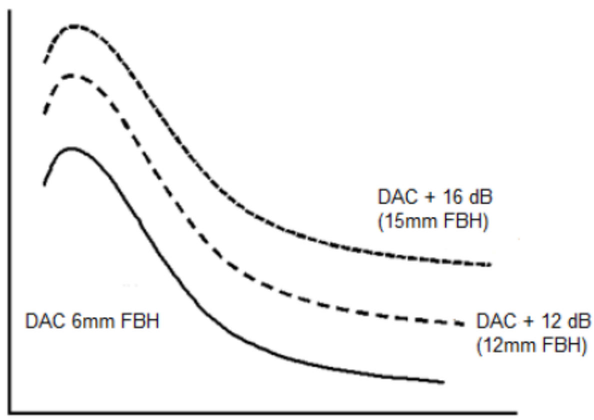
9.6.3.5 DGS and DAC methods may be used for determining sensitivity. The DAC method for normal beam probes may be based on a 6,0mm diameter reflector or flat bottomed hole (FBH). A DAC curve should be produced using reference blocks containing 6,0mm FBH reflectors over a range representative of the inspection thickness, after adjustment for transfer and attenuation losses.

9.6.3.6 For quality level UT1, any discontinuity producing a signal amplitude in excess of the 6,0 mm DAC curve is unacceptable.

9.6.3.7 For quality level UT2, the sensitivity may be based on actual size FBH (of 12 mm and 15 mm) or based on equivalent 6mm FBH, and the sensitivity adjusted to obtain equivalent amplitudes, as described in 9.6.3.8 below.

9.6.3.8 For use of FBH of 6mm for setting sensitivity, adjustment of signal amplitudes (measured in dB above 6mm DAC) can be determined for 12mm and 15mm FBH reflectors: to be DAC + 12dB and DAC + 16dB (plus any compensation for transfer and attenuation losses). This is illustrated in Figure 4.9.1. The increase in dB to the indicated levels represent the equivalent FBH sizes (for 12 mm and 15mm), and their respective corresponding ultrasonic response amplitudes.

Figure 4.9.1: DAC curve produced from 6,0mm FBH reflector and DAC curves adjusted to represent equivalent 12,0mm and 15,0mm FBH reflectors



Explanatory note for DAC and Figure 4.9.1:

The bottom curve (DAC) represents a sensitivity based on 6mm FBH, and the two additional curves (DAC + 12 and DAC + 16dB) above this represent the equivalent sensitivities converted for larger FBH's (12mm and 15mm).

When scanning using these curves, and applying Table 9.4.2 acceptance criteria, for UT2, any indication below DAC +12mm should be disregarded, and any indication above DAC +16mm should be rejected.

Any indication between these two curves should be evaluated according to its size, as per Table 9.4.2.

Table 4.9.2: Ultrasonic Acceptance Criteria for steel castings – Using DGS or DAC system

Quality Level	Allowable disc shape according to DGS (1) [mm] or diameter of FBH according to DAC (2), (3) Curve [mm]	Maximum number of indications to be registered (4)	Allowable size of all relevant indications [mm] (5), (6)
UT1	> 6	0	0
UT2	12-15	5	50
	> 15	0	0

Notes:

1) DGS: distance-gain size
2) DAC: Distance Amplitude Correction
3) The corresponding DAC level to each of the FBH reflectors is at 100% DAC
4) grouped in an area measuring 300 x 300 mm
5) measured on the scanning surface
6) the measured indication is regarded as the longest dimension, as measured in the scanning process

9.6.3.9 The maximum number of indications to be registered and the maximum length of indications permissible for quality level 2 (as stated in Table 9.4.2) apply to normal probes.

9.6.3.10 For quality level UT2, any discontinuity producing a signal amplitude in excess of the 15,0 mm DAC curve should be regarded as unacceptable.

9.6.3.11 Any signal between 12 + 15 curve should be evaluated for length of defect, and referred to table 2 for acceptance

9.7 Reporting

9.7.1 General

All reports of non-destructive examinations should include the following items:

1) Date of testing
2) Name(s), signature(s) and qualification level of inspection personnel
3) Type of casting
4) Product number and unique identification
5) Grade of steel
6) Heat treatment
7) Stage of testing
8) Locations for testing
9) Surface condition
10) Test standards used. including reference to the appropriate tables for acceptance purposes

11) Results, including documentation regarding the repair and testing history (as appropriate)
12) Statement of acceptance / non-acceptance
13) Locations of reportable indications
14) Details of weld repairs including sketches (where applicable)

9.7.2 In addition to the items listed in 9.7.1, reports of surface inspections should include at least the following items:

- for penetrant testing; the penetrant system used
- for magnetic particle testing: method of magnetising, test media and magnetic field strength and magnetic flux indicators (where appropriate)
- viewing conditions (as appropriate to the penetrant or magnetic technique and media used)
- testing details and procedure number
- details of any test restrictions

9.7.3 In addition to the items listed in 9.7.1, reports of ultrasonic inspection should include at least the following items:

- flaw detector, probe type, size, angle and frequency (and any adaptions to probes for curved surfaces), calibration and reference blocks, sensitivity method (including reflector size, transfer correction), maximum scanning rate (mm/s), and couplant.

9.8 Rectification of Defects

9.8.1 Indications that exceed the requirements of Table 4.9.1 and Table 4.9.2, should be classed as defects, and should be repaired or rejected as appropriate, according to LHR Rules.

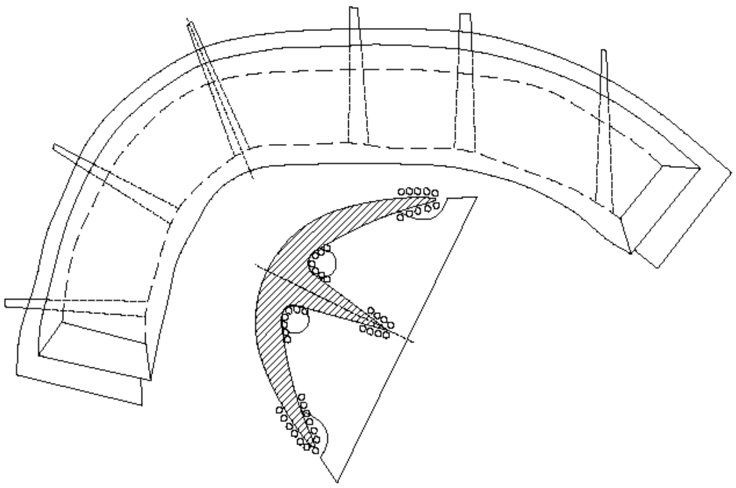
9.8.2 Generally it may be permissible to remove shallow indications by light grinding, however, all repairs should be undertaken in accordance with LHR Rules.

9.8.3 Complete removal of the defect should be proved by magnetic particle testing or penetrant testing, as appropriate.

9.8.4 Castings which are repaired should be examined by the same method as at initial inspection, as well as by any additional methods as requested by the Surveyor.

9.9 Extent and methods of non-destructive testing that should be applied to typical hull steel castings

Figure 4.9.2: Stern Frame



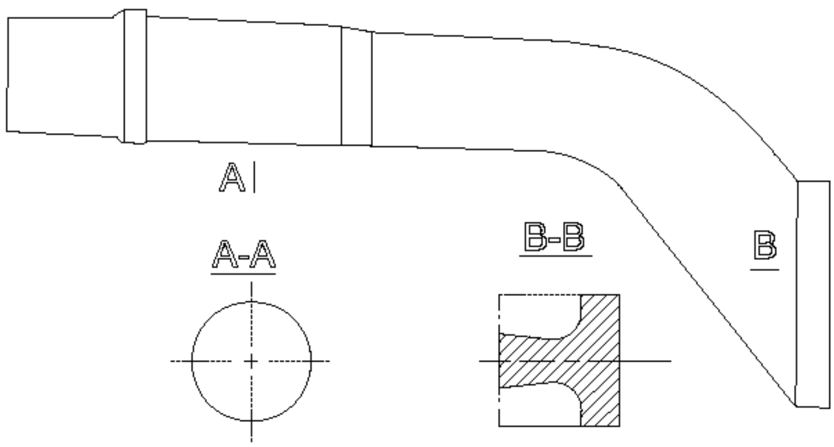
Notes: Location of non-destructive examination

1) All surfaces: Visual examination

2) Location indicated with (OOO): Magnetic particle and Ultrasonic testing

3) The detailed extents of examinations and quality levels are given in 9.4 and 9.6 of this SECTION.

Figure 4.9.3: Rudder Stock

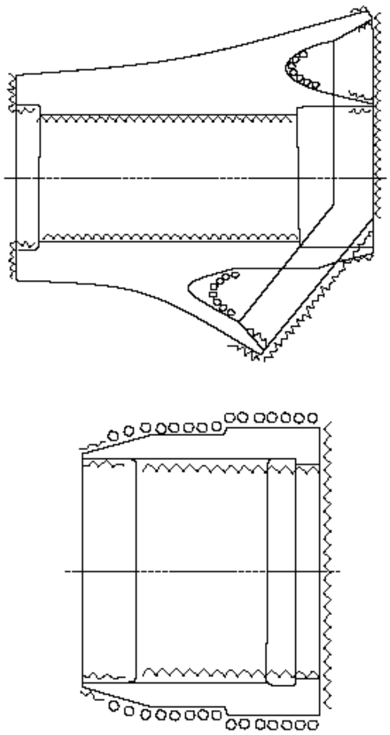


Notes: Location of non-destructive examination

1) All surfaces: Visual examination
Magnetic particle and Ultrasonic testing

2) The detailed extents of examinations and quality levels are given in 9.4 and 9.6 of this SECTION

Figure 4.9.4: Stern Boss



Notes: Location of non-destructive examination

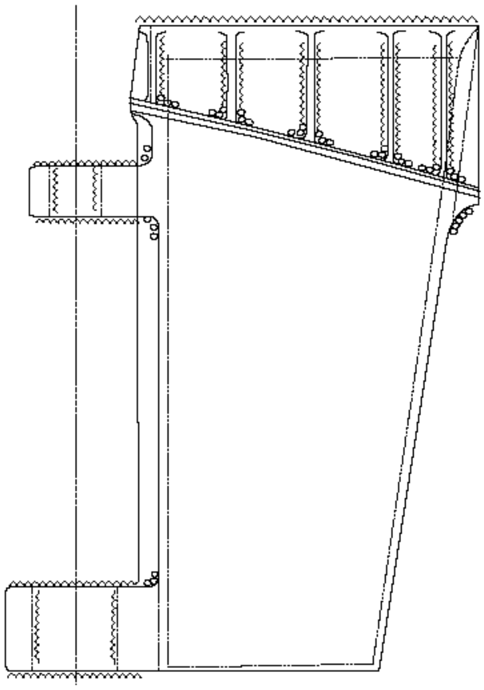
1) All surfaces: Visual examination

2) Location indicated with (OOO): Magnetic particle and Ultrasonic testing

3) Location indicated with (^^^^): Ultrasonic testing

4) The detailed extents of examinations and quality levels are given in 9.4 and 9.6 of this SECTION

Figure 4.9.5: Rudder Hangings



Notes: Location of non-destructive examination

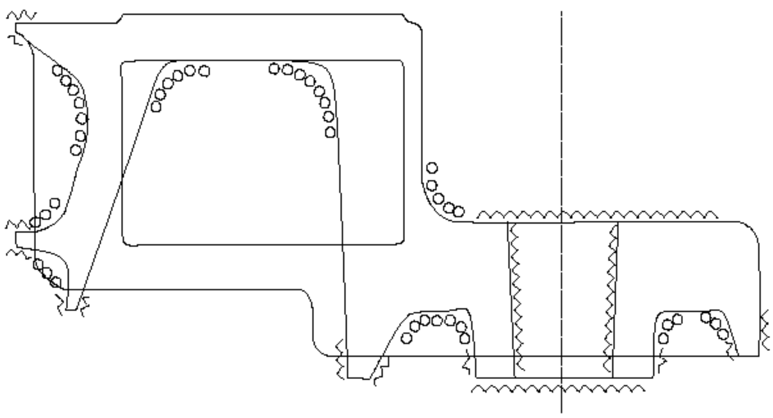
1) All surfaces: Visual examination

2) Location indicated with (OOO): Magnetic particle and Ultrasonic testing Ultrasonic testing

3) Location indicated with (^^^^): Ultrasonic testing

4) The detailed extents of examinations and quality levels are given in 9.4 and 9.6 of this SECTION.

Figure 4.9.6: Rudder (Upper Part)



Notes: Location of non-destructive examination

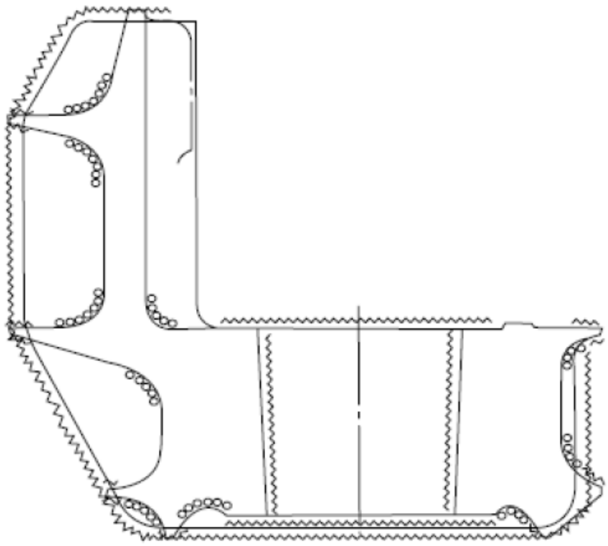
1) All surfaces: Visual examination

2) Location indicated with (OOO): Magnetic particle and Ultrasonic testing

3) Location indicated with (^^^^): Ultrasonic testing

4) The detailed extents of examinations and quality levels are given in 9.4 of this SECTION

Figure 4.9.7: Rudder (Lower Part)



Notes: Location of non-destructive examination

1) All surfaces: Visual examination

2) Location indicated with (OOO): Magnetic particle and Ultrasonic testing

3) Location indicated with (^^^^): Ultrasonic testing

4) The detailed extents of examinations and quality levels are given in 9.4 and 9.6 of this SECTION

APPENDIX A Welding Procedure Qualification Tests for repair of cast steel propeller (IACS UR W27 Appendix A, Corr.1 (2020))

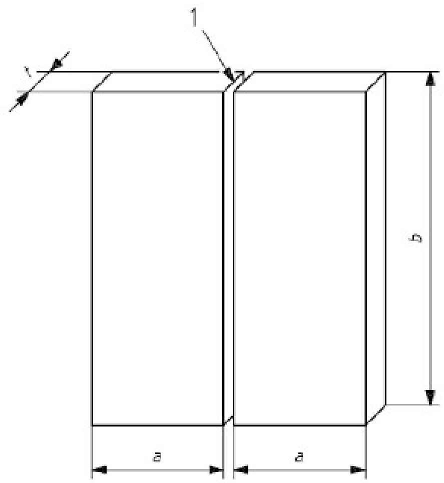
A1 Test piece and welding of sample

A1.1 The test assembly, consisting of cast samples, is to be of a size sufficient to ensure a reasonable heat distribution and according to Fig. A1 with the minimum dimensions:

1: Joint preparation and fit-up as detailed in the preliminary Welding Procedure Specification
a: minimum value 150 mm
b: minimum value 350 mm
t: material thickness

The dimensions and shape of the groove shall be representative of the actual repair work.

Figure A1: **Test piece for welding repair procedure**



A1.2 Preparation and welding of test pieces are to be carried out in accordance with the general condition of repair welding work which it represents.

A1.3 Welding of the test assemblies and testing of test specimens are to be witnessed by the Surveyor.

A2 Examination and tests

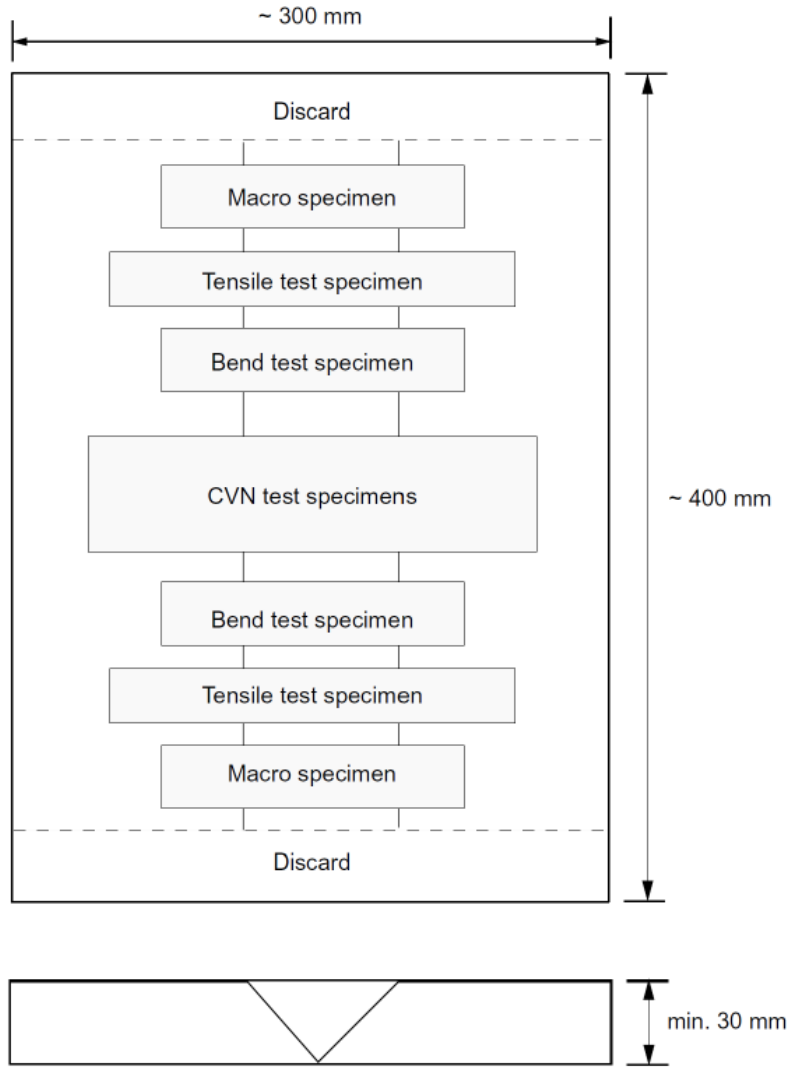
A2.1 Test assembly is are to be examined non-destructively and destructively in accordance with Table A.1 and Fig. A2.

A2.2 Non-destructive testing
Test assembly is to be examined by visual and liquid penetrant testing, or magnetic particle testing if applicable, prior to the cutting of test specimen. In case, that any post-weld heat treatment is required or specified, non-destructive testing is to be performed after heat treatment.
No cracks are permitted. Imperfections detected by liquid penetrant testing, or magnetic particle testing if applicable, are to be assessed in accordance with 8.10.

Table A1: Type of tests and extent of testing

Type of test	Extent of testing
Visual testing	100% as per article A2.2
Liquid penetrant testing (1)	100% as per article A2.2
Transverse tensile test	Two specimens as per article A2.3
Bend test (2)	Two root and two face specimens as per article A2.4
Macro examination	Three specimens as per article A2.5
Impact test	Two sets of three specimens as per article A2.6
Hardness test	As per article A2.7
(1): Magnetic particle testing may be used in lieu of liquid penetrant testing for martensitic stainless steels. (2): For t≥12mm, the face and root bend may be substituted by 4 side bend test specimens.	

Figure A2: Weld test assembly



A2.3 Tensile test

Two flat transverse tensile test specimens shall be prepared. Testing procedures shall be in accordance with Part2, Chapter 2, SECTION 3, 3.1.9(b). Alternatively tensile test specimens according to recognized standards acceptable to LHR may be used. The tensile strength shall meet the specified minimum value of the base material. The location of fracture is to be reported, i.e. weld metal, HAZ or base material.

A2.4 Bend test

Transverse bend tests for butt joints are to be in accordance with Part 2, Chapter 2, SECTION6, or, according to a recognized standard. The mandrel diameter shall be 4 x thickness except for austenitic steels, in which case the mandrel diameter shall be 3 x thickness.

The bending angle is to be 180°. After testing, the test specimens are not to reveal any open defects in any direction greater than 3 mm. Defects appearing at the corners of a test specimen during testing are to be investigated case by case.

Two root and two face bend specimens are to be tested. For thickness 12 mm and over, four side bend specimens may alternatively be tested.

A2.5 Macro-examination

Two macro-sections shall be prepared and etched on one side to clearly reveal the weld metal, the fusion line, and the heat affected zone. Cracks and lack of fusion are not permitted. Imperfections such as slag inclusions, and pores greater than 3mm are not permitted.

A2.6 Impact test

Impact test is required, where the base material is impact tested. Charpy V-notch test specimens shall be in accordance with Part 2, Chapter 2, SECTIONS 1-6. Two sets shall be taken, one set with the notch positioned in the center of the weld and one set with the notch positioned in the HAZ (i.e. the mid-point of the notch shall be at 1mm to 2mm from the fusion line), respectively.

The test temperature, and impact energy shall comply with the requirement specified for the base material.

A2.7 Hardness test

The macro-section representing the start of welding shall be used for HV 10 hardness testing. Indentations shall traverse 2 mm below the surface. At least three individual indentations are to be made in the weld metal, the HAZ (both sides) and in the base metal (both sides). The values are to be reported for information.

A2.8 Re-testing

If the test piece fails to comply with any of the requirements of this Appendix, reference is made to re-test procedures given in Part 2, Chapter 9, SECTION 2.

A3 Test record

A3.1 Welding conditions for test assemblies and test results are to be recorded in welding procedure qualification. Forms of welding procedure qualification records can be taken from the LHR's rules or from relevant standards.

A3.2 A statement of the results of assessing each test piece, including repeat tests, is to be made for each welding procedure qualification records. The relevant items listed for the WPS are to be included.

A3.3 The welding procedure qualification record is to be signed by the Surveyor witnessing the test and is to include the LHR´s identification.

A4 Range of approval

A4.1 All the conditions of validity stated below are to be met independently of each other. Changes outside of the ranges specified are to require a new welding procedure test.
A qualification of a WPS obtained by a manufacturer is valid for welding in workshops or sites under the same technical and quality control of that manufacturer.

A4.2 Range of approval for steel cast propeller is limited to steel grade tested.

A4.3 The qualification of a WPS carried out on a weld assembly of thickness t is valid for the thickness range given in Table A.2.

Table A2: Range of qualification for thickness

Thickness of the test piece, t (mm)	Range of approval
15<t≤30	3 mm to 2t
t>30	0,5t to 2t or 200 mm, whichever is the great

A4.4 Approval for a test made in any position is restricted to that position.

A4.5 The approval is only valid for the welding process used in the welding procedure test. Single run is not qualified by multi-run butt weld test used in this SECTION.

A4.6 The approval is only valid for the filler metal used in the welding procedure test.

A4.7 The upper limit of heat input approved is 15% greater than that used in welding the test piece. The lower limit of heat input approved is 15% lower than that used in welding the test piece.

A4.8 The minimum preheating temperature is not to be less than that used in the qualification test. The maximum interpass temperature is not to be higher than that used in the qualification test.

A4.9 The heat treatment used in the qualification test is to be specified in pWPS. Holding time may be adjusted as a function of thickness.

CHAPTER 5 Steel Forgings

CONTENTS

SECTION 1 General

1.1 Scope

1.1.1 This Section provides the general requirements to be applied in the manufacture and testing of steel forgings intended to be used in the construction of ships, other marine structures, machinery, boilers, pressure vessels and piping systems. This Section is also applicable to rolled slabs and billets used as a substitute for forgings, and to rolled bars used for the manufacture (by machining operations only) of shafts, bolts, studs and other components of simple shape.

1.1.2 The whole procedure of manufacture and testing is to be performed according to the requirements of Part 2, Chapters 1 and 2. The following Sections depict specific requirements for steel forgings.

1.1.3 Alternatively, forgings which comply with national or proprietary specifications may be accepted provided such specifications give reasonable equivalence to these requirements or are otherwise specially approved or required by LHR.

1.1.4 Where small and identical forgings are produced in large quantities the manufacturer may adopt alternative procedures for testing and inspection subject to the approval of LHR.

1.2 Manufacture

1.2.1 All important forgings are to be made at works where the manufacturer has demonstrated to the satisfaction of LHR that the necessary manufacturing and testing facilities are available and are supervised by qualified personnel.

1.2.2 The steel used in the manufacture of forgings is to be made by the open hearth, electric or basic oxygen process or by other processes approved by LHR.

1.2.3 Adequate top and bottom discards are to be made to ensure freedom from piping and harmful segregations in the finished forgings.

1.2.4 Given a reasonable machining allowance, workpieces shall as far as possible be forged to the final dimensions. Excessive machining to give the forging its final shape which may impair its characteristics, e.g. by penetrating the core zone, is not allowed. The plastic deformation is to be such as to ensure soundness, uniformity of structure and satisfactory mechanical properties after heat treatment. For components where the fiber deformation is mainly longitudinal, the total reduction ratio is generally to be in accordance with Table 5.1.1.

1.2.5 Disc type forgings, such as gear wheels, are to be made by upsetting, and the thickness of any part of the disc is to be not more than one half of the length of the billet from which it was formed, provided that this billet has received an initial forging reduction of not less than 1,5:1. Where the piece used has been cut directly from an ingot or where the billet has received an initial reduction of less than 1,5:1, the thickness of any part of the disc is to be not more than one third of the length of the original piece.

1.2.6 Rings and other types of hollow forgings are to be made from pieces cut from ingots or billets and which have been suitably punched, bored or trepanned prior to expanding or drawing on a suitable mandrel. Alternatively, pieces from hollow cast ingots may be used. The wall thickness of the forging is to be not more than one half of the thickness of the prepared hollow piece from which it was formed. Where this is not practicable the forging procedure is to be such as to ensure that adequate work is given to the piece prior to punching, etc. This may be either longitudinal or upset working of not less than 2:1.

1.2.7 For certain components, where grain flow is required in the most favorable direction having regard to the mode of stressing in service, the proposed method of manufacture may require special approval by LHR. In such cases, tests may be required to demonstrate that a satisfactory structure and grain flow are obtained.

Table 5.1.1

Method of manufacture	**Total reduction ratio**
Made directly from ingots or from forged blooms or billets	3:1 where L>D 1,5:1 where L≤D
Made from rolled products	4:1 where L>D 2:1 where L≤D

NOTES:

1. L and D are the length and diameter respectively of the part.

2. The reduction ratio is to be calculated with reference to the average cross-sectional area of the ingot. Where an ingot is initially upset, this reference area may be taken as the average cross-sectional area after this operation.

3. For rolled bars used as a substitute for forgings (see 2.1.1) the reduction ratio is to be not less than 6:1.

4. For forgings made by upsetting, the length after upsetting is to be not more than one-third of the length before upsetting or, in the case of an initial forging reduction of at least 1.5:1, not more than one-half of the length before upsetting

1.2.8 The shaping of forgings or rolled slabs and billets by flame cutting, scarfing or arc-air gouging is to be undertaken in accordance with recognized good practice and, unless otherwise approved, is to be carried out before the final heat treatment. Preheating is to be employed when necessitated by the composition and/or thickness of the steel. For certain components, subsequent machining of all flame cut surfaces may be required.

1.2.9 Where two or more forgings are joined by welding to form a composite component, details of the proposed procedure are to be submitted for approval. Welding procedure tests may be required.

1.3 Quality of Forgings - Freedom from defects

1.3.1 All forgings are to be free from surface or internal defects which would be prejudicial to their proper application in service.

1.4 Chemical composition

1.4.1 All forgings are to be made from killed steel and the chemical composition is to be appropriate for the type of steel, dimensions and required mechanical properties of the forgings being manufactured.

1.4.2 Details of the proposed chemical composition for alloy steel forgings are to be submitted for approval.

1.4.3 The chemical composition of each heat is to be determined by the manufacturer on a sample taken preferably during the pouring of the heat. When multiple heats are tapped into a common ladle, the ladle analysis shall apply.

1.4.4 At the option of the manufacturer, suitable grain refining elements such as aluminium, niobium or vanadium may be added. The content of such elements is to be reported in the ladle analysis.

1.4.5 Where steel forgings are intended for welded construction the proposed chemical composition is subject to approval by LHR.

1.4.6 Elements designated as residual elements in the individual specifications are not to be intentionally added to the steel. The content of such elements is to be reported.

1.5 Condition of supply

1.5.1 At an appropriate stage of manufacture, after completion of all hot working operations, forgings are to be suitably heat-treated to refine the grain structure and to obtain the required mechanical properties.

1.5.2 Heat treatment is to be carried out in properly constructed furnaces which are efficiently maintained and have adequate means for control and recording of temperature. The furnace dimensions are to be such as to allow the whole forging to be uniformly heated to the necessary temperature. In the case of very large forgings alternative methods of heat treatment will be specially considered by LHR. Sufficient thermocouples are to be connected to the furnace charge to measure and record that its temperature is adequately uniform unless the temperature uniformity of the furnace is verified at regular intervals.

1.5.3 If for any reason a forging is subsequently heated for further hot working the forging is to be re-heat-treated.

1.5.4 If any straightening operation is performed after the final heat treatment consideration should be given to a subsequent stress relieving heat treatment in order to avoid the possibility of harmful residual stresses.

1.5.5 Forgings whose section is substantially altered by machining after the forging operation the only possible heat treatment is quenching and tempering after they have undergone adequate rough machining. The weight of the quenched and tempered forging shall not exceed 1,25 times that of the finished part.

1.5.6 Where it is intended to surface harden forgings, full details of the proposed procedure and specification are to be submitted for the approval of LHR. For the purposes of this approval, the manufacturer may be required to demonstrate by test that the proposed procedure gives a uniform surface layer of the required hardness and depth and that it does not impair the soundness and properties of the steel.

1.5.7 Where induction hardening or nitriding is to be carried out after machining, forgings are to be heat-treated at an appropriate stage to a condition suitable for this subsequent surface hardening.

1.5.8 Where carburizing is to be carried out, machining forgings are to be heat-treated at an appropriate stage (generally either by full annealing or by normalizing and tempering) to a condition suitable for subsequent machining and carburizing.

1.6 Mechanical properties

1.6.1 Tensile tests shall be performed to ascertain that tensile strength, yield strength or 0,2% proof stress, elongation or reduction of area are in accordance with the requirements indicated in the tables of the following Sections.

1.6.2 The impact energy values specified for the various steel grades must be met by the average result produced by 3 specimens one of which may give a result below the specified average value, although not lower than 70% of the specified average value.

1.6.3 Where special characteristics are specified for the various particular grades of steel, e.g. resistance to intercrystalline corrosion or 0,2% proof stress at high temperatures, they are to be verified by appropriate tests.

1.6.4 Hardness tests may also be required.

1.7 Mechanical tests

1.7.1 Test material, sufficient for the required tests and for possible re-test purposes, is to be provided with a cross-sectional area of not less than that part of the forging which it represents. This test material is to be integral with each forging except as provided in 1.7.5 and 1.7.7. Where batch testing is permitted according to 1.7.7, the test material may alternatively be a production part or separately forged. Separately forged test material is to have a reduction ratio similar to that used for the forgings represented.

1.7.2 For the purpose of these requirements a set of tests is to consist of one tensile test specimen and, when required, three impact test specimens. When impact tests are required, Charpy V-notch test specimens may be used at the option of the manufacturer, unless otherwise specified by LHR.

1.7.3 Test specimens are to be cut with their axes either mainly parallel (longitudinal test) or mainly tangential (tangential test) to the principal direction of each product.

1.7.4 The location of the axes of test specimens with regard to the distance below the surface of the forging is to be $^{1}/_{10}$ of the diameter or thickness below the surface. Where specimens are to be taken at a greater distance from the surface, special agreements may, where necessary, be reached with LHR regarding the required characteristics.

1.7.5 When a forging is subsequently divided into a number of components, all of which are heat-treated together in the same furnace charge, for test purposes this may be regarded as one forging and the number of tests required is to be related to the total length and mass of the original multiple forging.

1.7.6 Except for components which are to be carburized or as otherwise specially agreed, test material is not to be cut from a forging until all heat treatment has been completed. The testing procedures for components which are to be carburized is to be in accordance with the details given in 2.6.7.

1.7.7 Where a number of small forgings of about the same size are made from one cast and heat-treated in the same furnace charge, batch testing procedures may be adopted using one of the forgings for test purposes or alternatively using separately forged test samples. These test samples are to have a reduction ratio similar to that used for the forgings which they represent. They are to be properly identified and heat-treated along with the forgings. In such cases at least one set of tests is to be taken from each batch. Hardness tests may additionally be required for certain types of forgings.

Normalized forgings with mass up to 1000kg each and quenched and tempered forgings with mass up to 500kg each may be batch tested. A batch is to consist of forgings of similar shape and dimensions, made from the same heat of steel, heat-treated in the same furnace charge and with a total mass not exceeding 6 tonnes for normalized forgings and 3 tonnes for quenched and tempered forgings, respectively.

1.7.8 Tensile and impact test specimens are to be machined to the dimensions given in Part 2, Chapter 2.

1.7.9 All tensile and impact tests are to be carried out at ambient temperature (generally 18-25°C).

Unless otherwise agreed all tests are to be carried out in the presence of the Surveyors.

1.7.10 Where the result of a tensile test does not comply with the requirements, two additional tests may be taken. If satisfactory results are obtained from both of these additional tests the forging or batch of forgings is acceptable. If one or both retests fail the forging or batch of forgings is to be rejected.

1.7.11 Where the results from a set of three impact test specimens do not comply with the requirements (see 1.6.2) an additional set of three impact test specimens may be taken provided that not more than two individual values are less than the required average value and of these not more than one is less than 70% of this average value. The results obtained are to be combined with the original results to form a new average which, for acceptance of the forgings or batch of forgings, is to be not less than the required average value. Additionally, for these combined results not more than two individual values are to be less than the required average value and of these not more than one is to be less than 70% of this average value.

1.7.12 The additional tests detailed in 1.7.10 and 1.7.11 are to be taken, preferably from material adjacent to the original tests, but alternatively from another test position or sample representative of the forging or batch of forgings.

1.7.13 At the option of the manufacturer, when a forging or a batch of forgings has failed to meet the test requirements, it may be re-heat-treated and re-submitted for acceptance tests.

1.8 Inspection

1.8.1 Before acceptance, all forgings are to be presented to the Surveyors for visual examination. Where applicable, this is to include the examination of internal surfaces and bores. Unless otherwise agreed the verification of dimensions is the responsibility of the manufacturer.

1.8.2 When required by the relevant Rules, or by the approved procedure for welded composite components (see 1.2.9) appropriate non-destructive testing is also to be carried out before acceptance and the results are to be reported by the manufacturer. All such tests are to be carried out by competent operators using reliable and efficiently maintained equipment. The testing procedures used are to be agreed with the Surveyors.

1.8.3 Magnetic particle or liquid penetrant testing is to be carried out when the forgings are in the finished condition. Where current flow methods are used for magnetization, particular care is to be taken to avoid damaging finished machined surfaces by contact burns from the prods. Unless otherwise agreed, these tests are to be carried out in the presence of the Surveyor. Acceptance standards for defects found by magnetic particle or liquid penetrant testing are to be to the satisfaction of LHR and in accordance with any specific requirements of the approved plan.

1.8.4 Ultrasonic examination is to be carried out following the final heat treatment and at a stage when the forgings have been machined to a condition suitable for this type of examination. Both radial and axial scanning are to be carried out by the manufacturer although Surveyors may request to be present in order to verify that the examination is being carried out in accordance with the agreed procedure.

1.8.5 When required by the conditions of approval for surface hardened forgings (see 1.5.7) additional test samples are to be processed at the same time as the forgings which they represent. These test samples are subsequently to be sectioned in order to determine the hardness, shape and depth of the locally hardened zone and which are to comply with the requirements of the approved specification.

1.8.6 In the event of any forging proving defective during subsequent machining or testing, it is to be rejected not withstanding any previous certification.

1.8.7 Hollow forgings subjected to internal pressure by the operating fluid must be leak proofed at the specified test pressure.

1.9 Rectification of defective forgings

1.9.1 Small surface imperfections may be removed by grinding or by chipping and grinding, provided the component dimensions are acceptable. Complete elimination of these imperfections is to be proved by magnetic particle or liquid penetrant examination. The resulting grooves are to have a bottom radius of approximately three times the groove depth and are to be blended into the surrounding surface so as to avoid any sharp contours. At the discretion of the Surveyor, the resulting shallow grooves or depressions can be accepted, provided that they are blended by grinding.

1.9.2 Repairs by welding may only be considered in special circumstances and, in general, are restricted to the rectification of defects of a minor nature in areas of low working stresses. In such cases, full details of the proposed repair and subsequent inspection procedures are to be submitted for the approval of the Surveyors prior to commencing the proposed specification. A statement and/or sketch detailing the extent and location of all repairs, together with details of the post weld heat treatment and nondestructive examination is to be provided for record purposes. The repair of composite components formed by welding is to be carried out in accordance with the approved procedure (see 1.2.9).

1.10 Marking

1.10.1 The manufacturer is to adopt a system of identification which will enable all finished forgings to be traced to the original cast and the Surveyor is to be given full facilities for so tracing the forgings when required.

1.10.2 Before acceptance, all forgings which have been tested and inspected with satisfactory results are to be clearly marked by the manufacturer containing the following particulars:

1. Steel quality
2. Identification number, cast number or other marking which will enable the full history of the forging to be traced.
3. Manufacturer's name or trade mark.
4. The LHR mark “LHR”.
5. Abbreviated name of the LHR's local office.

6. Personal stamp of Surveyor responsible for inspection.
7. Date of test.

1.10.3 Where small forgings are manufactured in large numbers, modified arrangements for identification may be specially agreed with LHR.

1.11 Certification

1.11.1 The manufacturer is to provide the Surveyor with a test certificate or shipping statement giving the following particulars for each forging or batch of forgings which has been accepted:

1. Purchaser's name and order number.
2. Description of forgings and steel quality.
3. Identification number.
4. Steelmaking process, cast number and chemical analysis of ladle sample.
5. Results of mechanical tests.
6. General details of heat treatment, including temperature and holding times.
7. Results of non-destructive tests and Test pressure, where applicable.

SECTION 2 Hull and machinery forgings (IACS UR W7 Rev.4 (2022))

2.1 Scope

2.1.1 This Section provides the specific requirements to be applied in the manufacture and testing of steel forgings intended for use in hull and machinery constructions, as specified in the relevant IACS unified requirements (e.g. UR M72, UR M68, etc.) and/or requirements of LHR. Where relevant, these requirements are also applicable to material for forging stock and to rolled bars intended to be machined into components of simple shape.

2.1.2 These requirements are applicable only to steel forgings where the design and acceptance tests are related to mechanical properties at ambient temperature. For other applications, additional requirements may be necessary especially when the forgings are intended for service at low or elevated temperatures. They are also applicable to rolled slabs and billets used as a substitute for forgings and to rolled bars used for the manufacture (by machining operations only) of shafts, bolts, studs and other components of simple shape.

2.1.3 Alternatively, forgings which comply with national or proprietary specifications may be accepted provided such specifications give reasonable equivalence to these requirements or are otherwise specially approved or required by LHR.

2.2 Manufacture

2.2.1 Forgings are to be made at a manufacturer approved by LHR.

2.2.2 The steel used in the manufacture of forgings is to be made by a process approved by LHR. The works at which the steel was produced is to be approved by LHR. Where the steel is produced at a separate works to the forging, the steel manufacturer is also to be approved by LHR.

2.2.3 Adequate top and bottom discards are to be made to ensure freedom from piping and harmful segregations in the finished forgings.

2.2.4 The plastic deformation is to be such as to ensure soundness, uniformity of structure and satisfactory mechanical properties after heat treatment. The reduction ratio is to be calculated with reference to the average cross-sectional area of the cast material. Where the cast material is initially upset, this reference area may be taken as the average cross-sectional area after this operation. Unless otherwise approved the total reduction ratio is to be at least:

- for forgings made from ingots or from forged blooms or billets, 3:1 where L>D and 1,5:1 where L≤D
- for forgings made from rolled products, 4:1 where L>D and 2:1 where L≤D
- for forgings made by upsetting, the length after upsetting is to be not more than one third of the length before upsetting or, in the case of an initial forging reduction of at least 1,5:1, not more than one-half of the length before upsetting
- for rolled bars, 6:1

L and D are the length and diameter respectively of the part of the forging under consideration.

2.2.5 For crankshafts, where grain flow is required in the most favourable direction having regard to the mode of stressing in service, the proposed method of manufacture may require special approval by LHR. In such cases, tests may be required to demonstrate that a satisfactory structure and grain flow are obtained.

2.2.6 The shaping of forgings or rolled slabs and billets by flame cutting, scarfing or arc-air gouging is to be undertaken in accordance with recognized good practice and, unless otherwise approved, is to be carried out before the final heat treatment. Preheating is to be employed when necessitated by the composition and/or thickness of the steel. For certain components, subsequent machining of all flame cut surfaces may be required.

2.2.7 When two or more forgings are joined by welding to form a composite component, the proposed welding procedure specification is to be submitted for approval. Welding procedure qualification tests are to be required.

2.2.8 Chapter 9, SECTION 2 of this Part, is applicable to the requirements for welding procedure qualification tests of steel forgings intended to be used for the components of hull construction and marine structures. Requirements for other WPS and qualification thereof, for welder certification and for type approval of welding consumables are at the discretion of LHR.

2.2.9 Welders intended to be engaged in fusion welding of steel forgings for hull structures are to be qualified in accordance with IACS UR W32: Qualification scheme for welders of hull structural steels Rev.1 2020.

2.3 Quality of forgings

2.3.1 All forgings are to be free from surface or internal defects which would be prejudicial to their proper application in service.

2.4 Chemical Composition

2.4.1 All forgings are to be made from killed steel and the chemical composition is to be appropriate for the type of steel, dimensions and required mechanical properties of the forgings being manufactured.

2.4.2 The chemical composition of each heat is to be determined by the manufacturer on a sample taken preferably during the pouring of the heat. When multiple heats are tapped into a common ladle, the ladle analysis shall apply.

2.4.3 The chemical composition is to comply with the overall limits given in Tables 5.2.1 and 5.2.2 or where applicable the requirements of the approved specification.

2.4.4 At the option of the manufacturer, suitable grain refining elements such as aluminium, niobium or vanadium may be added. The content of such elements is to be reported.

2.4.3 Elements designated as residual elements in the individual specifications are not to be intentionally added to the steel. The content of such elements is to be reported.

Table 5.2.1: Chemical composition limits (1) for hull steel forgings (2)

Steel type	C	Si	Mn	P	S	Cr (4)	Mo (4)	Ni (4)	Cu (4)	Total residuals
C, C-Mn	0,23 (2), (3)	0,45	0,30-1,50	0,035	0,035	0,30	0,15	0,40	0,30	0,85
Alloy	(5)	0,45	(5)	0,035	0,035	(5)	(5)	(5)	0,30	-

NOTES:

1. Composition in percentage mass by mass maximum unless shown as a range.
2. The carbon content may be increased above this level provided that the carbon equivalent (Ceq) is not more than 0,41%, calculated using the following formula:

$$C_{eq} = C + \frac{Mn}{6} + \frac{Cr+Mo+V}{5} + \frac{Ni+Cu}{15} \quad (\%)$$

3. The carbon content of C and C-Mn steel forgings not intended for welded construction may be 0,65 maximum.
4. Elements are considered as residual elements.
5. Specification is to be submitted for approval.
6. Rudder stocks and pintles should be of weldable quality.

Table 5.2.2: Chemical composition limits (1) for machinery steel forgings

Steel type	C	Si	Mn	P	S	Cr (4)	Mo (4)	Ni (4)	Cu (4)	Total residuals
C, C-Mn	0,23 (2), (3)	0,45	0,30-1,50	0,035	0,035	0,30	0,15	0,40	0,30	0,85
Alloy (5)	0,45	0,45	0,30-1,00	0,035	0,035	min 0,40 (6)	min 0,15 (6)	min 0,40 (6)	0,30	-

NOTES:

1. Composition in percentage mass by mass maximum unless shown as a range or as a minimum.
2. The carbon content may be increased above this level provided that the carbon equivalent (C_{eq}) is not more than 0,41%.
3. The carbon content of C and C-Mn steel forgings not intended for welded construction may be 0,65 maximum.
4. Elements are considered as residual elements unless shown as a minimum.
5. Where alloy steel forgings are intended for welded constructions, the proposed chemical proposition is subject to approval by LHR.
6. One or more elements is to comply with the minimum content.

2.5 Heat treatment (including surface hardening and straightening)

2.5.1 At an appropriate stage of manufacture, after completion of all hot working operations, forgings are to be suitably heat-treated to refine the grain structure and to obtain the required mechanical properties.

2.5.2 Except as provided in 5.6 and 5.7 forgings are to be supplied in one of the following conditions:

1. Carbon and carbon-manganese steels:
   - Fully annealed.
   - Normalized.
   - Normalized and tempered.
   - Quenched and tempered.
2. Alloy steels:
   - Normalized
   - Normalized and tempered
   - Quenched and tempered.

For all types of steel the tempering temperature is to be not less than 550°C. The delivery condition shall meet the design and application requirements, it is the manufacturers responsibility to select the appropriate heat treatment method to obtain the required mechanical properties. Where forgings for gearing are not intended for surface hardening, lower tempering temperature may be allowed.

2.5.3 Heat treatment is to be carried out in properly constructed furnaces which are efficiently maintained and have adequate means for control and recording of temperature. The furnace dimensions are to be such as to allow the whole furnace charge to be uniformly heated to the necessary temperature.

In the case of very large forgings alternative methods of heat treatment will be specially considered by LHR.

Sufficient thermocouples are to be connected to the furnace charge to measure and record that its temperature is adequately uniform unless the temperature uniformity of the furnace is verified at regular intervals.

2.5.4 If for any reasons a forging is subsequently heated for further hot working the forging is to be reheat treated.

2.5.5 Where it is intended to surface harden forgings, full details of the proposed procedure and specification are to be submitted for the approval of LHR. For the purposes of this approval, the manufacture may be required to demonstrate by test that the proposed procedure gives a uniform surface layer of the required hardness and depth and that it does not impair the soundness and properties of the steel.

2.5.6 Where induction hardening or nitriding is to be carried out, forgings are to be heat treated at an appropriate stage to a condition suitable for this subsequent surface hardening.

2.5.7 Where carburizing is to be carried out, forgings are to be heat treated at an appropriate stage (generally either by full annealing or by normalizing and tempering) to a condition suitable for subsequent machining and carburizing.

2.5.8 If a forging is locally reheated or any straightening operation is performed after the final heat treatment consideration is to be given to a subsequent stress relieving heat treatment. The manufacturer shall have strict control of this temperature in order to avoid any detrimental effects to the final heat treatment and resultant microstructure and mechanical properties of the forging.

2.5.9 The forge is to maintain records of heat treatment identifying the furnace used, furnace charge, date, temperature and time at temperature. The records are to be presented to the surveyor on request.

2.6 Mechanical tests

2.6.1 Test material, sufficient for the required tests and for possible retest purposes, is to be provided with a cross-sectional area of not less than that part of the forging which it represents. This test material is to be integral with each forging except as provided in 6.8 and 6.11. Where batch testing is permitted according to 6.11, the test material may alternatively be a production part or separately forged. Separately forged test material is to have a reduction ratio similar to that used for the forgings represented.

2.6.2 For the purpose of these requirements a set of tests is to consist of one tensile test specimen and, when required, three Charpy V-notch impact test specimens. Test specimens are normally to be cut with their axes either mainly parallel (longitudinal test) or mainly tangential (tangential test) to the principal axial direction of each product.

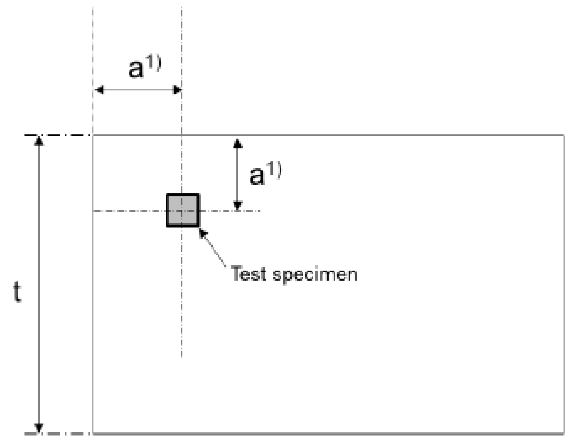
2.6.3 The test specimens shall be positioned as follows:

a. For forgings having a thickness, t, or diameter D up to maximum 50mm, the longitudinal axis of the test specimen is to be located at a distance of t/2 or D/2 below the heat treated surfaces.

b. For forgings having a thickness, t, or diameter D greater than 50mm, the longitudinal axis of the test specimen is to be located at a distance of t/4 or D/4 (mid-radius) or 80mm, whichever is less, below any heat treated surface. Test specimen is to be located with its longitudinal axis at a distance from any heat treated surface as shown in Fig. 5.2.1.

c. For ring and disc forgings (noting that the test specimen locations for these shaped forgings may be different to elongated or free form forgings), tangential sample shall be taken at t/2 for thickness ≤ 25mm and 12.5mm below the surface for thickness >25mm, in both the vertical and horizontal direction. Where achievable, for thickness >25mm, no part of the test material shall be closer than 12.5 mm to any heat treated surface, as shown in Fig. 5.2.1.

Figure 5.2.1: Position of the test specimen



Note 1): "a" is the distance from the test specimen to heat treated surface based on the above b) or c).

2.6.4 Where the manufacturer can demonstrate that a proposed testing location or orientation is more representative of the required mechanical properties of a component, this may be agreed with LHR. In such cases, the heat treatment process, a proposed testing location or orientation, and technical justification shall be submitted to LHR for approval.

2.6.5 Except as provided in 6.11, the number and direction of tests is to be as follows:

1) Hull components such as rudderstocks, pintles etc. General machinery components such as shafting, connecting rods, etc.

One set of tests is to be taken from the end of each forging in a longitudinal direction except that, at the discretion of the manufacturer and if agreed by the Surveyor, the alternative directions or positions as shown in Figure 5.2.2, Figure 5.2.3 and Figure 5.2.4 may be used. Where a forging exceeds both 4 tonnes in mass and 3 m in length, one set of tests is to be taken from each end. These limits refer to the "as forged" mass and length, but excluding the test material.

2) Pinions

Where the finished machined diameter of the toothed portion exceeds 200 mm one set of tests is to be taken from each forging in a tangential direction adjacent to the toothed portion (test position B in Figure 5.2.5). Where the dimensions preclude the preparation of tests from this position, tests in a transverse direction are to be taken from the end of the journal (test position C in Figure 5.2.5). If, however, the journal diameter is 200 mm or less, the tests are to be taken in a longitudinal direction (test position A in Figure 5.2.5). Where the finished length of the toothed portion exceeds 1,25 m, one set of tests is to be taken from each end.

3) Small pinions

Where the finished diameter of the toothed portion is 200 mm or less, one set of tests is to be taken in a longitudinal direction (test position A in Figure 5.2.5).

4) Gear wheels

One set of tests is to be taken from each forging in a tangential direction (test position A or B in Figure 5.2.6).

5) Gear wheel rims (made by expanding)

One set of tests is to be taken from each forging (test position A or B in Figure 5.2.7). Where the finished diameter exceeds 2,5 m or the mass (as heat-treated including test material) exceeds 3 tn, two sets of tests are to be taken from diametrically opposite positions (test positions A and B in Figure 5.2.7). The mechanical properties for longitudinal test are to be applied.

6) Pinion sleeves

One set of tests is to be taken from each forging in a tangential direction (test position A or B in Figure 5.2.8). Where the finished length exceeds 1,25 m, one set of tests is to be taken from each end.

7) Crankwebs

One set of tests is to be taken from each forging in a tangential direction.

8) Solid open die forged crankshafts

One set of tests is to be taken in a longitudinal direction from the coupling end of each forging (test position A in Figure 5.2.9). Where the mass (as heat-treated but excluding test material) exceeds 3 tonnes, tests in a longitudinal direction are to be taken from each end (test positions A and B in Figure 5.2.9). Where, however, the crankthrows are formed by machining or flame cutting, the second set of tests is to be taken in a tangential direction from material removed from the crankthrow at the end opposite to the coupling (test position C in Figure 5.2.9).

9) Forged Rings (such as slewing rings)

One set of tests is to be taken from each forging in a tangential direction (test positions are shown in Fig. 5.2.10). Where the finished diameter exceeds 2,5 m or the mass (as heat treated, including test material) exceeds 3 tonnes then two sets of tests are to be taken diametrically opposite positions.

2.6.6 For closed die crankshaft forgings and crankshaft forgings where the method of manufacture has been specially approved in accordance with 2.5, the number and position of test specimens is to be agreed with LHR having regard to the method of manufacture employed.

2.6.7 When a forging is subsequently divided into a number of components, all of which are heat treated together in the same furnace charge, for test purposes this may be regarded as one forging and the number of tests required is to be related to the total length and mass of the original multiple forging.

2.6.8 Except for components which are to be carburized or for hollow forgings where the ends are to be subsequently closed, test material is not to be cut from a forging until all heat treatment has been completed.

2.6.9 When forgings are to be carburized after machining, sufficient test material is to be provided for both preliminary tests at the forge and for final tests after completion of carburizing. For this purpose, duplicate sets of test material are to be taken from positions as detailed in 6.6, except that irrespective of the dimensions or mass of the forging, tests are required from one position only and, in the case of forgings with integral journals, are to be cut in a longitudinal direction. This test material is to be machined to a diameter of D/4 or 60 mm, whichever is less, where D is the finished diameter of the toothed portion. For preliminary tests at the forge, one set of test material is to be given a blank carburizing and heat treatment cycle simulating that which subsequently will be applied to the forging. For final acceptance tests, the second set of test material is to be blank carburized and heat-treated along with the forgings which they represent. At the discretion of the forge master or gear manufacturer, test samples of larger cross section may be either carburized or blank carburized, but these are to be machined to the required diameter prior to the final quenching and stress relieving heat treatment. Alternative procedures for the testing of forgings which are to be carburized may be specially agreed with LHR.

2.6.10 Normalized forgings with mass up to 1000kg each and quenched and tempered forgings with mass up to 500kg each may be batch tested. A batch is to consist of forgings of similar shape and dimensions, made from the same heat of steel, heat treated in the same furnace charge and with a total mass not exceeding 6 tonnes for normalized forgings and 3 tonnes for quenched and tempered forgings, respectively.

2.6.11 A batch testing procedure may also be used for hot rolled bars. A batch is to consist of either:

1. material from the same rolled ingot or bloom provided that where this is cut into individual lengths, these are all heat treated in the same furnace charge, or
2. bars of the same diameter and heat, heat-treated in the same furnace charge and with a total mass not exceeding 2,5 tonnes.

2.6.12 The preparation of test specimens and the procedures used for mechanical testing are to comply with the relevant requirements of Part 2, Chapter 2. Unless otherwise agreed, all tests are to be carried out in the presence of the Surveyor.

Figure 5.2.2: Plain shaft

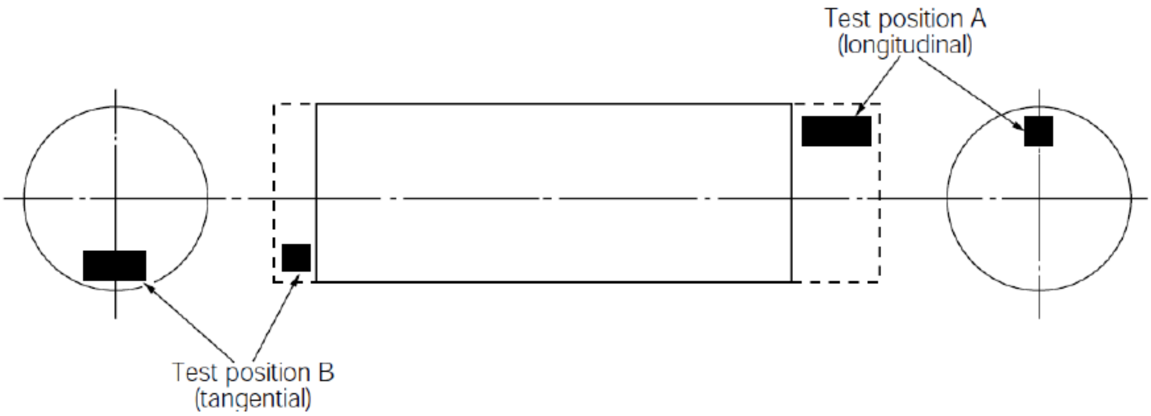


Figure 5.2.3: Flanged shaft

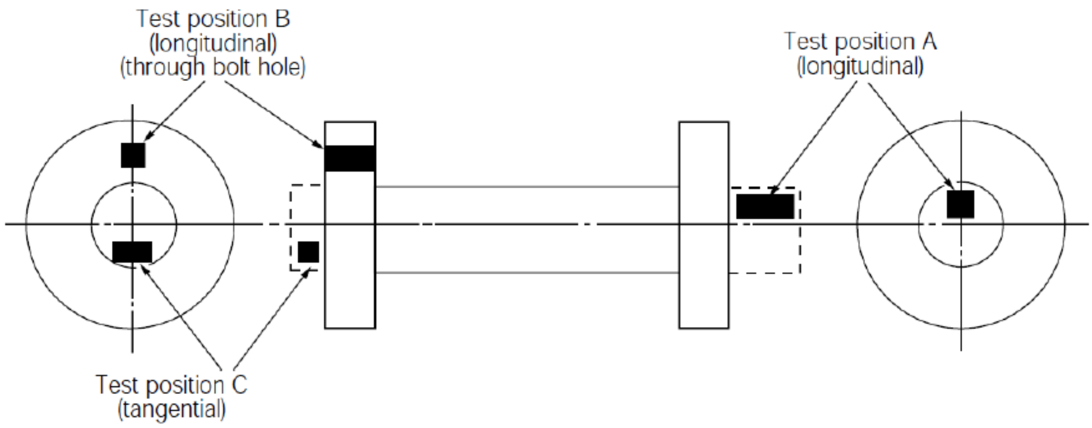


Figure 5.2.4: Flanged shaft with collar

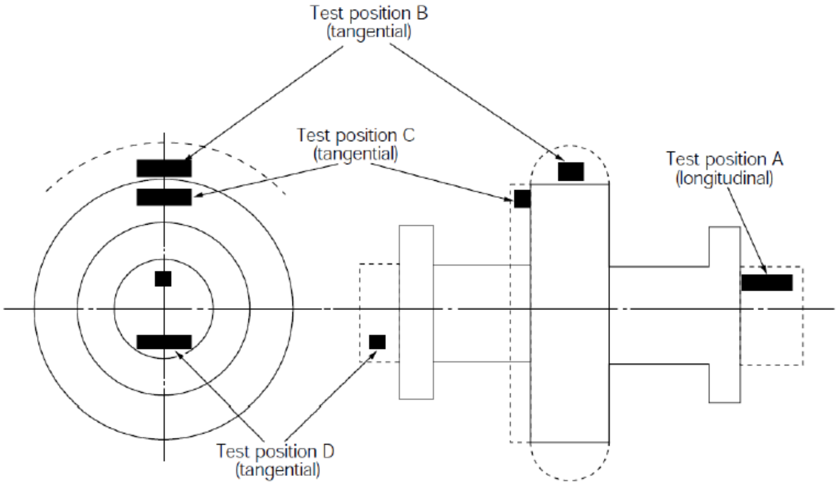


Figure 5.2.5: Pinion

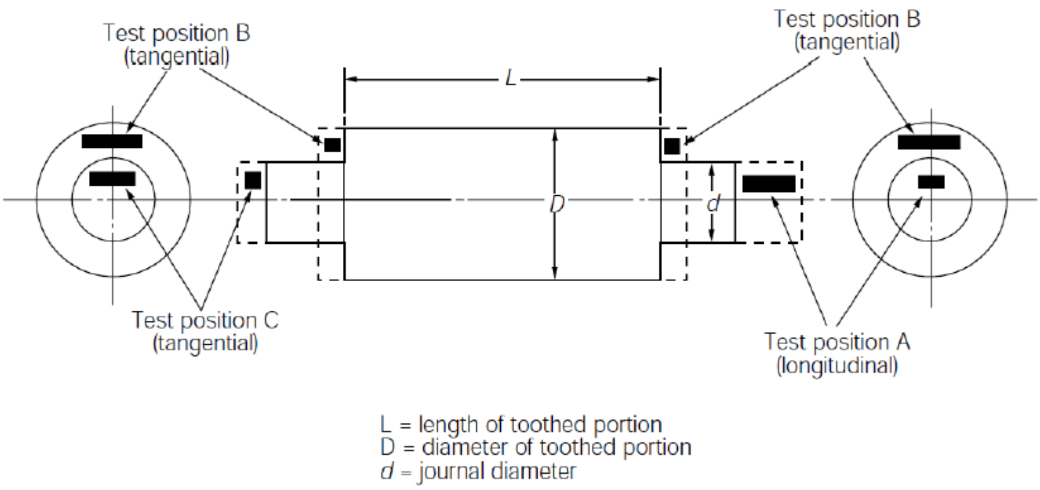


Figure 5.2.6: Gear wheel

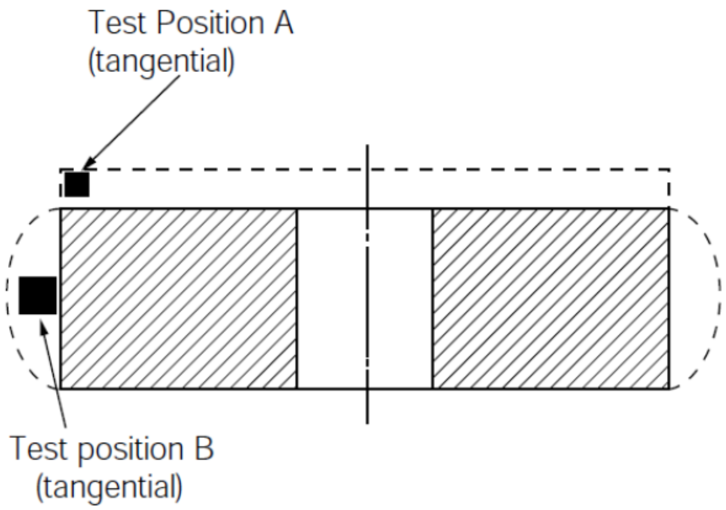


Figure 5.2.7: Gear rim (made by expanding)

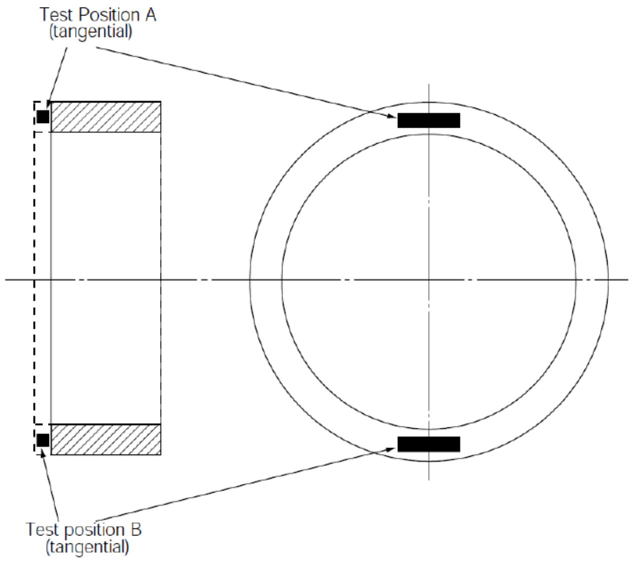


Figure 5.2.8: Pinion sleeve

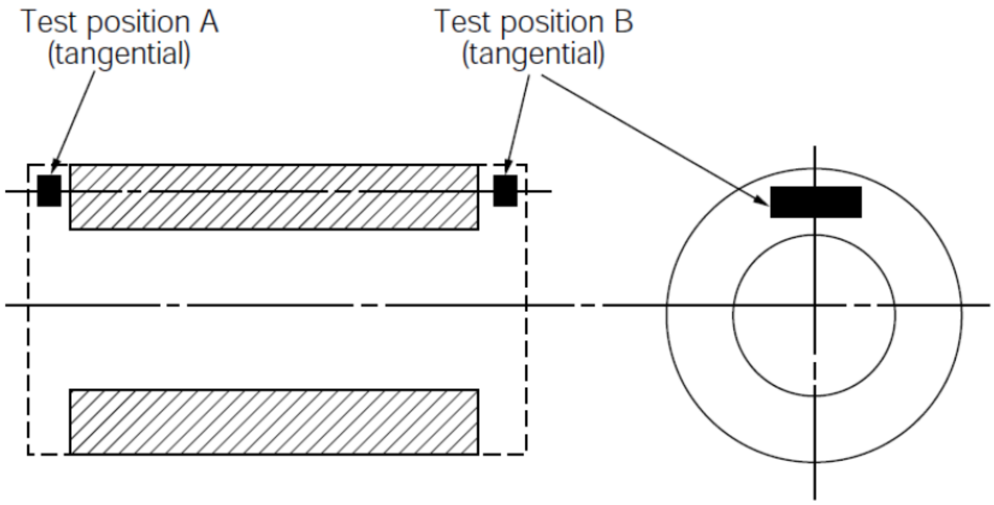


Figure 5.2.9: Solid forged crankshaft

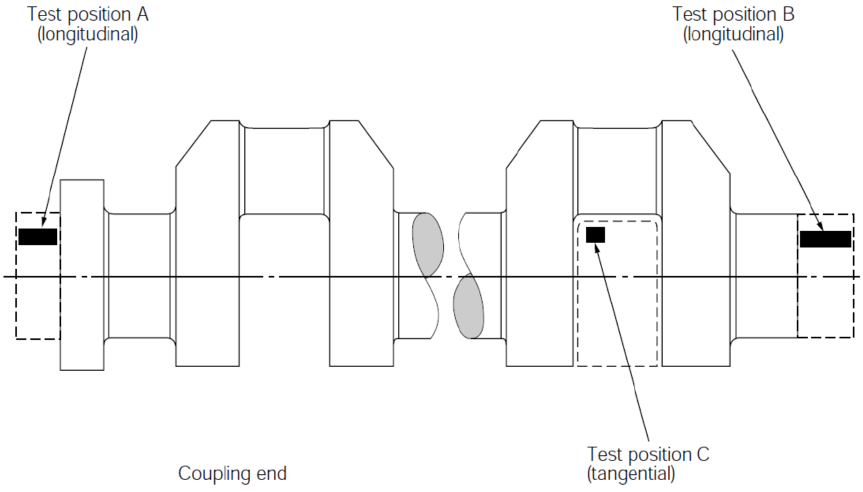
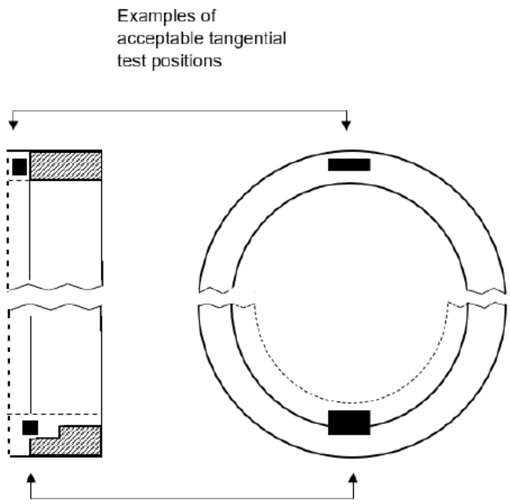


Figure 5.2.10: Forged rings



2.7 Mechanical properties

2.7.1 Table 5.2.3 and Table 5.2.4 give the minimum requirements for yield stress, elongation, reduction of area and impact test energy values corresponding to different strength levels but it is not intended that these should necessarily be regarded as specific grades. Where it is proposed to use a steel with a specified minimum tensile strength intermediate to those given, corresponding minimum values for the other properties may be obtained by interpolation.

2.7.2 Forgings may be supplied to any specified minimum tensile strength selected within the general limits detailed in Table 5.2.3 or Table 5.2.4 but subject to any additional requirements of the relevant Rules.

2.7.3 The mechanical properties are to comply with the requirements of Table 5.2.3 or Table 5.2.4 appropriate to the specified minimum tensile strength or, where applicable, the requirements of the approved specification.

2.7.4 Hardness tests are required on the following:

1. Gear forgings after completion of heat treatment and prior to machining the gear teeth. The hardness is to be determined at four positions equally spaced around the circumference of the surface where teeth will subsequently be cut. Where the finished diameter of the toothed portion exceeds 2,5 m, the above number of test positions is to be increased to eight. Where the width of a gear wheel rim forging exceeds 1,25 m the hardness is to be determined at eight positions at each end of the forging.

2. Small crankshaft and gear forgings which have been batch tested. In such cases at least one hardness test is to be carried out on each forging.

The results of hardness tests are to be reported and, for information purposes, typical Brinell hardness values are given in Table 5.2.4.

Table 5.2.3: Mechanical properties for hull forgings

Steel type	Tensile Strength(1) Rm min. N/mm²	Yield stress Re min. N/mm²	Elongation A5 min. %		Reduction of area Z min.		Charpy V-notch impact test(2)		
			Long.	Tang.	Long.	Tang.	Test temperature (°C)	Minimum average energy (J)	
								Long.	Tang.
C and C-Mn	400	200	26	19	50	35	0	27	18
	440	220	24	18	50	35			
	480	240	22	16	45	30			
	520	260	21	15	45	30			
	560	280	20	14	40	27			
	600	300	18	13	40	27			
Alloy	550	350	20	14	50	35			
	600	400	18	13	50	35			
	650	450	17	12	50	35			

Notes:

1. The following ranges for tensile strength may be additionally specified:
   - specified minimum tensile strength: < 600 N/mm² ≥ 600 N/mm²
   - tensile strength range: 120 N/mm² 150 N/mm²
2. Special consideration may be given to alternative requirements for Charpy V-notch test, depending on design and application, and subject to agreement by LHR.

Table 5.2.4: Mechanical properties for machinery steel forgings

Steel type	Tensile Strength(1) Rm min. N/mm^2	Yield stress Re min. N/mm^2	Elongation A5 min. %		Reduction of area Z min.		Hardness(3) (Brinell)	Charpy V-notch impact test(2),(4)		
			Long.	Tang.	Long.	Tang.		Test temperature (°C)	Minimum average energy (J) Long.	Tang.
C and C-Mn	400	200	26	19	50	35	110-150	AT(5)	27	18
	440	220	24	18	50	35	125-160			
	480	240	22	16	45	30	135-175			
	520	260	21	15	45	30	150-185			
	560	280	20	14	40	27	160-200			
	600	300	18	13	40	27	175-215			
	640	320	17	12	40	27	185-230			
	680	340	16	12	35	24	200-240			
	720	360	15	11	35	24	210-250			
	760	380	14	10	35	24	225-265			
Alloy	600	360	18	14	50	35	175-215			
	700	420	16	12	45	30	205-245			
	800	480	14	10	40	27	235-275			
	900	630	13	9	40	27	260-320			
	1000	700	12	8	35	24	290-365			
	1100	770	11	7	35	24	320-385			

Notes:

1. The following ranges for tensile strength may be additionally specified:
   - specified minimum tensile strength: < 900 N/mm^2 ≥ 900 N/mm^2
   - tensile strength range: 150 N/mm^2 200 N/mm^2
2. For materials used for machinery exposed to sea water temperature, such as propeller shafts and shaft bolts, intended for ships with ice class notation IA Super, IA, IB and IC, Charpy V-notch impact testing is to be carried out for all steel types at –10°C and the average energy value is to be minimum 20J (longitudinal test). One individual value may be less than the required average value provided that it is not less than 70% of this average value.
3. The hardness values are typical and are given for information purposes only.
4. Special consideration may be given to alternative requirements for Charpy V-notch test, depending on design and application, and subject to agreement by LHR.
5. AT refers to Ambient Temperature (i.e. 23°C±5°C), which is specified in ISO 148-1:2016 as amended.

2.7.5 Hardness tests are also required on forgings which have been induction hardened, nitrided or carburized. For gear forgings these tests are to be carried out on the teeth after, where applicable, they have been ground to the finished profile. The results of such tests are to comply with the approved specification (see 1.5.6).

2.7.6 Re-test procedures for tensile test are to be in accordance with 1.7.

2.7.7 Re-test requirements for Charpy impact tests are to be in accordance with Part 2, Chapter 2, SECTIONS 1-6.

2.7.8 The additional tests detailed in 7.6 and 7.7 are to be taken, preferably from material adjacent to the original tests, but alternatively from another test position or sample representative of the forging or batch of forgings.

2.7.9 At the option of the manufacturer, when a forging or a batch of forgings has failed to meet the test requirements, it may be reheat treated and re-submitted for acceptance tests.

2.8 Inspection

2.8.1 All forgings should be subjected to a 100% visual examination of all accessible surfaces by the manufacturer and made available to the Surveyor. Where applicable, this visual examination is to include the examination of internal surfaces and bores. Unless otherwise agreed, the verification of dimensions is the responsibility of the manufacturer.

2.8.2 When required by the relevant Rules or by the approved procedure for welded composite components (see 2.2.7 of this Chapter) appropriate nondestructive testing is also to be carried out before acceptance and the results are to be reported by the manufacturer.

2.8.3 Where required by the appropriate Rules or Recommendation 68, ultrasonic examination is to be carried out after the forgings have been machined to a condition suitable for this type of examination and after the final heat treatment. Both radial and axial scanning are to be carried out where appropriate for the shape and the dimensions of the forgings being examined.

2.8.4 The method and the extent of inspection, NDT and acceptance criteria are to be agreed with LHR. IACS Recommendation No. 68 is regarded as an example of an acceptable standard. For mass produced forgings the extent of examination is to be established at the discretion of LHR.

2.8.5 Unless otherwise agreed, examinations are to be carried out by the manufacturer, although Surveyors may request to be present in order to verify that the examination is being carried out in accordance with the agreed procedure.

2.8.6 If the forging is supplied in the "as forged" condition for machining at a separate works, the manufacturer is to ensure that a suitable ultrasonic examination is carried out to verify the internal quality of the forging.

2.8.7 Where advanced ultrasonic testing methods are applied, e.g. PAUT or TOFD, reference is made to UR W34 Advanced non-destructive testing of materials and welds –Dec. 2019, for general approach in adopting and application of these advanced methods. In such cases, acceptance levels regarding accept/reject criteria may be as per the applicable section in the IACS Recommendation No. 68.

2.8.8 When required by the conditions of approval for surface hardened forgings (2.5.5 of this Chapter refers) additional test samples are to be processed at the same time as the forgings which they represent. These test samples are subsequently to be sectioned in order to determine the hardness, shape and depth of the locally hardened zone and which are to comply with the requirements of the approved specification.

2.8.9 In the event of any forging proving defective during subsequent machining or testing, it is to be rejected notwithstanding any previous certification.

2.9 Rectification of defective forgings

2.9.1 Defects may be removed by grinding or chipping and grinding provided the component dimensions are acceptable. The resulting grooves are to have a bottom radius of approximately three times the groove depth and are to be blended into the surrounding surface so as to avoid any sharp contours. Complete elimination of the defective material is to be verified by magnetic particle testing or liquid penetrant testing.

2.9.2 Repair welding of forgings except those subjected to torsional fatigue, such as crankshaft forgings and propeller shaft forgings, may be permitted subject to prior approval of LHR. In such cases, full details of the extent and location of the repair, the proposed welding procedure, heat treatment and subsequent inspection procedures are to be submitted for the approval.

2.9.3 The forging manufacturer is to maintain records of repairs and subsequent inspections traceable to each forging repaired. The records are to be presented to the surveyor on request.

2.10 Identification of forgings

2.10.1 The manufacturer is to adopt a system of identification which will enable all finished forgings to be traced to the original cast and the Surveyor is to be given full facilities for so tracing the forgings when required.

2.10.2 Before acceptance, all forgings which have been tested and inspected with satisfactory results are to be clearly marked by the manufacturer. At the discretion of LHR any of the following particulars may be required:

- Steel quality.
- Identification number, cast number or other marking which will enable the full history of the forging to be traced.
- Manufacturer's name or trade mark.
- Test pressure where applicable.
- Date of final inspection.
- The LHR's name, initials or symbol.
- Abbreviated name of the LHR's local office.
- Personal stamp of Surveyor responsible for inspection.

2.10.3 Where small forgings are manufactured in large numbers, modified arrangements for identification may be specially agreed with LHR.

2.11 Certification

2.11.1 The manufacturer is to provide the required type of inspection certificate giving the following particulars for each forging or batch of forgings which has been accepted:

- Purchaser's name and order number.
- Description of forgings and steel quality.
- Identification number.
- Steelmaking process, cast number and chemical analysis of ladle sample.
- Results of mechanical tests.
- Results of non-destructive tests, where applicable.
- Details of heat treatment, including temperature and holding times.

SECTION 3 Forgings for turbines

3.1 Scope

3.1.1 This SECTION provides the specific requirements for steel forgings intended to be used in the manufacture of the rotors, shafts and discs of steam turbines for the main propulsion plant and for auxiliary turbines. For these parts of steam turbines, the manufacturer must submit to LHR for approval appropriate specifications containing the chemical composition of the steels and their mechanical properties, heat treatment and methods of testing.

3.1.2 The chemical composition, heat treatment and mechanical properties of rotors, shafts and discs of gas turbines and exhaust-driven turbosuperchargers shall be in accordance with the specifications issued by the gas turbine manufacturer, who must submit them to LHR for examination and approval. Unless otherwise agreed, the parts shall be tested in accordance to these Rules.

3.1.3 The use of suitable grades of steels conforming with national or international standards may be allowed with regard to 1.1.3.

3.1.4 Where it is proposed to use rotors of welded construction, the compositions of the steels, details of manufacture and proposed heat treatment are to be submitted for special consideration.

3.2 Manufacture

3.2.1 Forgings are to be manufactured in accordance with the requirements of 1.2. Steel for forgings with a large cross section, including all drum rotors (monobloc rotors), shall be vacuum treated. With regard to the forging reduction, drum rotors shall have at least 4:1 in relation to the cast or upset section of the starting ingot.

3.3 Chemical composition

3.3.1 The chemical composition is to conform with the approved specification. Steels for steam turbines shall comply with the following limit values:

Carbon: 0,35 % max

Manganese: 0,30-0,80 %

Silicon: 0,30 % max

Phosphorus: 0,020 % max

Sulphur: 0,020 % max

3.3.2 Where forgings are intended for welded construction, the carbon content is not to exceed 0,23%.

3.4 Condition of supply

3.4.1 Forgings shall normally undergo quenching and tempering. Wherever possible, the final heat treatment (heating to above the AC3 point followed by tempering) shall be applied to forgings which have already been rough-machined to remove the layer of scale and produce the final dimensions leaving only minor machining allowances.

3.4.2 For steels which are liable to temper brittleness under certain conditions, the nature of the heat treatment must be specially defined by the manufacturer having regard to the possible embrittlement and must be indicated in the specification.

3.4.3 Where the final heat treatment is applied to the unmachined forging, an additional stress relief heat treatment is required after rough machining. With the agreement of LHR, the hot running test may be accepted as fulfilling the role of the stress relief heat treatment provided that the temperatures and holding times constitute an equivalent means of stress relief.

Table 5.3.1: Minimum requirements for the mechanical properties of forgings for steam turbine construction.

Tensile strength, R_m 0,2% proof stress, $R_{p0,2}$ (N/mm²)	To recognized specification or standard		
	Orientation of specimens		
	long.	tang.	trans
Elongation A_5 (%)	17	15	12
Reduction in area Z (%)	50	45	35
Impact energy (J) (Note 1)	31	24	16

NOTE:

1. Tested on (ISO) Charpy V-notch specimens at ambient temperature

3.5 Mechanical properties

3.5.1 The tensile strength, 0,2 % proof stress, elongation, reduction of area and impact energy must conform to the values indicated in the specification or recognised standard for the grade of steel concerned. However, materials for steam turbines shall comply with the minimum requirements shown in Table 5.3.1.

3.6 Thermal stability

3.6.1 Finished turbine rotors must be substantially free from internal stresses and structural inhomogeneities (segregations, inadequate quenching and tempering) which may endanger satisfactory thermal stability in later service.

3.7 Mechanical tests

3.7.1 The mechanical properties shall be verified by tensile tests as required by Part 2, Chapter 2, SECTION 3. Test specimens shall be taken as detailed in the following.

3.7.2 In the case of drum rotors and rotors made in one piece, a longitudinal test specimen shall be taken from the extension of the bearing journal and a second tangential or transverse specimen from the end face of the drum or an end disc (see Figure 5.3.1). Where the diameter D is lower than 500 mm the specimen is considered to be transverse, and is regarded as tangential where D is bigger than 500 mm. The specimens shall be located on the side of the forging corresponding to the top of the original ingot.

Where the weight of the item exceeds 3 tn and where the length of the drum or the distance between the end discs is greater than 1 m, an additional longitudinal and tangential test specimen shall be taken from the opposite side. In addition, where the dimensions of the rotor make this possible, a radial test specimen shall be taken from one end face (top of the ingot), or from both end faces if the weight of the item exceeds 3000 kg or if the length of the drum or the distance between the end faces is greater than 1 m.

3.7.3 In the case of turbine discs, a tangential or transverse test specimen shall be taken from the area of the hub (see Figure 5.3.2).

3.7.4 In the case of turbine shafts, a longitudinal test specimen shall be taken from the end corresponding to the top of the ingot. If the weight exceeds 3 tn, a second specimen shall be taken from the opposite end.

3.7.5 Forgings of the same dimensions and having item weight not greater than 200 kg which are series manufactured may be grouped into batches, and at least one forging in each batch shall be subjected to testing. The number of forgings in each batch shall be agreed with LHR.

Figure 5.3.1: **Turbine rotor**

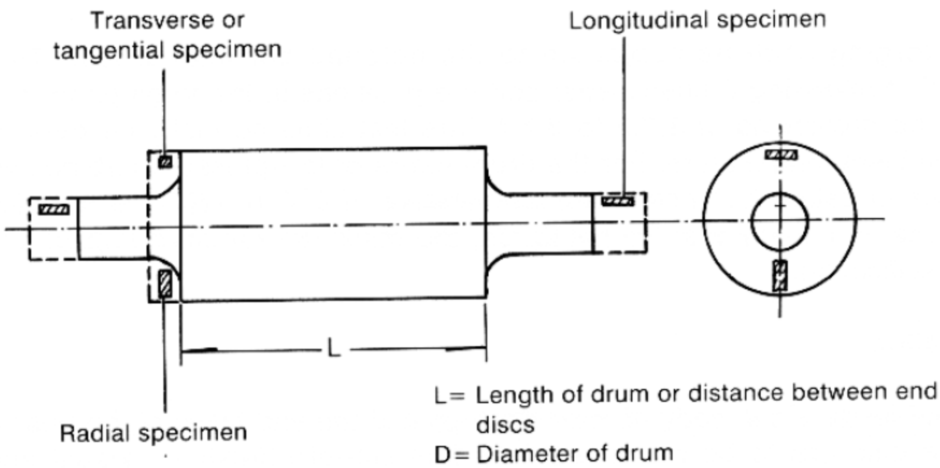
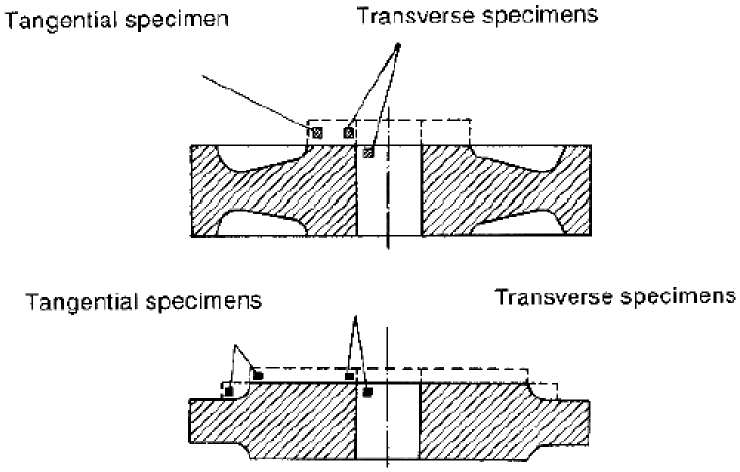


Figure 5.3.2: **Turbine discs**



3.7.6 Sufficient test material is to be left on each forging or on the particular item of the batch from which test material is being taken and is not to be removed until all heat treatment, including stress relieving, has been completed. In this connection, a thermal stability test does not form part of the heat treatment of a turbine forging. Any excess test material is not to be completely severed from a forging until all the mechanical tests have been completed with satisfactory results.

3.7.7 Normally the tensile tests are performed at ambient temperature. Nevertheless, where the material of turbine parts is subjected to temperatures above 400°C, one tensile test at elevated temperatures per heat shall be performed to determine the 0,2% proof stress. Unless otherwise agreed, the test shall be performed at the temperature level, in steps of 50°C, which corresponds more closely to the operating temperature. At the discretion of the Surveyor, the test may be dispensed with in the case of a standardized forged steel with known high-temperature mechanical characteristics which have been confirmed by practical experience.

3.7.8 Each forging shall be subjected to the notched bar impact test. The number of sets of specimens (each comprising 3 specimens) and the positions in the forgings from which they are taken are subject to the provisions of 3.7.2 to 3.7.4. The test shall normally be performed on ISO V-notch specimens at ambient temperature. For the drum rotors of low-pressure turbines with an astern section and for the discs of astern turbines a test temperature of 0°C or -20°C is specified depending on the service conditions. For these test temperatures, the minimum required impact energy values shall be stated in the specification.

3.8 Inspection

3.8.1 The end faces of the body of rotor forgings and the end faces of the boss and the bore surface of each turbine disc are to be machined to a fine smooth finish for visual and magnetic particle examination.

3.8.2 The manufacturer is to carry out an ultrasonic examination of each forging and is to provide the Surveyor with a signed statement that such inspection has not revealed any significant internal defects.

3.8.3 Rotor forgings for propulsion machinery and for auxiliary turbines are to be hollow bored for internal examination. The surface of the bore is to have a fine smooth finish and is to be examined by means of an optical instrument of suitable magnification. Where the bore size permits, magnetic particle examination is also to be carried out. These examinations are to be confirmed by the Surveyor. Alternatively, an approved method of ultrasonic examination may be accepted instead of hollow boring. Details of the proposed method of ultrasonic examination are to be submitted for special consideration.

3.8.4 Where rotors are made up of parts welded together all welds shall be tested for internal and external defects to the extent specified in the test of the welding procedure.

3.9 Thermal stability tests

3.9.1 The rotors of turbines belonging to the main propulsion plant which are forged in one piece or assembled by welding shall undergo a thermal stability test to verify their satisfactory thermal stability. This test shall also be carried out on the rotors of auxiliary turbines where the operating temperatures and rotor dimensions indicate the need for this in individual cases.

3.9.2 The test is to be conducted in accordance with the turbine manufacturer's specification. The specification must give full details of the conduct of the test and the amount of eccentricity allowed. The specification must be approved by LHR.

3.9.3 At the request of the turbine manufacturer, LHR may in special cases, e.g. in the case of steels susceptible to temper brittleness, dispense with the thermal stability test. Such dispensation requires that the material the rotor is made of be capable of full quenching and tempering over the whole cross section and that residual stress measurements be carried out by a suitable means. The results of the residual stress measurements shall be submitted to LHR for evaluation.

3.10 Marking

3.10.1 The particulars detailed in 1.10 are to be marked to all materials which have been accepted.

3.11 Certification

3.11.1 Each test certificate or shipping statement is to give the information contained in 1.11.

SECTION 4 Forgings for boilers, pressure vessels and piping systems

4.1 Scope

4.1.1 This SECTION provides the specific requirements which regulate the manufacture and testing of forgings intended for use in the construction of boilers, pressure vessels and piping systems.

4.1.2 This Section specifies the required mechanical properties of forgings working at ambient temperatures for acceptance purposes. Moreover, it gives details of appropriate mechanical properties at elevated temperatures to be used for design purposes.

4.1.3 Forged steel conforming to the requirements of this Section may be used for the cargo and processing equipment on ships carrying liquefied gases if its design temperature is not below 0°C. Forgings complying with SECTION 5 shall be used for lower temperatures.

4.1.4 Where two or more forgings are to be welded together details of the process shall be submitted to LHR for approval. The characteristics of the welds shall normally be proved by a preliminary welding procedure approval test.

4.2 Manufacture

4.2.1 The general provisions given in 1.2 are applicable.

4.3 Chemical composition

4.3.1 The chemical composition of ladle samples is to conform with the data of Table 5.4.1.

4.3.2 Where carbon or carbon-manganese steels are intended for weldments the carbon content may not be greater than 0,22%.

4.4 Condition of supply

4.4.1 All forgings shall be supplied in a properly heat-treated condition appropriate to the grade of steel.

4.4.2 Carbon and carbon-manganese steel forgings are to be normalized, normalized and tempered or quenched and tempered.

4.4.3 Alloy steel forgings are to be normalized and tempered or quenched and tempered.

Table 5.4.1: Chemical composition of forged steels for steam boilers, pressure vessels and piping

<table>
<tr><th rowspan="2">Grade</th><th colspan="8">Chemical Composition (%)</th></tr>
<tr><th>C</th><th>Si</th><th>Mn</th><th>P_{max}</th><th>S_{max}</th><th>Cr</th><th>Mo</th><th>Residual Elements (1)</th></tr>
<tr><td>360</td><td>≤ 0,20</td><td>≤ 0,35</td><td>0,3-0,6</td><td rowspan="4">0,035</td><td rowspan="4">0,030</td><td rowspan="4">-</td><td rowspan="4">-</td><td rowspan="7">Cr ≤ 0,3
Cu ≤ 0,3
Mo ≤ 0,5
Al ≤ 0,05</td></tr>
<tr><td>410</td><td>0,18-0,23</td><td>0,14-0,35</td><td>0,3-0,6</td></tr>
<tr><td>460</td><td>0,14-0,20</td><td>0,20-0,40</td><td>0,9-1,2</td></tr>
<tr><td>490</td><td>0,17-0,23</td><td>0,30-0,60</td><td>1,0-1,5</td></tr>
<tr><td>0.3Mo</td><td>0,12-0,22</td><td>0,10-0,35</td><td>0,4-0,8</td><td rowspan="3">0,035</td><td rowspan="3">0,030</td><td>-</td><td>0,25-0,35</td></tr>
<tr><td>1Cr 0.5Mo</td><td>0,10-0,18</td><td>0,10-0,35</td><td>0,4-0,7</td><td>0,8-1,15</td><td>0,4-0,8</td></tr>
<tr><td>2.25Cr 1Mo</td><td>0,08-0,15</td><td>0,15-0,50</td><td>0,4-0,7</td><td>2,0-2,5</td><td>0,9-1,1</td></tr>
</table>

NOTES:

– 1. Grades refined as fine-grained steels must have a total aluminum content of at least 0,020%. The aluminium may be replaced wholly or in part by other grain - refining elements.

4.5 Mechanical tests

4.5.1 Tensile tests at ambient temperature are to be performed in order to verify that the tensile strength, the yield stress or 0,2% proof stress, the elongation and reduction of area of the particular material is to meet the requirements of Table 5.4.2.

4.5.2 A tangential test specimen shall be taken from one end of each hollow forging. Where the length of a forged shell ring is greater than 4 m, a test specimen shall be taken from each end. Where hollow forgings are closed by dishing, a test section shall be taken prior to the dishing operation. This shall then be subjected to the required heat treatment together with the forging. With open forged shells, the test sections may only be removed after the final heat treatment.

4.5.3 In the case of other forging, the manufacturer may specify the position of test specimens in agreement with the Surveyor, unless this is stipulated in the order. Apart from the testing prescribed in 4.5.4, at least one test specimen shall be taken from each workpiece.

4.5.4 Small forgings of the same type, the unit weight of which is not more than 1000 kg, may be grouped in batches of 5000 kg. The test specimens may be taken from surplus forgings, separately forged test sections or from manufacturing waste.

Table 5.4.2: Mechanical properties of forged steels for steam boilers, pressure vessels and piping (Note 1)

Type of steel	Grade	0,2% proof stress (N/mm^2) min	Tensile strength (N/mm^2)	Elongation, A_5 (%) min	
				long	trans (Note 3)
Carbon manganese	360	210	340-470	26	24
	410	210	400-520	25	19
	460	250	460-550	23	21
	490 (N) (Note 2)	260	490-610	22	20
	490 (Q) (Note 2)	295	490-610	23	21
0.3 Mo	470	275	470-590	17	15
1 Cr 0.5 Mo	440	255	440-590	18	16
2.25 Cr 1 Mo	450	265	450-600	18	16

NOTES:

1. Applicable up to 250 mm diameter or up to 200 mm wall thickness for hollow forgings. For larger dimensions the values are subject to agreement.

2. N = normalized, Q = quenched and tempered.

3. The values to be measured on transverse specimens are also applicable to tangential (tang.) specimens.

4.6 Mechanical properties for design purposes

4.6.1 In Table 5.4.3 nominal values for the minimum lower yield or 0,2% proof stress at elevated temperatures are depicted for design purposes only. Verification is not required except for materials complying with national or proprietary specifications where the elevated temperature properties used for design purposes are higher than those given in Table 5.4.3.

4.6.2 In such cases, at least one tensile test at the proposed design or other agreed temperature is to be made on each forging or each batch of forgings. The test specimen is to be taken from material adjacent to that used for tests at ambient temperature, and the test procedure is to be in accordance with the requirements of Part 2, Chapter 2. The results of all tests are to comply with the requirements of the national or proprietary specification.

4.7 Marking

4.7.1 The particulars detailed in 1.10 are to be marked to all materials which have been accepted.

4.8 Certification

4.8.1 Each test certificate or shipping statement is to give the information contained in 1.11.

Table 5.4.3: Design values for the 0,2% proof stress at elevated temperatures

Type or grade of steel	0,2% proof stress (N/mm²) at temperatures (°C)						
	200	250	300	350	400	450	500
360	160	140	120	-	-	-	-
410	160	140	125	105	85	-	-
460	180	165	150	135	120	-	-
490 (N)	210	190	170	150	130	-	-
490 (Q)	235	215	195	175	155	-	-
0,3 Mo	190	175	150	145	140	135	130
1 Cr 0,5 Mo	210	200	185	175	165	155	150
2,25 Cr 1 Mo	215	210	200	185	175	165	155

NOTE:

1. These values relate to products up to 250 mm thick. Where higher values are to be applied, e.g. for lesser product thicknesses, relevant proof shall be submitted to LHR.

SECTION 5 Ferritic steel forgings for low temperature service

5.1 Scope

5.1.1 This Section provides the specific requirements regulating the manufacture and testing of carbon-manganese steels and nickel alloy steels to be used in the construction of cargo and processing equipment on ships carrying liquefied gases where the design temperature is below 0°C or on other applications where guaranteed impact properties at low temperatures are desired.

5.1.2 Where the forgings are used for cargo and processing equipment on gas tankers, the minimum design temperatures, depicted on Table 5.5.2 are applicable.

5.2 Chemical composition

5.2.1 The chemical composition of ladle samples shall comply with the data given in Table 5.5.1.

5.3 Condition of supply

5.3.1 All forgings are to be suitably heat-treated as prescribed in Table 5.5.2.

5.3.2 Where an additional stress relief heat treatment is required, this may not impair the mechanical characteristics of the material or its toughness at low temperatures.

5.4 Mechanical tests

5.4.1 At least one tensile and three Charpy V-notch specimens are to be taken from each forging or each batch of forgings. Where the dimensions and shape allow, the test specimens are to be severed in a longitudinal direction.

5.4.2 The required values of tensile strength, 0,2% proof stress, elongation, reduction of area specified in Table 5.5.3 shall be met by tensile tests performed at ambient temperature.

5.4.3 The impact tests are to be carried out at a temperature appropriate to the type of steel and for the proposed application. Where forgings are intended for gas tankers the test temperature is to be in accordance with the contents of Table 5.5.3.

5.4.4 The average energy values for impact tests are to comply with the requirements of Table 5.5.3.

Table 5.5.1: Chemical composition of forged steels for low temperature service

Type of steel	Grade	Chemical composition (%)								
		Cmax	Si	Mn	Pmax	Smax	Cr	Mo	Ni	Residual elements
Carbon manganese	410 - LT 460 - LT 490 - LT	0,18	0,10-0,40	0,50-1,70	0,03	0,03	-	-	-	Al ≥ 0,02 (Notes 1, 2)
3.5 Ni	470	0,16	0,15-0,40	≤ 0,8	0,03	0,02	-	-	3,25-3,75	Al ≥ 0,02 (Notes 1, 3)
9 Ni	640	0,13	0,15-0,40	≤ 0,8	0,03	0,02	-	-	8,5-10,0	

NOTES

1. Aluminium may be replaced wholly or in part by other grain-refiring elements.
2. Residual elements: Cr ≤ 0,15, Ni ≤ 0,3, Cu ≤ 0,15, Mo ≤ 0,10, total ≤ 0,5
3. Residual elements: Cr ≤ 0,15, Cu ≤ 0,15, Mo ≤ 0,10, total ≤ 0,3

Table 5.5.2: Condition of supply and minimum design temperatures of ferritic forged steel for low temperature service

Steel type	Condition of supply	Minimum design temperature (°C)
Carbon manganese	Normalizing and tempering or quenching and tempering	- 55
3.5 Ni	Normalizing and tempering or quenching and tempering	- 90
9 Ni	Double normalizing and tempering or quenching and tempering	- 165

Table 5.5.3: Mechanical properties of forged ferritic steel for low temperature services

Type of steel	Grade	0,2% proof stress (N/mm²) min	Tensile strength (N/mm²)	Elongation A_5 (%) min	Reduction of area (%) min	Charpy V-notch impact test	
						Test temperature (°C)	Average energy (J) min
Carbon manganese	410 LT	235	410-530	25	45	5°C below design temperature or -20°C whichever is lower	27
	460 LT	275	460-580	22	50		
	490 LT	305	490-610	20	35		
3,5 Ni	470	335	470-640	20	40	- 95	34
9 Ni	640	470	640-840	18	40	- 196	41

NOTE:

1. For impact tests, longitudinal test specimens shall be taken.

5.5 Inspection

5.5.1 Unless otherwise agreed, the magnetic particle or liquid penetrant testing and ultrasonic examination of forgings for acceptance purposes is only required when the wall thickness exceeds 100 mm.

5.6 Tightness tests

5.6.1 When applicable, pressure tests are to be carried out in accordance with 1.8.7

5.7 Marking

5.7.1 The particulars detailed in 1.10 are to be marked to all materials which have been accepted.

5.8 Certification

5.8.1 Each test certificate or shipping statement is to give the information contained in 1.11.

SECTION 6 Austenitic stainless-steel forgings

6.1 Scope

6.1.1 This SECTION provides the specific requirements for the manufacture and testing of austenitic stainless-steel forgings intended to be used in the construction of cargo and processing equipment for chemicals, liquefied gases and wherever chemical stability is required.

6.1.2 With regard to the subsequent processes to be applied to the material, e.g. welding, the grades of steel shall be so selected as to ensure the chemical stability required for the application concerned.

6.2 Condition of supply

6.2.1 All forgings must be supplied in the solution treated and quenched condition.

6.3 Chemical composition

6.3.1 According to the grade of steel concerned, the data given in Table 5.6.1 are applicable.

6.4 Mechanical tests

6.4.1 According to the grade of steel concerned, the data given in Table 5.6.2 are applicable.

6.4.2 Unless otherwise agreed, impact tests are not required.

6.4.3 The selection of specimens shall be performed as in 5.4.

6.5 Resistance to intercrystalline corrosion

6.5.1 In the condition in which they are supplied, all forgings must be resistant to intercrystalline corrosion. Where forgings are to be welded without subsequent heat treatment, only those grades of steel shall be chosen which remain resistant to intercrystalline corrosion in this condition, e.g. Ti or Nb stabilized steels or steels with carbon contents of C < 0.3 %.

6.6 Inspection

6.6.1 Unless otherwise agreed, the magnetic particle or liquid penetrant testing and ultrasonic examination of forgings for acceptance purposes is only required when the wall thickness exceeds 100 mm.

6.7 Tightness tests

6.7.1 When applicable, pressure tests are to be carried out in accordance with 1.8.7.

6.8 Marking

6.8.1 The particulars detailed in 1.10 are to be marked to all materials which have been accepted.

6.9 Certification

6.9.1 Each test certificate or shipping statement is to give the information contained in 1.11.

Table 5.6.1: Chemical composition of austenitic stainless steel forgings

<table>
<tr><th rowspan="2">Grade</th><th colspan="9">Chemical composition (%)</th></tr>
<tr><th>C_{max}</th><th>Si</th><th>Mn</th><th>P_{max}</th><th>S_{max}</th><th>Cr</th><th>Mo</th><th>Ni</th><th>Others</th></tr>
<tr><td>304</td><td>0,08</td><td rowspan="6">≤ 1,0</td><td rowspan="6">≤ 2,0</td><td rowspan="6">0,04</td><td rowspan="6">0,03</td><td>18,0-20,0</td><td>-</td><td>8,0-11,0</td><td></td></tr>
<tr><td>304 L</td><td>0,035</td><td>18,0-20,0</td><td>-</td><td>8,0-13,0</td><td></td></tr>
<tr><td>316</td><td>0,08</td><td>16,0-18,0</td><td>2,0-3,0</td><td>10,0-14,0</td><td></td></tr>
<tr><td>316 L</td><td>0,035</td><td>16,0-18,0</td><td>2,0-3,0</td><td>10,0-15,0</td><td></td></tr>
<tr><td>321</td><td>0,08</td><td>17,0-19,0</td><td>-</td><td>9,0-12,0</td><td>Ti ≥ 5 x C max. 0,70</td></tr>
<tr><td>347</td><td>0,08</td><td>19,0-20,0</td><td>-</td><td>9,0-13,0</td><td>Nb + Ta ≥ 10 x C max. 1,1</td></tr>
</table>

Table 5.6.2: Mechanical properties of austenitic stainless steel forgings

Grade	Tensile strength (N/mm^2) min	1,0% proof stress (N/mm^2) min	Elongation A_5 (%) min	Reduction of area Z (%) min
304	515	205	40	50
304 L	485	170		
316	515	205		
316 L	485	170		
321	515	205		

CHAPTER 6 Steel Pipes and Tubes

CONTENTS

SECTION 1 General

1.1 Scope

1.1.1 This SECTION contains the general requirements for seamless and welded pipes to be used for the construction of boilers, superheaters, pressure vessels and pressure piping systems.

1.1.2 Classes I, II and III of pressure systems are defined in Part 5, Chapter 8. The Rules in this Chapter are applicable to all pipes and tubes except those intended for use in Class III pressure systems.

1.1.3 Steels for piping systems operating at sub-zero temperatures (liquefied gases) are to comply with the specific requirements of SECTION 4 and SECTION 5. Steel pipes for structural applications are to comply with the rules for sections detailed in Part 2, Chapter 3.

1.1.4 Pipes conforming to national standards or proprietary specifications may be accepted provided that these specifications give equivalence to these Rules, or where special approval has been granted for their use.

1.1.5 Pipes for Class III piping systems must comply with an acceptable national standard.

1.2 Manufacture

1.2.1 Pipes for pressure systems and boiler and superheater tubes are to be manufactured at works approved by LHR, except as otherwise specially provided.

1.2.2 In the case of welded pipes, in addition, the method used and the quality of the seam shall be subjected to a procedure approval test to be specified by LHR.

1.2.3 The following methods of manufacturing are acceptable:

2. Seamless hot finished or cold finished.
3. Induction or electric resistance welded.
4. Cold finished, induction or electric resistance welded.
5. Fusion welded.

1.2.4 Pipe steels are to be manufactured and cast in ingot moulds or by an approved continuous casting process and killed, unless otherwise specified.

1.3 Condition of supply

1.3.1 Pipes and tubes should not have any surface defects that might cause a significant effect on their application or further treatment. Surface grinding within the minimum wall thickness is allowable but repair welding is not.

1.3.2 Pipes and tubes should be reasonably straight and smooth inside and outside. Their ends are to be nominally square with the pipe axis and free from excessive burrs.

1.3.3 Dimensional tolerances on the wall thickness and the diameter are to be in accordance with an acceptable national standard.

1.4 Chemical composition

1.4.1 The requirements for chemical composition (ladle analysis) and for methods of deoxidation, are detailed in the following Sections.

1.5 Heat treatment

1.5.1 All pipes and tubes are to be heat-treated as specified in the following SECTIONS.

1.6 Test samples

1.6.1 Pipes and tubes are to be presented for tests in batches. A batch of pipes is a group made of pipes having similar dimensions, coming from the same grade of steel and, in the case of heat treatment, the same one. For alloy steels, they may also come from the same heat. The standard size of a batch is 100 pipes. Residual quantities of up to 50 pipes may be evenly allocated to the various batches. Welded pipes should be cut to a length of not more 30 m.

1.6.2 Samples for testing shall be as follows: two pipes shall be taken from each of the first two batches and one pipe from every subsequent batch. Where a batch comprises less than 50 pipes, 2 per cent of the number of lengths in the batch shall be selected at random for testing.

1.6.3 From the sample pipes, normally longitudinal specimens shall be taken. For pipe diameters 200 mm or more, test specimens may also be taken transversely to the pipe axis. Test specimens from welded pipes shall be taken alternately without a seam and with the welded seam in the middle of the specimen.

1.6.4 Tests shall be performed according to the specifications laid down in Part 2, Chapter 2.

1.7 Weldability

1.7.1 All pipes must be so manufactured and finished that they are capable of being welded by standard established methods.

1.8 Marking

1.8.1 The following details are to be marked by the manufacturer on each accepted pipe, in addition to those specified in Part 2, Chapter 1:

1. LHR mark "LHR".
2. Material grade designation number.
3. For alloy pipes, the heat number so that the history of the item can be traced.
4. Manufacturer's trade mark.

1.9 Certification

1.9.1 For all material accepted, a certificate must be provided by the manufacturer to LHR, containing the following details:

1. Purchaser's name and order number.
2. Project number for which the material is intended, if known.
3. Steel grade or material specification.
4. Description, number, dimensions and weight of pipes.
5. Identification number.
6. Cast number and chemical composition of ladle samples.
7. Method of pipe manufacture.
8. Results of all tests required for the material.
9. Condition of supply, including heat treatment.

SECTION 2 Seamless ferritic steel pipes

2.1 Scope

2.1.1 This Section refers to seamless pressure pipes in carbon, carbon-manganese, Mo, CrMo and CrMoV (low alloy) steels to be used mainly in heat transfer equipment but also in pipelines, at ambient and at elevated temperatures.

2.2 Chemical composition

2.2.1 The chemical composition of ladle samples and the method of deoxidation must be according to Table 6.2.1.

2.3 Manufacture and heat treatment

2.3.1 Pipes are to be manufactured by a seamless process and to be hot or cold finished. Their heat treatment is to be according to Table 6.2.2.

2.4 Testing

2.4.1 All tests specified in this Section shall be in accordance with the requirements of Part 2, Chapter 2.

2.4.2 All pipes shall be subjected to a hydraulic test by the manufacturer. Either an ultrasonic or an eddy current test can be accepted instead of the hydraulic test provided it is able to cover the whole circumference of the pipe.

2.4.3 Sample pipes for testing must be subjected to the following tests the results of which are to comply with the requirements of Table 6.2.3:

1. Tensile test
2. Flattening test

2.4.4 The flattening test may be replaced by the bend test, to be performed in accordance with the requirements of Part 2, Chapter 2, SECTION 5, 5.7.

2.5 Design values of mechanical properties

2.5.1 Values of the nominal minimum yield stress or 0,2% proof stress at elevated temperatures are given in Table 6.2.4 and are to be used for design purposes only. For temperatures lower than 200°C the values of stresses shall be taken equal to those corresponding to 200°C. Verification of such properties is only required, when according to national or proprietary standards, their values at elevated temperatures are higher than those specified in Table 6.2.4.

2.5.2 In such cases, the tensile test is to be repeated at the elevated temperature at which the pipe is going to be used, for the sample pipes for which ambient temperature tests were performed, from each cast and from the thickest pipe to be supplied from the cast.

2.5.3 Design values for the estimated average stress to rupture in 100000 hours, are given in Table 6.2.5.

Table 6.2.1: Chemical composition of seamless ferritic steel pipes

Type of steel	Grade	Deoxid. method	Chemical composition of ladle samples (%)											
			C	Si	Mn	S	P	Residual Elements						
Carbon and Carbon Manganese	320	semi killed or killed	≤ 0,16	—	0,40-0,70	0,05	0,05	Ni 0,30 max						
	360	semi killed or killed	≤ 0,17	≤ 0,35	0,40-0,80	0,046	0,045	Cr 0,25 max						
	410	Killed	≤ 0,21	≤ 0,35	0,40-1,20	0,045	0,045	Mo 0,10 max						
	460	killed	≤ 0,22	≤ 0,35	0,80-1,40	0,045	0,045	Cu 0,30 max						
	490	killed	≤ 0,23	≤ 0,35	0,80-1,50	0,045	0,045	Total 0,70 max						
0,3 Mo	450	killed	0,12	0,10-0,35	0,40-0,80	0,035	0,035	Ni	Cr	Mo	Cu	Sn	V	Al
										0,25-0,35				
1 Cr 0,5 Mo	440	killed	0,1-0,18	0,15-0,35	0,40-0,70	0,04	0,04	0,3 max	0,7-1,7	0,45-6,65	0,25 max	0,03 max	—	≤ 0,020
2,25 Cr 1 Mo	490	killed	0,08-0,15	0,10-0,50	0,40-0,70	0,04	0,04	0,3 max	2-2,5	0,90-1,2	0,25 max	0,03 max	—	≤ 0,020
0,5Cr 0,5 Mq 0,25V	460	killed	0,10-0,18	0,1-0,35	0,40-0,70	0,04	0,04	0,3 max	0,3-0,6	0,5-0,7	0,25 max	0,03 max	0,22-0,32	≤ 0,020

Table 6.2.2: Heat treatment for seamless ferritic steel pipes

Type of steel		Heat treatment
Carbon and Carbon Manganese	Hot finished	Hot finished (Note 1) Normalized
	Cold finished	Normalized
Alloy Steel	0,3Mo	Normalized
	1Cr 0,5Mo	Normalized and tempered
	2,25Cr 1Mo	Normalized and tempered 650-780°C
	0,5Cr 0,5Mo 0,25V	Normalized and tempered

NOTE:

– 1. The finishing temperature must be high enough to soften the material.

Table 6.2.3: Mechanical properties for acceptance purposes of seamless ferritic steel pipes

Type of steel	Grade	Yield stress (N/mm²)	Tensile Strength (N/mm²)	Elongation on $5,65 \cdot \sqrt{S_o}$ (%) minimum	Flattening constant C
Carbon and Carbon Manganese	320	195	320-440	25	0,1
	360	215	360-480	24	0,1
	410	235	410-530	22	0,08
	460	265	460-580	21	0,07
	490	285	490-610	21	0,07
0,3 Mo	450	260	450-600	22	0,07
1Cr 0,5Mo	440	275	440-590	22	0,07
2,25Cr 1Mo	490	275	490-640	16	0,07
0,5Cr 0,5Mo 0,25V	460	275	460-610	15	0,07

Table 6.2.4: Mechanical properties for design purposes of seamless ferritic steel pipes

Type of steel	Grade	Nominal minimum lower yield or 0.2% proof stress (N/mm²)								
		Temperature (°C)								
		200	250	300	350	400	450	500	550	600
Carbon and Carbon Manganese	320	147	125	100	91	88	87	-	-	-
	360	165	145	122	111	109	107	-	-	-
	410	188	170	149	137	134	132	-	-	-
	460	212	195	177	162	159	156	-	-	-
	490	226	210	193	177	174	171	-	-	-
0,3Mo	450	210	195	170	160	150	145	140	-	-
1Cr 0,5Mo	440	220	210	183	169	164	161	156	151	-
2,25Cr 1Mo	490	245	236	230	224	218	205	189	167	145
0,5Cr 0,5Mo 0,25V	460	235	218	192	184	177	168	155	148	-

Table 6.2.5: Mechanical properties for design purposes of seamless ferritic steel pipes-Estimated values for stress to rupture in 100,000 hours (N/mm²)

Temperature (°C)	Carbon and carbon manganese		0,3Mo	1Cr 0,5Mo	2,25Cr 1Mo	0,5Cr 0,5Mo 0,25V
	Grades 320 360 410	Grades 460 490	Grade 450	Grade 440	Grade 410	Grade 460
380	171	227	-	-	-	-
390	155	203	-	-	-	-
400	141	179	-	-	-	-
410	127	157	-	-	-	-
420	114	136	-	-	-	-
430	102	117	-	-	-	-
440	90	100	-	-	-	-
450	78	85	245	-	221	-
460	67	73	209	-	204	-
470	57	63	174	-	186	-
480	47	55	143	210	170	218

490	36	47	117	177	153	191
500	-	41	93	146	137	170
510	-	-	74	121	122	150
520	-	-	59	99	107	131
530	-	-	49	81	93	116
540	-	-	38	67	79	100
550	-	-	31	54	69	85
560	-	-	-	43	59	72
570	-	-	-	35	51	59
580	-	-	-	-	44	46

SECTION 3 ferritic steel pipes

3.1 Scope

3.1.1 This SECTION refers to welded pressure pipes in carbon, carbon-manganese and Mo (low alloy) steels to be used mainly in heat transfer equipment but also in pipelines, at ambient and at elevated temperatures.

3.2 Chemical composition

3.2.1 The chemical composition of ladle samples and the method of deoxidation must be according to Table 6.3.1.

3.3 Manufacture and heat treatment

3.3.1 Pipes covered in this Section are to be manufactured by the electric resistance or induction welding process and, if required, may be subsequently hot reduced or cold finished. If the method of submerged arc for longitudinally welded pipes is to be used, details of the specification are to be submitted for approval.

3.3.2 Heat treatment of pipes is to be performed according to Table 6.3.2.

Table 6.3.1: Chemical composition of welded ferritic steel pipes

Type of steel	Grade	Deoxidizing method	Chemical composition of ladle sample (%)					
			C	Si	Mn	S max	P max	Residual elements
Carbon and Carbon Manganese	320	semi killed or killed	≤0,16	-	0,30-0,70	0,05	0,05	Ni 0,30 max Cr 0,25 max Mo 0,10 max Cu 0,30 max Total 0,70 max
	360	semi killed or killed	≤0,17	≤0,35	0,40-1,00	0,045	0,045	
	410	killed	≤0,21	≤0,35	0,40-1,20	0,045	0,045	
	460	killed	≤0,22	≤0,35	0,80-1,40	0,045	0,045	
0.3Mo	450	killed	0,12-0,20	0,10-0,35	0,40-0,8	0,035	0,035	Mo 0,25-0,35

Table 6.3.2: Heat treatment of welded ferritic steel pipes

Type of steel	Condition of supply
Carbon and Carbon Manganese	Normalized (Normalized and tempered at the option of the manufacturer)
0,3 Mo	Normalized

3.4 Testing

3.4.1 All tests specified in this Section shall be in accordance with the requirements of Part 2, Chapter 2.

3.4.2 All pipes shall be subjected to a hydraulic test by the manufacturer. Either an ultrasonic or an eddy current test can be accepted instead of the hydraulic test provided it is able to cover the whole circumference of the pipe.

3.4.3 Sample pipes for testing must be subjected to the following tests the results of which are to comply with the requirements of Table 6.3.3:

(1) Tensile test.

(2) Flattening test.

Table 6.3.3: Mechanical properties for acceptance purposes of welded ferritic steel pipes

Type of steel	Grade	Yield stress (N/mm²)	Tensile strength (N/mm²)	Elongation on $5{,}65 \cdot \sqrt{S_o}$ (%) min	Flattening constant C
Carbon and Carbon Manganese	320	195	320-440	25	0,1
	360	215	360-480	24	0,1
	410	235	410-530	22	0,08
	460	265	460-580	21	0,07
0.3Mo	450	260	450-600	22	0,07

3.4.4 The flattening test may be replaced by the bend test, to be performed in accordance with the requirements of Part 2, Chapter 2, SECTION 5, 5.7.

3.5 Design values of mechanical properties

3.5.1 Values of the mechanical properties at elevated temperatures of the materials in this Section (appearing in Table 6.3.1) can be taken from the appropriate Tables in SECTION 2, and are to be used for design purposes only.

SECTION 4 Ferritic steel pressure pipes for low temperature applications

4.1 Scope

4.1.1 These Rules are intended for application on carbon, carbon-manganese and nickel steel pipes, either seamless or welded, which are going to be used in the piping systems for liquefied gases where the design temperature is less than 0°C, or where the use of steels with suitable impact properties at low temperatures is required.

4.1.2 These Rules apply to pipes with a wall thickness of up to 25 mm. Where this limit is exceeded, special approval by LHR is required.

4.2 Chemical composition

4.2.1 The chemical composition of ladle samples and the method of deoxidation must be according to Table 6.4.1.

4.3 Manufacture and heat treatment

4.3.1 Carbon and carbon-manganese steel pipes are to be manufactured by a seamless, electric resistance or induction welding process.

4.3.2 Nickel steel pipes are to be manufactured by a seamless process.

4.3.3 Before heat treatment, the following methods of finishing may be used:

- Seamless pipes may be hot or cold finished.
- Welded pipes may be as welded, hot or cold finished.

4.3.4 Pipes are to be heat-treated according to the method shown in Table 6.4.2, where minimum design temperatures are also shown.

Table 6.4.1: Ferritic steel pressure pipes for low temperature applications - Chemical composition

Type of steel	Grade	Deoxidizing Method	C max	Si	Mn	P max	S max	Cr	Ni	Mo	other elements
					Chemical composition (%)						
Carbonand	LHR-360	fully killed	0,17	≤0,35	≥0,40	0,03	0,03	-	-	-	Al≥0,015 (Note 1) (Note 2)
carbon	LHR-410		0,19	≤0,35	≥0,60	0,03	0,03	-	-	-	
manganese	LHR-460		0,2	≤0,35	≥0,80	0,03	0,03	-	-	-	
3,5 Ni	LHR-440	fully killed	0,12	0,15-0,35	0,30-0,80	0,03	0,03	-	3,25-3,75	-	
9 Ni	LHR-690		0,1	0,10-0,30	0,30-0,80	0,03	0,03	-	8,50-9,50	-	

NOTES:

1. Aluminium may be wholly or partly replaced by other grain refining elements.

2. Residual elements: Cr ≤ 0,15 Ni ≤ 0,15 Cu ≤ 0,15 Mo ≤ 0,10 total ≤ 0,40.

Table 6.4.2: Ferritic steel pressure pipes for low temperature applications - Design temperatures and heat treatment

Minimum design temperature (°C)	Type of steel	Heat treatment
-55	Carbon and carbon manganese	Normalised (Note 1)
-90	3.5 Ni	Normalised or normalised and tempered (Note 1)
-165	9 Ni	Double normalised and tempered or quenched and tempered

NOTE:

1. A lower design temperature may be specially agreed with LHR for quenched and tempered materials.

4.4 Testing

4.4.1 All tests specified in this SECTION shall be in accordance with the requirements of Part 2, Chapter 2.

4.4.2 All pipes shall be subjected to a hydraulic test by the manufacturer. Either an ultrasonic or an eddy current test can be accepted instead of the hydraulic test provided it is able to cover the whole circumference of the pipe.

4.4.3 Sample pipes for testing must be subjected to the following tests the results of which are to comply with the requirements of Table 6.4.3:

1. Tensile test.
2. Flattening test.
3. Impact test: only where the pipe wall thickness is 6 mm or more, at the temperature specified in Table 6.4.3.

4.4.4 A set of three Charpy V-notch test specimens cut in the longitudinal direction with the notch perpendicular to the original surface of the pipe is to be subjected to the impact test. The average energy value is to comply with the requirements of Table 6.4.3.

4.4.5 The flattening test may be replaced by the bend test, to be performed in accordance with the requirements of Part 2, Chapter 2, SECTION 5, 5.7.

4.4.6 The bend test is required for welded pipes.

Table 6.4.3: Ferritic steel pressure pipes for low temperature applications - Mechanical properties for acceptance purposes

Type of steel	Grade	0,2 proof stress (N/mm²) min (Note 1)	Tensile strength (N/mm²)	Elongation on $5{,}65 \cdot \sqrt{S_0}$		Charpy V-notch impact test			Flatting constant C
				long (min)	trans (min)	Test temperature (°C)	long (J) min (Note 2)	trans (J) min (Note 2)	
Carbon and carbon manganese	LHR-360 LHR-410 LHR-460	235 255 270	360-480 410-530 460-580	24 22 21	22 20 19	5°C below design temperature or -20°C (whichever is lower)	27(19) 27(19) 27(19)	22(15) 22(15) 22(15)	0,09 0,07 0,07
3,5 Ni	LHR-440	345	440-590	19	16	-95	34(24)	24(17)	
9 Ni	LHR-690	510	690-840	17	15	-196	41(27)	27(19)	0,07
									0,06

NOTES:

1. Applicable to wall thicknesses up to 16 mm. For larger wall thicknesses the values are subject to agreement.

2. Average value of three specimens. The values in brackets are the individual minima.

SECTION 5 Austenitic stainless steel pressure pipes

5.1 Scope

5.1.1 These Rules are applicable to seamless and welded austenitic stainless-steel pipes suitable for use in the construction of the piping systems for chemicals and for liquefied gases where the design temperature is not less than -165°C and for bulk chemical tankers.

5.1.2 Austenitic stainless steels are also suitable for service at elevated temperatures. Where such applications are proposed, details of the chemical composition, heat treatment and mechanical properties are to be submitted for consideration and approval.

5.2 Chemical composition

5.2.1 The chemical composition of the ladle samples must be in accordance with the requirements of Table 6.5.1.

5.3 Manufacture and heat treatment

5.3.1 The pipes shall be seamless or manufactured from flat plate, sheet or strip, longitudinally welded across the abutting edges by a continuous automatic electric welding process with or without the addition of filler metal.

5.3.2 All pipes are to be supplied in the solution heat-treated condition.

5.4 Testing

5.4.1 All tests specified in this Section shall be in accordance with the requirements of Part 2, Chapter 2.

5.4.2 All pipes shall be subjected to a hydraulic test by the manufacturer. Either an ultrasonic or an eddy current test can be accepted instead of the hydraulic test provided it is able to cover the whole circumference of the pipe.

5.4.3 Sample pipes for testing must be subjected to the following tests the results of which are to comply with the requirements of Table 6.5.2:

1. Tensile test.
2. Flattening test.
3. Intercrystalline corrosion test, required only for pipes intended for use in the piping systems of chemical tankers.

5.4.4 The intercrystalline corrosion test shall be performed in accordance with a recognized national standard (e.g. DIN 50914).

5.4.5 The flattening test may be replaced by the bend test, to be performed in accordance with the requirements of Part 2, Chapter 2, SECTION 5, 5.7.

5.4.6 The bend test is required for welded pipes.

Table 6.5.1: Chemical composition of austenitic stainless steel for pipes

Type of steel	Grade	Chemical composition of ladle sample (%)								
		C max	Si	Mn	P max	S max	Cr	Mo	Ni	Others
TW 46 (304 L)	490	0,03	<1,00	<2,00	0,045	0,07	17-19	-	9-13	-
TW 57 (316 L)	490	0,03	<1,00	<2,00	0,045	0,03	16-18,5	2-3	11-14,5	-
TW 53 (321)	510	0,08	<1,00	<2,00	0,045	0,03	17-19	-	9-13	Ti ≥ 5 x C ≤ 0,8
TW 50 (347)	510	0,08	<1,00	<2,00	0,045	0,03	17-19	-	9-13	Nb ≥ 10 x C ≤ 1,0

Table 6.5.2: Mechanical properties for acceptance purposes of austenitic stainless steel for pipes

Type of Steel	Grade	0,2% proof stress (N/mm²) (Note 1)	1% proof stress (N/mm²)	Tensile Strength (N/mm²)	Elongation on $5,65 \cdot \sqrt{S_o}$ (%) minimum	Flattening constant C
TW 46 (304 L)	490	175	205	490-690	30	0.09
TW 57 (316 L)	490	185	215	490-690	30	0.09
TW 53 (321)	510	195	235	510-710	30	0.09
TW 50 (347)	510	205	245	510-710	30	0.09

NOTE:

1. The 0,2% proof stress values are given for information purposes and unless otherwise agreed are not required to be verified by test.

SECTION 6 Boiler and superheater tubes

6.1 Scope

6.1.1 This Section refers to tubes for boilers and superheaters, in carbon, carbon-manganese and low alloy steels.

6.1.2 Austenitic stainless steels may also be used for such applications. In such cases, details of the chemical composition, heat treatment and mechanical properties at elevated temperatures are to be submitted for approval.

6.2 Manufacture and chemical composition

6.2.1 Tubes are to comply with the relevant requirements of SECTION 2 and SECTION 3.

6.3 Heat treatment

6.3.1 All tubes are to be heat-treated as required in SECTION 2 and SECTION 3, except that 1Cr0,5Mo steel may be supplied in the normalised only condition when the carbon content is not more than 0,15 per cent.

6.4 Testing

6.4.1 All tests specified in this Section shall be in accordance with Part 2, Chapter 2.

6.4.2 Sample pipes for testing must be subjected to the following tests the results of which are to comply with the requirements of Table 6.6.1:

1. Tensile test.
2. Flattening test.
3. Drift expanding or flanging test.

Table 6.6.1: Mechanical properties for acceptance purpose of boiler and superheater tubes

Type of steel	Grade	Yield stress (N/mm²)	Tensile strength (N/mm²)	Elongation on $5,65 \cdot \sqrt{S_o}$ (%) min C	Flattening constant C	Drift expanding and flanging test minimum % increases in outside diameter Ratio: Inside diameter /Outsid ed iameter		
						≤ 0,6	0,6 < … ≤ 0,8	> 0,8
Carbon and	320	195	320-440	25	0,10	12	15	19
	360	215	360-480	24	0,10	12	15	19
carbon	410	235	410-530	22	0,08	10	12	17
	460	265	460-580	21	0,07	8	10	15
manganese	15							
1Cr 0,5Mo	440	275	440-590	22	0,07	8	10	15
2,25Cr 1Mo	490	275	490-640	16	0,07	8	10	15

6.5 Design values of mechanical properties

6.5.1 Values of the mechanical properties at elevated temperatures are to be taken from the appropriate Tables in SECTION 2.

CHAPTER 7 Non-Ferrous Materials

CONTENTS

SECTION 1 Cast Copper Alloy Propellers (IACS UR W24 Rev.4 (2020))

1.1 Scope

1.1.1 These requirements are applicable to the manufacture, inspection and repair procedures of cast copper alloy propellers, blades and bosses.

1.1.2 Where the use of alternative alloys is proposed, particulars of chemical composition, mechanical properties and heat treatment are to be submitted for approval.

1.1.3 These requirements may also be used for the repair of propellers damaged in service, subject to prior agreement with the LHR.

1.2 Foundry approval

1.2.1 Approval

All propellers and propeller components are to be manufactured by foundries approved by the LHR.. The castings are to be manufactured and tested in accordance with the requirements of these Rules.

1.2.2 Application for approval

It is the manufacturer’s responsibility to assure that effective quality, process and production controls during manufacturing are adhered to within the manufacturing specification. The manufacturing specification shall be submitted to LHR at the time of initial approval and shall at least include the following particulars: description of foundry facilities, copper alloy material specification, runner and feeder arrangements, manufacturing procedures, non-destructive testing and repair procedures.

1.2.3 Scope of the approval test

The scope of the approval test is to be agreed with LHR. This should include the presentation of cast test coupons of the propeller materials in question for approval testing in order to verify that the chemical composition and the mechanical properties of these materials comply with these Rules.

1.2.4 Inspection facilities

The foundry is to have an adequately equipped laboratory, manned by experienced personnel, for the testing of moulding materials chemical analyses, mechanical testing, microstructural testing of metallic materials and non-destructive testing. Where testing activities are assigned to other companies or other laboratory, additional information required by LHR is to be included.

1.3 Moulding and casting

1.3.1 Pouring

The pouring must be carried out into dried moulds using degassed liquid metal. The pouring is to be controlled as to avoid turbulences of flow. Special devices and/or procedures must prevent slag flowing into the mould.

1.3.2 Stress relieving

Subsequent stress relieving heat treatment may be performed to reduce the residual stresses. For this purpose, the manufacturer shall submit a specification containing the details of the heat treatment to LHR for approval. For stress relieving temperatures and holding times see Table 7.1.4 and Table 7.1.5.

1.4 Quality of castings

1.4.1 Freedom from defects

All castings must have a workmanlike finish and must be free from defects which would be prejudicial to their proper application in service. Minor casting defects which may still be visible after machining such as small sand and slag inclusions, small cold shuts and scabs shall be trimmed off by the manufacturer, in accordance with 1.11.

1.4.2 Removal of defects

Casting defects which may impair the serviceability of the castings, e.g. major non-metallic inclusions, shrinkage cavities, blow holes and cracks, are not permitted. They may be removed by one of the methods described in 1.11 and repaired within the limits and restrictions for the severity zones. Full description and documentation are to be available for the surveyor.

1.5 Dimensions, dimensional and geometrical tolerances

1.5.1 The verification of dimensions, the dimensional and geometrical tolerances is the responsibility of the manufacturer. The report on the relevant examinations is to be submitted to the Surveyor, who may require checks to be made in his presence.

1.5.2 Static balancing is to be carried out on all propellers in accordance with the approved drawing. Dynamic balancing is necessary for propellers running above 500 rpm.

1.6 Chemical composition and metallurgical characteristics

1.6.1 Chemical composition

Typical copper propeller alloys are grouped into the four types CU 1, CU 2, CU 3 and CU 4 depending on their chemical composition as given in Table 7.1.1. Copper alloys whose chemical composition deviate from the typical values of Table 7.1.1 must be specially approved by LHR.

Table 7.1.1: Typical chemical compositions of cast copper alloys for propellers

Alloy Type	Cu(%)	Al(%)	Mn(%)	Zn(%)	Fe(%)	Ni(%)	Sn(%)	Pb(%)
CU1	52-62	0,5-3,0	0,5-4,0	35-40	0,5-2,5	max 1,0	0,1-1,5	max 0,5
CU2	50-57	0,5-2,0	1,0-4,0	33-38	0,5-2,5	3,0-8,0	max. 0,15	max 0,5
CU3	77-82	7,0-11	0,5-4,0	max 1,0	2,0-6,0	3,0-6,0	max 0,1	max 0,03
CU4	70-80	6,5-9,0	8,0-20,0	max 6,0	2,0-5,0	1,5-3,0	max 1,0	max 0,05

The manufacturer is to maintain records of the chemical analyses of the production casts, which are to be made available to the Surveyor.

1.6.2 Metallurgical characteristics

NOTE:

"The main constituents of the microstructure in the copper-based alloys categories CU 1 and CU 2 are alpha and beta phase.

Important properties such as ductility and resistance to corrosion fatigue are strongly influenced by the relative proportion of beta phase (too high a percentage of beta phase having a negative effect on these properties). To ensure adequate cold ductility and corrosion fatigue resistance, the proportion of beta phase is to be kept low. The concept of the zinc equivalent should be used as control since it summarizes the effect of the tendency of various chemical elements to produce beta phase in the structure."

The structure of CU 1 and CU 2 type alloys must contain an alpha phase component of at least 25% as measured on a test bar by the manufacturer. To ensure adequate ductility and corrosion fatigue resistance, the proportion of beta phase is to be kept low. For this purpose, the zinc equivalent defined by the following formula shall not exceed a value of 45%:

$$Zinc\ equivalent\ (\%) = 100 - \frac{100\% \cdot Cu}{100 + A}$$

In which A = % Sn+ 5 · % Al -0,5 · % Mn -0,1 · % Fe -2,3 · % Ni

Note: The negative sign in front of the elements Mn, Fe and Ni signifies that these elements tend to reduce the proportion of beta phase.

The micro structure of alloy types CU 1 and CU 2 shall be verified by determining the proportion of alpha phase. For this purpose, at least one specimen shall be taken from each heat. The proportion of alpha phase shall be determined as the average value of 5 counts.

1.7 Mechanical properties and tests

1.7.1 Standardized alloys

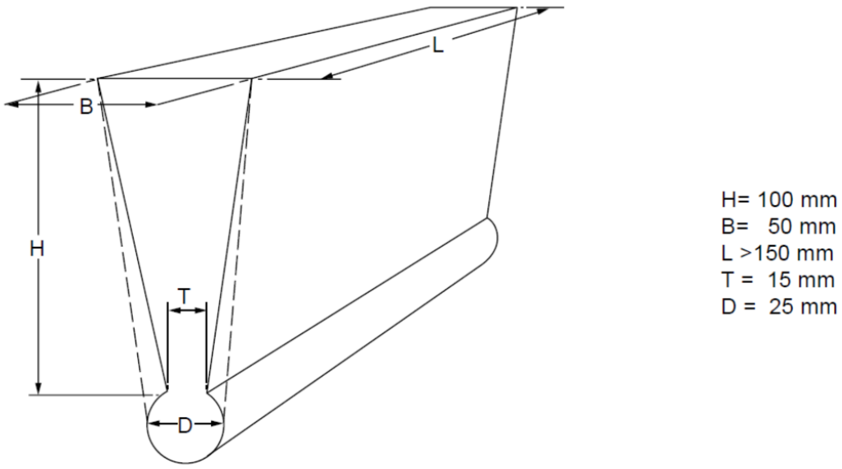
The mechanical properties are to comply with the values given in Table 7.1.2. These values are applicable to test specimens taken from separately cast samples in accordance with Figure 7.1.1, or with a recognized standard.

Note: These properties are a measure of the mechanical quality of the metal in each heat; and they are generally not representative of the mechanical properties of the propeller casting itself, which may be up to 30% lower than that of a separately cast test coupon. For integrally cast test specimens the requirements are specially to be agreed with LHR.

Table 7.1.2: Mechanical properties of cast copper alloys for propellers (separately cast test coupons)

Alloy type	Proof stress $R_{p0,2}$ min. N/mm²	Tensile strength R_m min. [N/mm²]	Elongation A_5 min. [%]
CU 1	175	440	20
CU 2	175	440	20
CU 3	245	590	16
CU 4	275	630	18

Figure 7.1.1: Test sample casting



1.7.2 Other alloys

The mechanical properties of alloys not meeting the minimum values of Table 7.1.2 are to comply with a specification approved by LHR.

1.7.3 Tensile tests and specimens

Tensile tests and specimens are to be in accordance with Part 2, Chapter 2. Generally, the specimens shall be taken from separately cast sample pieces in accordance with 1.7.1. The test samples shall be cast in moulds made of the same material as the mould for the propeller and they must be cooled down under the same conditions as the propeller. At least one tensile test specimen shall be taken from each ladle.

If propellers are subjected to a heat treatment the test samples are to be heat treated together with them.

Where test specimens are to be taken from integrally cast test samples, this shall be the subject of special agreement with LHR. Wherever possible, the test samples shall be located on the blades in an area lying between 0,5 to 0,6 R, where R is the radius of the propeller. The test sample material must be removed from the casting by non thermal procedures.

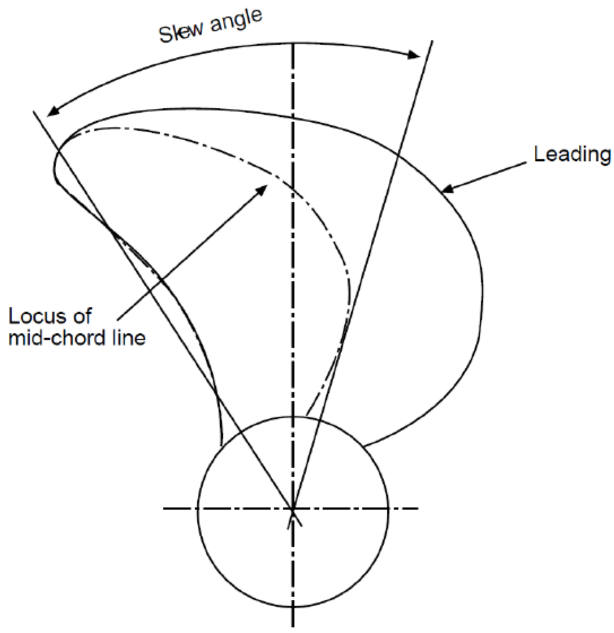
1.8 Definition of skew, severity zones

1.8.1 Definition of skew

The skew of a propeller is defined as follows:

The maximum skew angle of a propeller blade id defined as the angle, in projected view of the blade, between a line drawn through the blade tip and the shaft centerline and a second line through the shaft centerline which acts as a tangent to the locus of the mid-points of the helical blade section see Figure 7.1.2. High skew propellers have a skew angle greater than 25°, low skew propellers a skew angle of up to 25°.

Figure 7.1.2: Definition of skew angle



1.8.2 Severity zones

In order to relate the degree of inspection to the criticality of defects in propeller blades and to help reduce the risk of failure by fatigue cracking after repair, propeller blades are divided into the three severity zones designated A, B and C.

Zone A is the region carrying the highest operating stresses and which, therefore, requires the highest degree of inspection. Generally, the blade thicknesses are greatest in this area giving the greatest degree of restraint in repair welds and this in turn leads to the highest residual stresses in and around any repair welds. High residual tensile stresses frequently lead to fatigue cracking during subsequent service so that relief of these stresses by heat treatment is essential for any welds made in this zone. Welding is generally not permitted in Zone A and will only be allowed after special consideration by LHR. Every effort should be made to rectify a propeller which is either defective or damaged in this area without recourse to welding even to the extent of reducing the scantlings, if this is acceptable. If a repair using welding is agreed, post-weld stress relief heat treatment is mandatory.

Zone B is a region where the operation stresses may be high. Welding should preferably be avoided but generally is allowed subject to prior approval from LHR. Complete details of the defect / damage and the intended repair procedure are to be submitted for each instance in order to obtain such approval.

Zone C is a region in which the operation stresses are low and where the blade thicknesses are relatively small so that repair welding is safer and, if made in accordance with an approved procedure is freely permitted.

a) Low-skew propellers

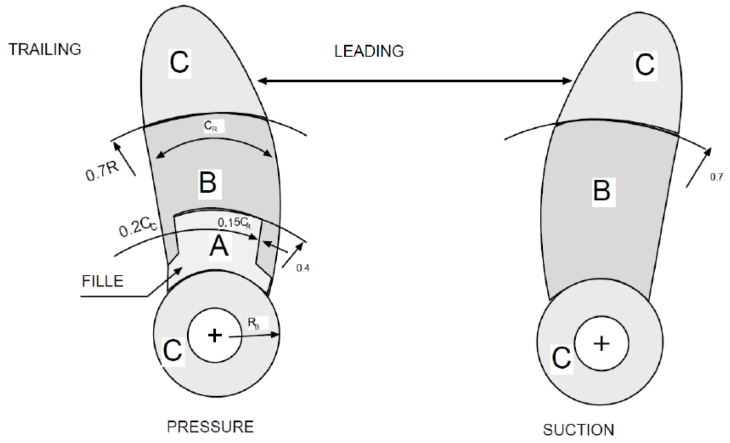
Zone A is in the area on the pressure side of the blade, from and including the fillet to 0,4R, and bounded on either side by lines at a distance 0,15 times the chord length Cr from the leading edge and 0,2 times Cr from the trailing edge, respectively (see Figure 7.1.3).

Where the hub radius (Rb) exceeds 0,27R, the other boundary of zone A is to be increased to 1,5Rb. Zone A also includes the parts of the separate cast propeller hub which lie in the area of the windows as described in Figure 7.1.5 and the flange and fillet area of controllable pitch and built-up propeller blades as described in Figure 7.1.6.

Zone B is on the pressure side the remaining area up to 0,7R and on the suction side the area from the fillet to 0,7R (see Figure 7.1.2).

Zone C is the area outside 0,7R on both sides of the blade. It also includes the surface of the hub of a monoblock propeller and all the surfaces of the hub of a controllable pitch propeller other than those designated Zone A above.

Figure 7.1.3: Severity zones for integrally cast low skew propellers



b) High-skew Propellers

Zone A is the area on the pressure face contained within the blade root-fillet and a line running from the junction of the leading edge with the root fillet to the trailing edge at 0,9·R and at passing through the mid-point of the blade chord at 0,7·R and a point situated at 0,3 of the chord length from the leading edge at 0,4·R. It also includes an area along the trailing edge on the suction side of the blade from the root to 0,9·R and with its inner boundary at 0,15 of the chord lengths from the trailing edge.

Zone B constitutes the whole of the remaining blade surfaces.

Zone A and B are illustrated in Figure 7.1.4.

Figure 7.1.4: Severity zones in blades with skew angles greater than 25°

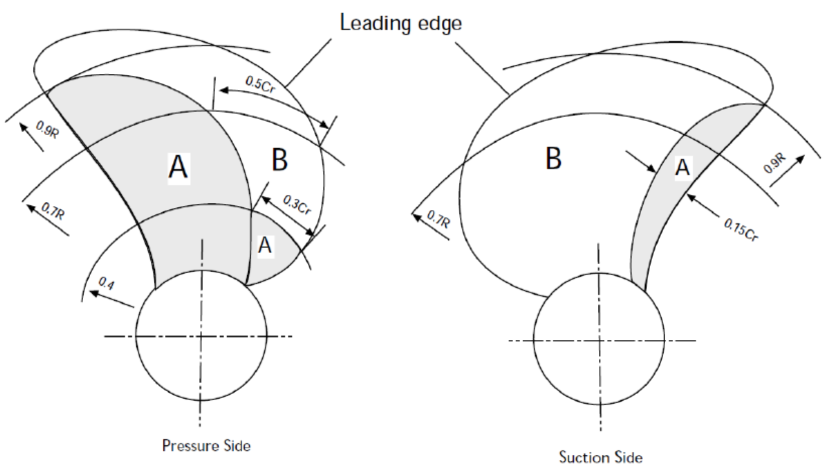


Figure 7.1.5: **Severity zones for controllable pitch propeller boss**

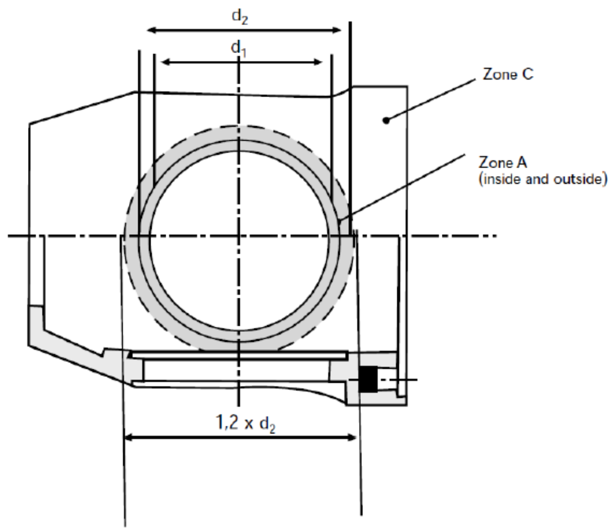
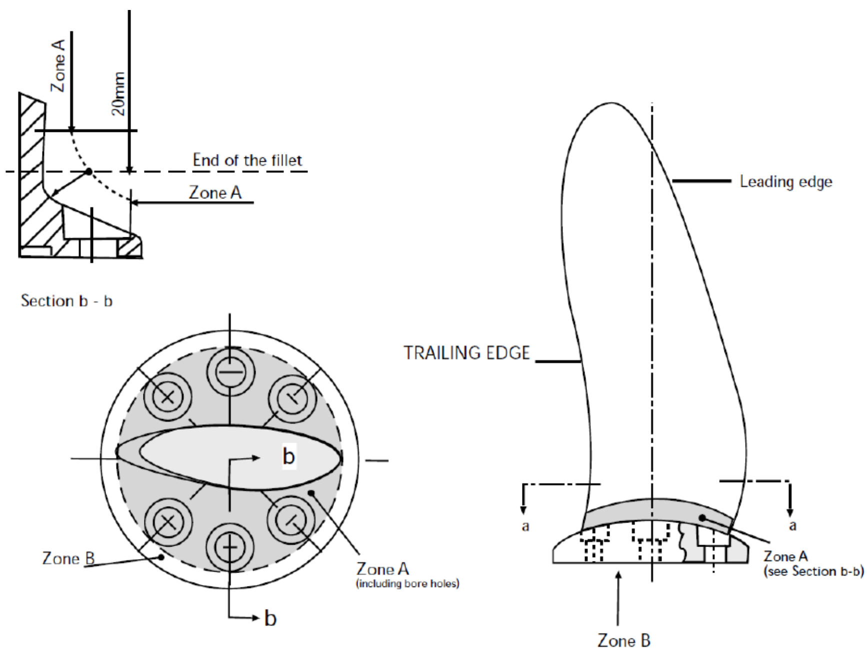


Figure 7.1.6: **Severity zones for controllable pitch and built-up propeller**



NOTE:

The remaining surface of the propeller blades are to be divided into the severity zones as given for solid cast propellers (cf. Figure 7.1.3 and Figure 7.1.4).

1.9 Non-destructive testing

1.9.1 Qualification of personnel involved in NDT

Refer to *LHR's Requirements for Service Suppliers*

1.9.2 Visual testing

All finished castings are to be 100% visually inspected by the manufacturer. Castings are to be free from cracks, hot tears or other imperfections which, due to their nature, degree or extent, will interfere with the use of the castings. A general visual examination is to be carried out by the Surveyor.

1.9.3 Liquid penetrant testing

Liquid penetrant testing procedure is to be submitted to LHR and is to be in accordance with ISO 3452-1:2013 as amended or a recognized standard. The acceptance criteria are specified in 1.10.

The severity Zone A is to be subjected to a liquid penetrant testing in the presence of the Surveyor. In Zones B and C the liquid penetrant testing is to be performed by the manufacturer and may be witnessed by the Surveyor upon his request.

If repairs have been made either by grinding, straightening or by welding the repaired areas are additionally to be subjected to the liquid penetrant testing independent of their location and/or severity zone.

1.9.4 Radiographic and ultrasonic testing

When required by LHR or when deemed necessary by the manufacturer, further nondestructive testing (e.g. radiographic and/or ultrasonic testing) are to be carried out. The acceptance criteria or applied quality levels are to be agreed between the manufacturer and the LHR in accordance with a recognized standard.

Note: due to the attenuating effect of ultrasound within cast copper alloys, ultrasonic testing may not be practical in some cases, depending on the shape/type/thickness, and grain-growth direction of the casting. In such cases, effective ultrasound penetration into the casting should be practically demonstrated on the item. This would normally be determined by way of back-wall reflection, and/or target features within the casting.

1.10 Acceptance criteria for liquid penetrant testing

1.10.1 Definitions of liquid penetrant indications

Indication: In the liquid penetrant testing, an indication is the presence of detectable bleed-out of the penetrant liquid from the material discontinuities appearing at least 10 minutes after the developer has been applied.

Relevant indication: Only indications which have any dimension greater than 1.5mm shall be considered relevant for the categorization of indications.

Non-linear indication: an indication with a largest dimension less than three times its smallest dimension (i.e. $l < 3w$).

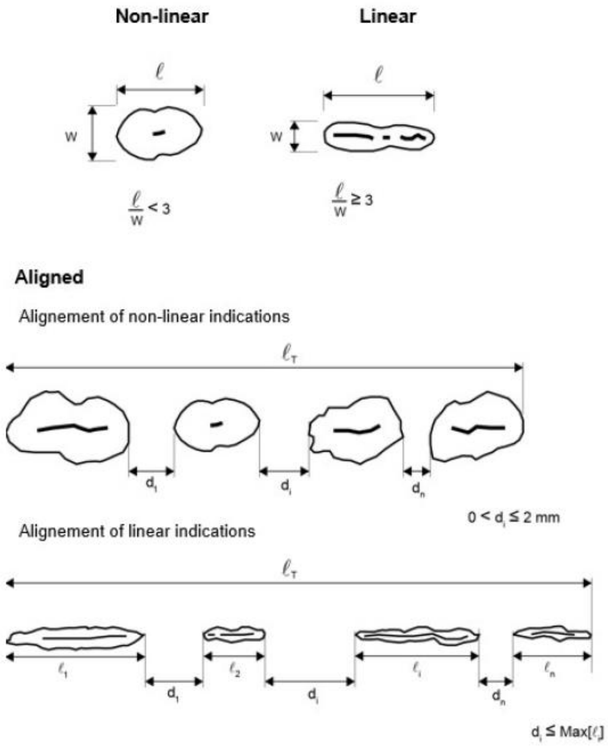
Linear indication: an indication with a largest dimension three or more times its smallest dimension (i.e. $l \geq 3w$).

Aligned indications:

a) Non-linear indications form an alignment when the distance between indications is less than 2mm and at least three indications are aligned. An alignment of indications is considered to be a unique indication and its length is equal to the overall length of the alignment.
b) Linear indications form an alignment when the distance between two indications is smaller than the length of the longest indication.

Illustration of liquid penetrant indication is given in Figure 7.1.7.

Figure 7.1.7: Shape of indications



1.10.2 Acceptance standard

a) The surface to be inspected is to be divided into reference areas of 100 cm². Each reference area may be square or rectangular with the major dimension not exceeding 250mm. The area shall be taken in the most unfavorable location relative to the indication being evaluated.
The relevant indications detected shall, with respect to their size and number, not exceed the values given in the Table 7.1.3.

b) Areas which are prepared for welding are independent of their location always to be assessed according to zone A. The same applies to the welded areas after being finished machined and/or grinded.

Table 7.1.3: Allowable number and size of relevant indications in a reference area of 100 cm², depending on severity zones(1)

Severity zones	Max. total number of indications	Type of indication	Max. number of each type(1) (2)	Max. acceptable value for "a" or "l" of indications [mm]
A	7	Non-linear	5	4
		Linear	2	3
		Aligned	2	3
B	14	Non-linear	10	6
		Linear	4	6
		Aligned	4	6
C	20	Non-linear	14	8
		Linear	6	6
		Aligned	6	6

Notes:

1) Singular circular non-linear indications less than 2 mm for zone A and less than 3 mm for the other zones may be disregarded are not considered relevant.
2) The total number of circular non-linear indications may be increased to the max. total number, or part thereof, represented by the absence of linear and/or aligned indications.

1.11 Repair of defects

1.11.1 Indications exceeding the acceptance standard of Table 7.1.3, cracks, shrinkage cavities, sand, slag and other non-metallic inclusions, blow holes and other discontinuities which may impair the safe service of the propeller are defined as defects and must be repaired.

1.11.2 Repair procedures

In general, the repairs shall be carried out by mechanical means, e. g. by grinding, chipping or milling. Welding may be applied subject to the agreement of LHR if the requirements of 1.11.3, 1.11.4 and/or 1.11.5 will be complied with.

1.11.3 After milling or chipping grinding is to be applied for such defects which are not to be welded. Grinding is to be carried out in such a manner that the contour of the ground depression is as smooth as possible in order to avoid stress concentrations or to minimize cavitation corrosion. Complete elimination of the defective material is to be verified by liquid penetrant testing.

1.11.4 Welding of areas less than 5 cm^2 is to be avoided.

1.11.5 In Zone A, repair welding will generally not be allowed unless specially approved by LHR. In some cases the propeller designer may submit technical documentation to propose a modified zone A based on detailed hydrodynamic load and stress analysis for consideration by LHR. Grinding may be carried out to an extent which maintains the blade thickness of the approved drawing. The possible repair of defects which are deeper than those referred to above is to be considered by LHR.

1.11.6 In Zone B, defects that are not deeper than dB = (t/40) mm (t = min. local thickness in mm according to the Rules) or 2 mm (whichever is greatest) below min. local thickness according to Rules should be removed by grinding. Those defects that are deeper than allowable for removal by grinding may be repaired by welding.

1.11.7 In zone C, repair welds are generally permitted.

1.11.8 The foundry is to maintain records of inspections, welding, and any subsequent heat treatment, traceable to each casting. Before welding is started, full details of the extent and location of the repair, the proposed welding procedure, heat treatment and subsequent inspection procedures are to be submitted to LHR for approval.

1.12 Welding repair procedure

1.12.1 General

a) Before welding is started, manufacturer shall submit to LHR a detailed welding procedure specification covering the weld preparation, welding parameters, filler metals, preheating and post weld heat treatment and inspection procedures.

b) All weld repairs are to be carried out in accordance with qualified procedures, and, by welders who are qualified to a recognized standard. Welding Procedure Qualification Tests are to be carried out in accordance with 1.16 of this SECTION and witnessed by the Surveyor.

1.12.2 Defects to be repaired by welding are to be ground to sound material according to the requirements as given under 1.11.2. The welding grooves are to be prepared in such a manner which will allow a good fusion of the groove bottom. The resulting ground areas are to be examined in the presence of the Surveyor by liquid penetrant testing in order to verify the complete elimination of defective material.

1.12.3 Welding repair procedure

a) Metal arc welding is to be used for all types of welding repair on cast copper alloy propellers. Arc welding with coated electrodes and gas-shielded metal arc process (GMAW) are generally to be applied. Argon-shielded tungsten welding (GTAW) should be used with care due to the higher specific heat input of this process. Recommended filler metals, pre-heating and stress relieving temperatures are listed in Table 7.1.4.

b) All propeller alloys are generally to be welded in down-hand (flat) position. Where this cannot be done, gas-shielded metal arc welding should be carried out.

c) The section to be welded is to be clean and dry. Flux-coated electrodes are to be dried before welding according to the maker's instructions. To minimize distortion and the risk of cracking, interpass temperatures are to be kept low. This is especially the case with CU 3 alloys. Slag, undercuts and other defects are to be removed before depositing the next run.

d) All welding work is to be carried out preferably in the shop free from draughts and influence of the weather.

e) With the exception of alloy CU 3 (Ni-Al-bronze) all weld repairs are to be stress relief heat-treated, in order to avoid stress corrosion cracking. However, stress relief heat treatment of alloy CU 3 propeller castings may be required after major repairs in zone B (and specially approved welding in Zone A) or if a welding consumable susceptible to stress corrosion cracking is used. In such cases the propeller is to be either stress relief heat-treated in the temperature 450 to 500°C or annealed in the temperature range 650-800°C, depending on the extent of repair, cf. Table 7.1.4.

f) The soaking times for stress relief heat treatment of copper alloy propellers should be in accordance with Table 7.1.5. The heating and cooling is to be carried out slowly under controlled conditions. The cooling rate after any stress relieving heat treatment shall not exceed 50°C/h until the temperature of 200°C is reached.

Table 7.1.4: Recommended filler metals and heat treatments

Alloy type	Filler metal	Preheat temperature °C min	Interpass temperature °C max	Stress relief temperature °C	Hot straightening temperature °C
CU1	Al-bronze (1) Mn-bronze	150	300	350-500	500-800
CU2	Al-bronze Ni-Mn-bronze	150	300	350-550	500-800
CU3	Al-bronze Ni-Al-bronze (2) Mn-Al-bronze	50	250	450-500	700-900
CU4	Mn-Al-bronze	100	300	450-600	700-850

NOTES:
1. Ni-Al-bronze and Mn-Al-bronze are acceptable.
2. Stress relieving not required, if filler metal Ni-Al-bronze is used.

Table 7.1.5: Soaking times for stress relief heat treatment of copper alloy propellers

Stress relief temperature, °C	Alloy grade CU1 and CU2		Alloy grade CU3 and CU4	
	Hours per 25 mm thickness	Max. recommended total time hours	Hours per 25 mm thickness	Max. recommended total time hours
350	5	15	-	-
400	1	5	-	-
450	½	2	5	15
500	¼	1	1	5
550	¼	½	½ (1)	2 (1)
600	-	-	¼ (1)	1 (1)

Note:
1. 550°C and 600°C only applicable for CU 4 alloys.

1.13 Straightening

1.13.1 Application of load

For hot and cold straightening purposes, static loading only is to be used.

1.13.2 Hot straightening

Weld repaired areas may be subject to hot straightening, provided it can be demonstrated that weld properties are not impaired by the hot straightening operations.

Straightening of a bent propeller blade or a pitch modification should be carried out after heating the bent region and approximately 500 mm wide zones on either side of it to the suggested temperature range given in Table 7.1.4.

The heating should be slow and uniform and the concentrated flames such as oxy-acetylene and oxy-propane should not be used. Sufficient time should be allowed for the temperature to become fairly uniform through the full thickness of the blade section. The temperature must be maintained within the suggested range throughout the straightening operation. A thermocouple instrument or temperature indicating crayons should be used for measuring the temperature.

1.13.3 Cold straightening

Cold straightening should be used for minor repairs of tips and edges only. Cold straightening on CU 1, CU 2 and CU 4 bronze should always be followed by a stress relieving heat treatment, see Table 7.1.4.

1.14 Identification and marking

1.14.1 Identifications

The manufacturer is to adopt a system for the identification of all castings, which enable the material to be traced to its original cast. The Surveyor is to be given full facilities for so tracing the castings when required.

1.14.2 Marking

Each finished casting propeller shall be marked by the manufacturer at least with the following particulars:

a) Grade of cast material or corresponding abbreviated designation
b) Manufacturer's mark
c) Heat number, casting number or another mark enabling the manufacturing process to be traced back
d) Date of final inspection
e) Number of the LHR's test certificate
f) Ice class symbol, where applicable
g) Skew angle for high skew propellers

1.15 Manufacturer's certificates

1.15.1 For each casting propeller the manufacturer is to supply to the Surveyor a certificate containing the following details:

a) Purchaser and order number
b) Shipbuilding project number, if known
c) Description of the casting with drawing number

d) Diameter, number of blades, pitch, direction of turning
e) Grade of alloy and chemical composition of each heat
f) Heat or casting number
g) Final weight
h) Results of non-destructive tests and details of test procedure where applicable
i) Portion of alpha-structure for CU 1 and CU 2 alloys
j) Results of the mechanical tests
k) Casting identification No.
l) Skew angle for high skew propellers, see 1.8.1

1.16 Welding procedure qualification tests for repair of cast copper alloy propeller

1.16.1 General

1.16.1.1 This document gives requirements for qualification tests of welding procedures intended for the repair of cast copper alloy propellers.

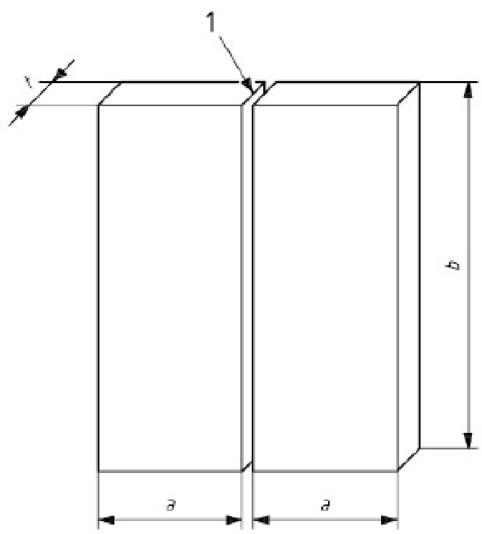
1.16.1.2 For the welding procedure approval the welding procedure qualification tests are to be carried out with satisfactory results. The qualification tests are to be carried out with the same welding process, filler metal, preheating and stress-relieving treatment as those intended applied by the actual repair work. Welding procedure specification (WPS) is to refer to the test results achieved during welding procedure qualification testing.

1.16.1.3 Welding procedures qualified at a manufacturer are valid for welding in workshops under the same technical and quality management.

1.16.2 Test piece and welding sample

1.16.2.1 The test assembly, consisting of cast samples, is to be of a size sufficient to ensure a reasonable heat distribution and according to Fig. 7.1.8 with the minimum dimensions:

Figure 7.1.8: Test piece for welding repair procedure



1= Joint preparation and fit-up as detailed in the preliminary welding procedure specification

a=minimum value 150mm

b= minimum value 300mm

t= material thickness

A test sample of minimum 30mm thickness is to be used.

1.16.2.2 Preparation and welding of test pieces are to be carried out in accordance with the general condition of repair welding work which it represents. Welding of the test assemblies and testing of test specimens are to be witnessed by the Surveyor.

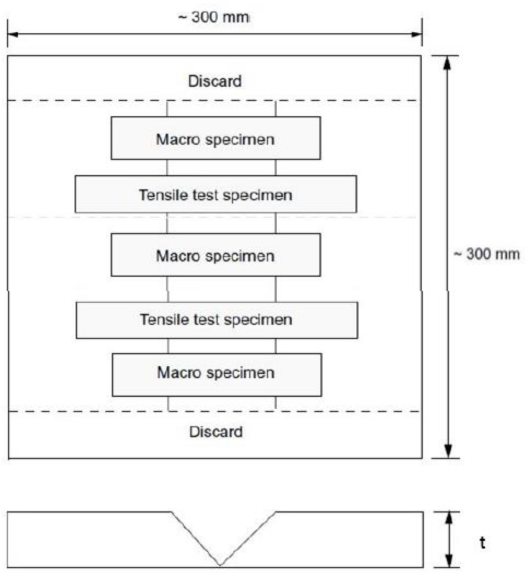
1.16.3 Examinations and Tests

1.16.3.1 Test assembly is to be examined non-destructively and destructively in accordance with the Table 7.1.6 and Fig. 7.1.9:

Table 7.1.6: Type of tests and extent of testing

Type of test (1)	Extent of testing
Visual testing	100% as per article 3.2
Liquid penetrant testing	100% as per article 3.2
Transverse tensile test	Two specimens as per article 3.3
Macro examination	Three specimens as per article 3.4
Note 1: bend or fracture test are at the discretion of LHR	

Figure 7.1.9: Test specimen



1.16.3.2 Non-destructive testing

Test assembly is to be examined by visual and liquid penetrant testing prior to the cutting of test specimen. In case, that any post-weld heat treatment is required or specified, nondestructive testing is to be performed after heat treatment. No cracks are permitted. Imperfections detected by liquid penetrant testing are to be assessed in accordance with 1.10.

1.16.3.3 Tensile test

Two tensile tests are to be prepared as shown in Part 2, Chapter 2, SECTION 3, 3.1.9 b). Alternatively tensile test specimens according to recognized standards acceptable to LHR may be used. The tensile strength shall meet the values given in Table 7.1.7.

Table 7.1.7: Required tensile strength values

Alloy Type	Tensile Strength Rm (N/mm2) min.
CU1	370
CU2	410
CU3	500
CU4	550

1.16.3.4 Macroscopic examination

Three test specimens are to be prepared and etched on one side to clearly reveal the weld metal, the fusion line and the heat affected zone (see Figure 7.1.9). A suitable etchant for this purpose is:

- 5 g iron (III) chloride
- 30 ml hydrochloric acid (cone)
- 100 ml water.

The test specimens are to be examined for imperfections present in the weld metal and the heat affected zone. Cracks and lack of fusion are not permitted. Imperfections such as pores, or slag inclusions, greater than 3 mm are not permitted.

1.16.3.5 Re-testing

If the test piece fails to comply with any of the requirements of this Appendix, reference is made to re-test procedures given in Part 2, Chapter 9, SECTION 2.

1.16.4 Test record

1.16.4.1 Welding conditions for test assemblies and test results are to be recorded in welding procedure qualification record. Forms of welding procedure qualification records can be taken from the Rules or from relevant standards.

1.16.4.2 A statement of the results of assessing each test piece, including repeat tests, is to be made for each welding procedure qualification records. The relevant items listed for the WPS are to be included.

1.16.4.3 The welding procedure qualification record is to be signed by the Surveyor witnessing the test and is to include the LHR´s identification.

1.16.5 Range of approval

1.16.5.1 General

All the conditions of validity stated below are to be met independently of each other. Changes outside of the ranges specified are to require a new welding procedure test. A qualification of a WPS obtained by a manufacturer is valid for welding in workshops or sites under the same technical and quality control of that manufacturer.

1.16.5.2 Base metal

The range of qualification related to base metal is given in Table 7.1.8.

Table 7.1.8: Range of qualification for base metal

Copper alloy material grade used for qualification	Range of approval
CU1	CU1
CU2	CU1; CU2
CU3	CU3
CU4	CU4

1.16.5.3 Thickness

The qualification of a WPS carried out on a weld assembly of thickness t is valid for the thickness range given in Table 7.1.9.

Table 7.1.9: Range of qualification for thickness

Thickness of the test piece, t (mm)	Range of approval
30≤ t	≥3 mm

1.16.5.4 Welding position

Approval for a test made in any position is restricted to that position.

1.16.5.5 Welding process

The approval is only valid for the welding process used in the welding procedure test. Single run is not qualified by multi-run butt weld test used in this SECTION.

1.16.5.6 Filler metal

The approval is only valid for the filler metal used in the welding procedure test.

1.16.5.7 Heat input

The upper limit of heat input approved is 25% greater than that used in welding the test piece. The lower limit of heat input approved is 25% lower than that used in welding the test piece.

1.16.5.8 Preheating and interpass temperature

The minimum preheating temperature is not to be less than that used in the qualification test. The maximum interpass temperature is not to be higher than that used in the qualification test.

11.16.5.9 Post-weld heat treatment

The heat treatment used in the qualification test is to be specified in pWPS. Soaking time may be adjusted as a function of thickness.

SECTION 2 Copper alloy castings for valves, liners and bushes

2.1 Scope

2.1.1 This Section makes provision for copper alloy castings for valve and pump housings, shaft liners, bushes and other parts for use in piping systems and machinery construction. Typical applications are shown in Table 7.2.1.

Table 7.2.1: Typical applications of copper alloy castings for valves, liners, bushes

Material designation	Typical application			
	liners	Valves	bushes	fittings
Phosphor Bronze CuSn 10	X	X	X	X
Leaded Bronze CuPb 9 Sn 5			X	
Gunmetal CuZn 10 Zn 2	X		X	X
Leaded Gunmetal CuZn 5 Pb 5 Sn 5		X	X	X
Coper-Nickel CuNi 30 Mn 1 Fe	X	X		X
Copper-Nickel CuNi 10 Fe 1 Mn		X		X
Ni-Aluminum Bronze CuAl 10 Ni 5 Fe 4		X	X	X

2.1.2 Castings for these products are to be manufactured and tested in accordance with the general requirements of Part 2, Chapter 1 and Part 2, Chapter 2 and the specific requirements of this Section.

2.1.3 As an alternative to 2.1.2, other alloys and methods may be used if approved by LHR after submission of the relevant specifications stating the composition, the mechanical properties and the corrosion behavior in sea water.

2.2 Freedom from defects

2.2.1 All castings are to be free from surface or internal defects liable to impair their proper application in service.

2.3 Chemical composition

2.3.1 The chemical composition must comply with the requirements given in Table 7.2.2.

2.3.2 Where castings are wholly prepared from ingots of starting material of the same grade, without further additions to the heat, the ingot maker's certified analysis can be accepted.

2.4 Mechanical tests

2.4.1 At least one round tensile test specimen, representative of each cast, is to be prepared in accordance with the requirements of Part 2, Chapter 2, Section 3, 3.1.4.

2.4.2 The test material may be taken from integrally cast bars, or, for liners and bushes, it may be cut from the ends of the castings. Alternatively, the test material may be separately cast as a keel block sample in accordance with Figure 7.1.1.

Table 7.2.2: Chemical composition of copper alloys for valves, liners, bushes

Material Designation	Chemical composition of ladle sample (%)								
	Cu	Sn	Zn	Pb	Ni	Mn	P	Fe	Al
Phosphor Bronze CuSn 10	Remainder	9,0-11,0	0,5 max	0,75 max	0,5 max	—	0,5 max	—	—
Leaded Bronze Cu Pb 9 Sn 5	Remainder	4,0-6,0	2,0 max	9,0-11,0	2,0 max	—	0,10 max	—	—
Gunmetal CuSn 10Zn 2	Remainder	8,5-11,0	1,0-3,0	1,5 max	1,0 max	—	—	—	—
Leaded Gunmetal CuPb 5 Sn 5 Zn 5	Remainder	4,0-6,0	4,0-6,0	4,0-6,0	2,0 max	—	—	—	—
Copper-Nickel CuNi 30 Mn 1 Fe	Remainder	—	—	—	29,0-32,0	0,5-1,5	—	0,40-1,0	—
Copper-Nickel CuNi 10 Fe 1 Mn	Remainder	—	—	—	9,0-11,0	0,5-1,0	—	1,0-1,8	—
Ni-aluminium Bronze CuAl 10 Ni 5 Fe 4	Remainder	0,10 max	1,0 max	0,03 max	3,0-6,0	0,5-4,0		2,0-6,0	7,0-11,0

2.4.3 Where castings are supplied in the heat-treated condition, the test samples shall be subjected to the same heat treatment prior to the preparation of the tensile specimens.

2.4.4 The results of all tests are to comply with the requirements given in Table 7.2.3.

Table 7.2.3: Mechanical properties of copper alloys for valves, liners, bushes

Material designation	0,2% proof stress (N/mm^2) minimum Note 1	Tensile strength (N/mm^2)	Elongation on $5,65 \cdot \sqrt{S_o}$ (%) minimum
Phosphor Bronze CuSn 10	120	250	15
Leaded Bronze CuPb 9 Sn 5	100	200	16
Gunmetal Cu Sn 10 Zn 2	130	270	13
Leaded Gunmetal CuPb 5 Sn 5 Zn	100	200	16
Copper-Nickel CuNi 30 Mn 1 Fe	220	420	20
Copper-Nickel CuNi 10 Fe 1 Mn	160	320	20
Ni-Aluminium bronze CuAl 10 Ni 5 Fe 4	240	590	16

NOTE:

1. The 0,2% proof stress values are for information purposes only and, unless otherwise agreed, are not required to be verified by test.

2.5 Inspection

2.5.1 All finished castings are to be cleaned and presented for examination by the Surveyor; this is to include the examination of internal surfaces.

2.5.2 A report shall be prepared by the manufacturer containing the final dimensions and the results of the surface finish inspection, after finish-machining; this report shall be submitted to the Surveyor.

2.6 Rectification of defective castings

2.6.1 Defective castings containing local porosity may be rectified by impregnation with a suitable plastic filler subject to prior approval by LHR. The extent of the porosity must be shown to be such that it does not affect adversely the strength of the casting.

2.6.2 Welding may be used for rectifying defective castings if the relevant approval is obtained from the Surveyor before commencement of the work. The extent of the defect must be shown to be such that the castings can be effectively repaired.

2.6.3 A sketch together with a statement describing the weld repair must be prepared by the manufacturer as permanent record.

2.6.4 It is not allowed to weld repair liners in copper alloys containing more than 0,5% lead.

2.7 Hydraulic test

2.7.1 Where required by the relevant construction Rules, the castings shall be subjected to a hydraulic pressure test in the presence of the Surveyor. Shaft liners shall be tested at a pressure of at least 2 bar. For all other components, the test pressure is 1,5 times the operating pressure.

2.8 Marking

2.8.1 The manufacturer must adopt a system of identification which will enable all finished castings to be traced back to the original cast, and the Surveyor is to be given proof of this.

2.8.2 Castings must be marked by the manufacturer according to the requirements of Part 2,

Chapter 1. The following details are to be shown on each casting which has been accepted:

- Identification mark which will enable the full history of the item to be traced.
- Alloy designation.
- LHR mark “LHR”.
- The manufacturer's mark.
- Personal stamp of Surveyor responsible for the final inspection.
- Test pressure, where applicable.
- Date of final inspection.

2.9 Certification

2.9.1 For each casting, the manufacturer must supply to the Surveyor a written certificate containing the following details:

1. Purchaser's name and order number.
2. Description of the casting with drawing number.
3. Alloy designation and chemical composition.
4. Identification number of casting.
5. Final weight.
6. Details of heat treatment, where applicable.

2.9.2 In addition to 2.9.1, the manufacturer is to provide, where applicable, a description detailing the extent and position of all weld repairs made to each casting.

SECTION 3 Copper alloy tubes

3.1 Scope

3.1.1 This Section refers to seamless copper and copper alloy tubes to be used in condensers, heat exchangers and pressure piping systems.

3.1.2 All tubes are to be manufactured and tested in accordance with the general requirements of Part 2, Chapters 1 and 2 and the requirements of this Section, except for tubes for Class III pressure systems.

3.1.3 Alternatively, pipes conforming to national or international standards, or manufacturer's specification, may be approved provided that these standards can be considered equivalent to the requirements of this Section, or where LHR has given special approval for their use.

3.1.4 Tubes for Class III pressure systems must be manufactured and tested according to the requirements of an acceptable national standard.

3.2 Manufacture

3.2.1 Manufacturers wishing to supply products in accordance with these Rules are not required to obtain approval of works, as detailed in Part 2, Chapter 1.

3.2.2 Tubes shall generally be manufactured by a seamless process, unless otherwise agreed.

3.2.3 Where welded tubes are to be used, details of the methods of manufacture and inspection shall be submitted.

3.3 Freedom from defects and dimensions

3.3.1 Pipes and tubes should not have any surface defects that might cause a significant effect on their application or further treatment. Surface grinding within the minimum wall thickness is allowable but repair welding is not.

3.3.2 Pipes and tubes should be reasonably straight and smooth inside and outside. Their ends are to be nominally square with the pipe axis and free from excessive burrs.

3.3.3 Dimensional tolerances on the wall thickness and the diameter are to be in accordance with an acceptable national standard.

3.4 Chemical composition

3.4.1 The chemical compositions of copper and copper alloy tubes must comply with the requirements of Table 7.3.1.

3.5 Heat treatment

3.5.1 All tubes must be supplied in the annealed condition. Additional stress relieving heat treatment may be required for aluminium brass tubes which have been subjected to a cold straightening operation after annealing.

3.6 Hydraulic test

3.6.1 Each tube is to be subjected to a hydraulic test by the manufacturer at his works.

3.6.2 The hydraulic test pressure is to be 1,5 times the design pressure, or 70 bar, whichever is greater.

3.7 Mechanical tests

3.7.1 Batches for testing purposes shall consist of 300 lengths of tubes of the same size, manufactured from the same material.

3.7.2 All tests specified in this Section shall be carried out in accordance with Part 2, Chapter 2.

3.7.3 One length is to be selected at random from each batch and subjected to the following tests the results of which are to comply with the requirements given in Table 7.3.2:

- Tensile test.
- Flattening test.
- Drift expanding test.

3.7.4 The test specimens, in the flattening test, shall be pressed together until the inner surfaces touch.

3.7.5 The mandrel, for the drift expanding test shall have an included angle of 45°. The test should stop when the increase in the outside diameter of the end of the test specimen reaches 30%.

Table 7.3.1: Chemical composition of copper and copper alloys for tubes

Material designation	Chemical composition of ladle samples (%)									
	Cu	P	As	Fe	Pb	Ni	Al	Mn	Zn	Maximum impurities
Copper Cu-DHP	99,8 min	0,015 - 0,04	—	—	—	—	—	—	—	—
Aluminium brass CuZn 20 Al 2	76,0-79	—	0,020 - 0,035	—	—	—	1,8-2,3		Remainder	Fe: 0,07 Mn: 0,1 Ni: 0,1 Mg: 0,05 P: 0,01 Pb: 0,07 Other impurities: 0,1
Copper-nickel 90/10 CuNi 10 Fe 1 Mn (Note 1)	Remainder	—	—	1-2	—	9-11	—	0,5-1	—	C: 0,05 S: 0,05 Pb: 0,03 Zn: 0,5 Other impurities: 0,3
Copper-nickel 70/30 CuNi 30 Mn 1 Fe (Note 1)	Remainder	—	—	0,4-1	—	30-32	—	0,5-1,5	—	C: 0,05 S: 0,05 Pb: 0,03 Zn: 0,5 Other impurities: 0,3

NOTE:

1. Where copper-nickel tubes are to be welded in the course of further manufacture, the permitted impurities are subject to the following limits: Pb ≤ 0,02, P ≤ 0,02, S ≤ 0,02, S ≤ 0,02.

Table 7.3.2: Mechanical properties of copper and copper alloys for tubes

Material designation	0,2% proof stress (N/mm²)	Tensile strength (N/mm²)	Elongation on $5{,}65 \cdot \sqrt{S_o}$ (%) minimum
Copper Cu-DHP	100	200 - 260	40
Aluminium brass CuZn 20Al 2	120	330	35
Copper-nickel 90/10 CuNi 10Fe 1Mn	90	290	30
Copper-nickel 70/30 CuNi 30Mn 1Fe	120	370	35

3.8 Inspection

3.8.1 All tubes must be presented for visual examination and verification of dimensions under adequate lighting conditions.

3.9 Stress corrosion cracking test

3.9.1 This test is applicable to aluminium brass only. It is to be performed in accordance with a recognized national standard (e.g. DIN 50911).

3.9.2 Should a specimen reveal cracks during this test, the batch represented by that specimen shall be rejected but may be re-submitted after a renewed heat treatment.

3.10 Rectification of defects

3.10.1 Surface imperfections may be removed by grinding provided that a gradual transition is made to the surface of the pipe and that the dimensional tolerances are not exceeded. Repair by welding is not permitted.

3.11 Marking

3.11.1 Each tube shall be marked by the manufacturer with the following information:

– Manufacturer' mark.

– LHR mark “LHR”.

– Material designation.

– Manufacturing batch number.

3.11.2 The marks shall be applied by an indelible and weatherproof dye. Punching of marks is not permitted.

3.12 Certification

3.12.1 Each test certificate or shipping statement is to include the following particulars:

1. Purchaser's name and order number.
2. Number, size and weight of tubes.
3. Alloy designation and chemical composition.
4. Manufacturing batch number.
5. Results of all tests.

SECTION 4 Aluminium alloys for hull construction and marine structure (IACS UR W25 Rev.6 (2021))

4.1 Scope

4.1.1 These requirements apply to wrought aluminium alloys used in the construction of hulls, superstructures and other marine structures. They are not applicable to the use of aluminium alloys at low temperature for cryogenic applications.

4.1.2 These requirements are applicable to wrought aluminium alloy products within a thickness range of 3 mm and 50 mm inclusive. The application of aluminium alloys products outside this thickness range requires prior agreement of LHR.

4.1.3 The numerical designation (grade) of aluminium alloys and the temper designation are based on those of the Aluminium Association.

4.1.4 Temper conditions (delivery heat treatment) are defined in the European Standard EN 515:2017 or ANSI H35.1:2017.

4.1.5 Consideration may be given to aluminium alloys not specified in these Requirements, and to alternative temper conditions, subject to prior agreement with LHR further to a detailed study of their properties, including corrosion resistance, and of their conditions of use (in particular welding procedures).

4.2 Approval

4.2.1 All materials, including semi finished products, are to be manufactured at works which are approved by LHR for the grades of aluminium alloy supplied.

4.3 Aluminium alloys and their temper conditions

4.3.1 Rolled products (sheets, strips and plates)

The following aluminium alloys are covered by these requirements:

5083, 5086, 5383, 5059, 5754, 5456

with the hereunder temper conditions:

O, H111, H112, H116, H321

4.3.2 Extruded products (sections, shapes, bars and closed profiles)

The following aluminium alloys are covered by these requirements:

5083, 5383, 5059, 5086

with the hereunder temper conditions:

O, H111, H112,

and

6005A, 6061, 6082

with the hereunder temper conditions:

T5 or T6.

NOTE:
The alloy grades 6005A, 6061 of the 6000 series should not be used in direct contact with sea water unless protected by anodes and/or paint system.

4.4 Chemical composition

4.4.1 The Manufacturer is to determine the chemical composition of each cast.

4.4.2 The chemical composition of aluminium alloys is to comply with the requirements given in Table 7.4.1.

4.4.3 The Manufacturer's declared analysis will be accepted subject to occasional checks if required by the Surveyor; in particular, product analysis may be required where the final product chemistry is not well represented by the analysis from the cast.

4.4.4 When the aluminium alloys are not cast in the same works in which they are manufactured into semi finished products, the Surveyor shall be given a certificate issued by the works in question which indicates the reference numbers and chemical composition of the heats.

4.5 Mechanical properties

4.5.1 The mechanical properties are to comply with the requirements given in Table 7.4.2 and Table 7.4.3.

NOTE: It should be recognized that the mechanical properties of the welded joint are lower for strain hardened or heat-treated alloys, when compared with those of the base material, in general. For reference, see Part 2, Chapter 10, Section 9 for Aluminium Consumables.

4.6 Freedom of defects

4.6.1 The finished material is to have a workmanlike finish and is to be free from internal and surface defects prejudicial to the use of the concerned material for the intended application.

4.6.2 Slight surface imperfections may be removed by smooth grinding or machining as long as the thickness of the material remains within the tolerances given in 4.7.

4.7 Tolerances

4.7.1 The underthickness tolerances for rolled products given in Table 7.4.4 are minimum requirements.

4.7.2 The underthickness tolerances for extruded products are to be in accordance with the requirements of recognized international or national standards.

4.7.3 Dimensional tolerances other than underthickness tolerances are to comply with a recognized national or international standard.

4.8 Testing and inspection

4.8.1 Tensile test

The test specimens and procedures are to be in accordance with Part 2, Chapter 2.

4.8.2 Non-destructive examination.

In general, the non-destructive examination of material is not required for acceptance purposes.

NOTE:
Manufacturers are expected, however, to employ suitable methods of non-destructive examination for the general maintenance of quality standards.

4.8.3 Dimensions

It is the manufacturer's responsibility to check the materials for compliance with the tolerances given in 4.7.

4.8.4 Verification of proper fusion of press welds for closed profiles

4.8.4.1 The Manufacturer has to demonstrate by macrosection tests or drift expansion tests of closed profiles performed on each batch of closed profiles that there is no lack of fusion at the press welds.

4.8.4.2 Drift expansion tests

- Every fifth profile shall be sampled after final heat treatment. Batches of five profiles or less shall be sampled one profile. Profiles with lengths exceeding 6 m shall be sampled every profile in the start of the production. The number of tests may be reduced to every fifth profile if the results from the first 3-5 profiles are found acceptable.
- Each profile sampled will have two samples cut from the front and back end of the production profile.
- The test specimens are to be cut with the ends perpendicular to the axis of the profile. The edges of the end may be rounded by filing.
- The length of the specimen is to be in accordance with Part 2, Chapter 2.
- Testing is to be carried out at ambient temperature and is to consist of expanding the end of the profile by means of a hardened conical steel mandrel having an included angle of at least 60°.
- The sample is considered to be unacceptable if the sample fails with a clean split along the weld line which confirms lack of fusion.

4.8.5 Corrosion testing

a) Rolled 5xxx-alloys of type 5083, 5383, 5059, 5086 and 5456 in the H116 and H321 tempers intended for use in marine hull construction or in marine applications where frequent direct contact with seawater is expected are to be corrosion tested with respect to exfoliation and intergranular corrosion resistance.

b) The manufacturers shall establish the relationship between microstructure and resistance to corrosion when the above alloys are approved. A reference photomicrograph taken at 500x, under the conditions specified in ASTM B928:2015 Section 9.4.1, shall be established for each of the alloy-tempers and thickness ranges relevant. The reference photographs shall be taken from samples which have exhibited no evidence of exfoliation corrosion and a pitting rating of PB or better, when subjected to the test described in ASTM G66:2018 (ASSET). The samples shall also have exhibited resistance to intergranular corrosion at a mass loss no greater than 15mg/cm^2, when subjected to the test described in ASTM G67:2018 (NAMLT). Upon satisfactory establishment of the relationship between microstructure and resistance to corrosion, the master photomicrographs and the results of the corrosion tests are to be approved by LHR. Production practices shall not be changed after approval of the reference micrographs.

   Other test methods may also be accepted at the discretion of LHR.

c) For batch acceptance of 5xxx-alloys in the H116 and H321 tempers, metallographic examination of one sample selected from mid width at one end of a coil or random sheet or plate is to be carried out. The microstructure of the sample is to be compared to the reference photomicrograph of acceptable material in the presence of the Surveyor. A longitudinal section perpendicular to the rolled surface shall be prepared for metallographic examination, under the conditions specified in ASTM B928:2015, Section 9.6.1. If the microstructure shows evidence of continuous grain boundary network of aluminum-magnesium precipitate in excess of the reference photomicrographs of acceptable material, the batch is either to be rejected or tested for exfoliation-corrosion resistance and intergranular corrosion resistance subject to the agreement of the Surveyor. The corrosion tests are to be in accordance with ASTM G66:2018 and ASTM G67:2018 or equivalent standards. Acceptance criteria are that the sample shall exhibit no evidence of exfoliation corrosion and a pitting rating of PB or better when test subjected to ASTM G66:2018 ASSET test, and the sample shall exhibit resistance to intergranular corrosion at a mass loss no greater than 15mg/cm2 when subjected to ASTM G67:2018 NAMLT test. If the results from testing satisfy the acceptance criteria stated in 4.8.5(b) the batch is accepted, else it is to be rejected.

As an alternative to metallographic examination, each batch may be tested for exfoliation-corrosion resistance and intergranular corrosion resistance, in accordance with ASTM G66:2018 and ASTM G67:2018 under the conditions specified in ASTM B928:2015, or equivalent standards. If this alternative is used, then the results of the test must satisfy the acceptance criteria stated in paragraph 4.8.5.

4.9 Test materials

4.9.1 Definition of batches

Each batch is made up of products:

- of the same alloy grade and from the same cast
- of the same product form and similar dimensions (for plates, the same thickness)
- manufactured by the same process
- having been submitted simultaneously to the same temper condition.

4.9.2 The test samples are to be taken

- at one third of the width from a longitudinal edge of rolled products.
- in the range ⅓ to ½ of the distance from the edge to the centre of the thickest part of extruded products.

4.9.3 Test samples are to be taken so that the orientation of test specimens is as follows:

- Rolled products

  Normally, tests in the transverse direction are required. If the width is insufficient to obtain transverse test specimen, or in the case of strain hardening alloys, tests in the longitudinal direction will be permitted.
- Extruded products

  The extruded products are tested in longitudinal direction.

4.9.4 After removal of test samples, each test specimen is to be marked in order that its original identity, location and orientation is maintained.

4.10 Mechanical test specimens

4.10.1 Type and location of tensile test specimen

The type and location of tensile test specimens are to be in accordance with Part 2, Chapter 2.

4.11 Number of test specimens

4.11.1 Tensile Test

- Rolled products

One tensile test specimen is to be taken from each batch of the product. If the weight of one batch exceeds 2000 kg, one extra tensile test specimen is to be taken from every 2000 kg of the product or fraction thereof, in each batch. For single plates or for coils weighting more than 2000 kg each, only one tensile test specimen per plate or coil shall be taken.

– Extruded products

For the products with a nominal weight of less than 1 kg/m, one tensile test specimen is to be taken from each 1000 kg, or fraction thereof, in each batch. For nominal weights between 1 and 5 kg/m, one tensile test specimen is to be taken from each 2000 kg or fraction hereof, in each batch. If the nominal weight exceeds 5 kg/m, one tensile test specimen is to be taken for each 3000 kg of the product or fraction thereof, in each batch.

4.11.2 Verification of proper fusion of press welds

For closed profiles, verification of proper fusion of press welds is to be performed on each batch as indicated in 4.8.4 here before.

4.11.3 Corrosion tests

For rolled plates of grade 5083, 5383, 5059, 5086 and 5456 delivered in the tempers H116 or H321, one sample is to be tested per batch.

4.12 Retest procedures

4.12.1 When the tensile test from the first piece selected in accordance with 4.11 fails to meet the requirements, two further tensile tests may be made from the same piece. If both of these additional tests are satisfactory, this piece and the remaining pieces from the same batch may be accepted.

4.12.2 If one or both the additional tests referred to above are unsatisfactory, the piece is to be rejected, but the remaining material from the same batch may be accepted provided that two of the remaining pieces in the batch selected in the same way, are tested with satisfactory results. If unsatisfactory results are obtained from either of these two pieces then the batch of material is to be rejected.

4.12.3 In the event of any material bearing the LHR's brand failing to comply with the test requirements, the brand is to be unmistakably defaced by the manufacturer.

4.13 Branding

4.13.1 The manufacturer shall mark each product at least one place with the following details:

- Manufacturer's mark
- Abbreviated designation of aluminium alloy according to 4.3
- Abbreviated designation of temper condition according to 4.3
- Tempers that are corrosion tested in accordance with 4.8.5 are to be marked "M" after the temper condition, e.g., 5083 H321 M.
- Number of the manufacturing batch enabling the manufacturing process to be traced back.

4.13.2 The product is also to bear the LHR's brand.

4.13.3 When extruded products are bundled together or packed in crates for delivery, the marking specified in 4.13.1 should be affixed by a securely fastened tag or label.

4.14 Documentation

4.14.1 For each tested batch, the manufacturer must supply to LHR's Surveyor a test certificate, or a shipping statement containing the following details:

– Purchaser and order number
– Construction project number, when known,
– Number, dimensions and weight of the product
– Designation of the aluminium alloy (grade) and of its temper condition (delivery heat treatment)
– Chemical composition
– Manufacturing batch number or identifying mark
– Corrosion Test results (if any).

Table 7.4.1: Chemical composition (1)

Grade	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other Elements (2)	
									Each	Total
5083	0,40	0,40	0,10	0,40-1,00	4,00-4,90	0,05-0,25	0,25	0,15	0,05	0,15
5383	0,25	0,25	0,20	0,70-1,00	4,00-5,20	0,25	0,40	0,15	0,05 (5)	0,15 (5)
5059	0,45	0,50	0,25	0,60-1,20	5,00-6,00	0,25	0,40-0,90	0,20	0,05 (6)	0,15 (6)
5086	0,40	0,50	0,10	0,20-0,70	3,50-4,50	0,05-0,25	0,25	0,15	0,05	0,15
5754	0,40	0,40	0,10	0,50 (3)	2,60-3,60	0,30 (3)	0,20	0,15	0,05	0,15
5456	0,25	0,40	0,10	0,50-1,00	4,70-5,50	0,05-0,20	0,25	0,20	0,05	0,15
6005A	0,50-0,90	0,35	0,30	0,50 (4)	0,40-0,70	0,30 (4)	0,20	0,10	0,05	0,15
6061	0,40-0,80	0,70	0,15-0,40	0,15	0,80-1,20	0,04-0,35	0,25	0,15	0,05	0,15
6082	0,7-1,30	0,50	0,10	0,40-1,00	0,60-1,20	0,25	0,20	0,10	0,05	0,15

Notes:

1. Composition in percentage mass by mass maximum unless shown as a range or as a minimum.
2. Includes Ni, Ga, V and listed elements for which no specific limit is shown. Regular analysis need not be made.
3. Mn + Cr: 0,10-0,60
4. Mn + Cr: 0,12-0,50
5. Zr: maximum 0,20. The total for other elements does not include Zirconium.
6. Zr: 0,05-0,25. The total for other elements does not include Zirconium.

Table 7.4.2: Mechanical properties for rolled products, 3mm≤t≤50mm

Grade	Temper Condition [3]	Thickness, t	Yield Strength $R_{p0.2}$ min. or range N/mm²	Tensile Strength R_m min. or range N/mm²	Elongation, % min. [1]	
					A_{50} mm	A_{5d}
5083	O	3 ≤ t ≤ 50 mm	125	275-350	16	14
	H111	3 ≤ t ≤ 50 mm	125	275-350	16	14
	H112	3 ≤ t ≤ 50 mm	125	375	12	10
	H116	3 ≤ t ≤ 50 mm	215	305	10	10
	H321	3 ≤ t ≤ 50 mm	215-295	305-385	12	10
5383	O	3 ≤ t ≤ 50 mm	145	290	-	17
	H111	3 ≤ t ≤ 50 mm	145	290	-	17
	H116	3 ≤ t ≤ 50 mm	220	305	10	10
	H321	3 ≤ t ≤ 50 mm	220	305	10	10
5059	O	3 ≤ t ≤ 50 mm	160	330	24	24
	H111	3 ≤ t ≤ 50 mm	160	330	24	24
	H116	3 ≤ t ≤ 20 mm	270	370	10	10
		3 ≤ t ≤ 50 mm	260	360	-	10
	H321	3 ≤ t ≤ 20 mm	270	370	-	10
		3 ≤ t ≤ 50 mm	260	360	16	10
5086	O	3 ≤ t ≤ 50 mm	95	240-305	16	14
	H111	3 ≤ t ≤ 50 mm	95	240-305	16	14
	H112	3 ≤ t ≤ 12.5 mm	125	250	8	-
		12.5 < t ≤ 50 mm	105	240	-	9
	H116	3 ≤ t ≤ 50 mm	195	275	10 [2]	9
5754	O	3 ≤ t ≤ 50 mm	80	190-240	18	17
	H111	3 ≤ t ≤ 50 mm	80	190-240	18	17
5456	O	3 ≤ t ≤ 6.3 mm	130-205	290-365	16	
		6.3 < t ≤ 50 mm	125-205	285-360	16	14
	H116	3 ≤ t ≤ 30 mm	230	315	10	10
		30 < t ≤ 40 mm	215	305	-	10
		40 < t ≤ 50 mm	200	285	-	10

Notes:

1. Elongation in 50 mm apply for thicknesses up to and including 12,5 mm and in 5d for thicknesses over 12,5 mm.
2. 8 % for thicknesses up to and including 6,3 mm.
3. The mechanical properties for the O and H111 tempers are the same. However, they are separated to discourage dual certification as these tempers represent different processing.

Table 7.4.3: Mechanical properties for extruded products, 3 mm≤t≤50 mm

Grade	Temper	Thickness, t	Yield Strength $R_{p0.2}$ min. or range N/mm²	Tensile Strength R_m min. or range N/mm²	Elongation, % min. (1) (2)	
					A_{50} mm	A_{5d}
5083	O	3 ≤ t ≤ 50 mm	110	270-350	14	12
	H111	3 ≤ t ≤ 50 mm	165	275	12	10
	H112	3 ≤ t ≤ 50 mm	110	270	12	10
5383	O	3 ≤ t ≤ 50 mm	145	290	17	17
	H111	3 ≤ t ≤ 50 mm	145	290	17	17
	H112	3 ≤ t ≤ 50 mm	190	310		13
5059	H112	3 ≤ t ≤ 50 mm	200	330		10
5086	O	3 ≤ t ≤ 50 mm	95	240-315	14	12
	H111	3 ≤ t ≤ 50 mm	145	250	12	10
	H112	3 ≤ t ≤ 50 mm	95	240	12	10
6005A	T5	3 ≤ t ≤ 50 mm	215	260	9	8
	T6	3 ≤ t ≤ 10 mm	215	260	8	6
		3 ≤ t ≤ 50 mm	200	250	8	6
6061	T6	3 ≤ t ≤ 50 mm	240	260	10	8
6082	T5	3 ≤ t ≤ 50 mm	230	270	8	6
	T6	3 ≤ t ≤ 5 mm	250	290	6	
		3 ≤ t ≤ 50 mm	260	310	10	8

NOTES:

1. The values are applicable for longitudinal and transverse tensile test specimens as well.
2. Elongation in 50 mm applies for thicknesses up to and including 12,5 mm and in 5d for thicknesses over 12,5 mm.

Table 7.4.4: Underthickness tolerances for rolled products

Nominal thickness (t), mm	Thickness tolerances for nominal width (w), mm		
	W ≤ 1500	1500 < w ≤ 2000	2000 < w ≤ 3500
3,0 ≤ t < 4,0	0,10	0,15	0,15
4,0 ≤ t < 8,0	0,20	0,20	0,25
8,0 ≤ t < 12,0	0,25	0,25	0,25
12,0 ≤ t < 20,0	0,35	0,40	0,50
20,0 ≤ t < 50,0	0,45	0,50	0,65

CHAPTER 8 Materials for Mooring and Anchoring Equipment

CONTENTS

SECTION 1 Requirements for manufacture of anchors (IACS UR W29 (2005))

1.1 Scope

1.1.1. These Rules apply to the materials, manufacture and testing, and certification of anchors, shanks and anchor shackles made of forged or cast steel, or fabricated by welded rolled steel plate and bars. Frequent reference is made to Part 3, Chapter 17.

With regard to holding power tests at sea for high holding power (HHP) and super high holding power (SHHP) anchors, refer to Part 3, Chapter 17.

1.1.2. The types of anchors covered include:

- Ordinary anchors (refer to Part 3, Chapter 17, SECTION 3, 3.1.1):
  - Stockless anchors
  - Stocked anchors
- High Holding Power (HHP) anchors (refer to Part 3, Chapter 17, SECTION 3, 3.1.2).
- Super High Holding Power (SHHP) anchors, not exceeding 1500kg in mass (refer to Part 3, Chapter 17, SECTION 3, 3.1.3).

Any changes to the design made during manufacture are to have prior written agreement from LHR.

1.2 Materials

1.2.1 Materials for anchors

All anchors are to be manufactured from materials meeting the requirements of LHR Rules as indicted below:

a) Cast steel anchor flukes, shanks, swivels and shackles are to be manufactured and tested in accordance with the requirements of Part 2, Chapter 4, SECTION 2 and comply with the requirements for castings for welded construction. The steel is to be fine grain treated with Aluminium. If test programme B is selected in 1.4.2 of this SECTION then Charpy V notch (CVN) impact testing of cast material is required. Special consideration is to be given to the use of other grades of steels for the manufacture of swivels.

b) Forged steel anchor pins, shanks, swivels and shackles are to be manufactured and tested in accordance with the requirements Part 2, Chapter 5, SECTION 2. Shanks, swivels and shackles are to comply with the requirements for carbon and carbon-manganese steels for welded construction. Special consideration is to be given to the use of other grades of steels for the manufacture of swivels

c) Rolled billets, plate and bar for fabricated steel anchors are to be manufactured and tested in accordance with the requirements of Part 2, Chapter 3, SECTION 3.

d) Rolled bar intended for pins, swivels and shackles are to be manufactured and tested in accordance with the requirements of Part 2, Chapter 5, SECTION 2 or Part 2, Chapter 3, SECTION 3.

1.2.2 Materials for SHHP anchors

In addition to the requirements of 1.2.1, SHHP anchors are to be produced in accordance with the requirements of Part 2, Chapter 5, SECTION 2 or Part 2, Chapter 3, SECTION 3.

1.3 Manufacture of anchors

1.3.1 Tolerance

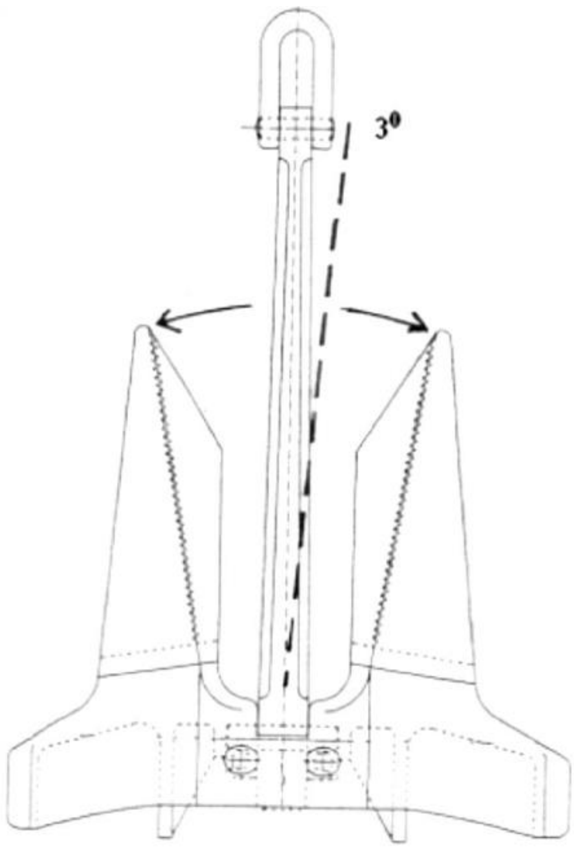
If not otherwise specified on standards or on drawings demonstrated to be appropriate, the following assembly and fitting tolerance are to be applied.

The clearance either side of the shank within the shackle jaws is to be no more than 3 mm for small anchors up to 3 tonnes weight, 4 mm for anchors up to 5 tonnes weight, 6 mm for anchors up to 7 tonnes weight and is not to exceed 12 mm for larger anchors.

The shackle pin is to be a push fit in the eyes of the shackle, which are to be chamfered on the outside to ensure a good tightness when the pin is clenched over on fitting. The shackle pin to hole tolerance is to be no more than 0,5 mm for pins up to 57 mm and 1,0 mm for pins of larger diameter.

The trunnion pin is to be a snug fit within the chamber and be long enough to prevent horizontal movement. The gap is to be no more than 1% of the chamber length. The lateral movement of the shank is not to exceed 3 degrees, see Figure 8.1.1.

Figure 8.1.1: Allowable lateral movement of shank



1.3.2 Welding of anchors

Welded construction of fabricated anchors is to be done in accordance with procedures approved by LHR. Welding is to be carried out by qualified welders, following the approved welding procedures qualified in accordance with Part 2, Chapter 9, Section 2, using consumables manufactured in accordance with the requirements of Part 2, Chapter 10, Sections 1-7. NDE is to be carried in accordance with the requirements of 1.4.2 of this SECTION.

1.3.3 Heat treatment

Components for cast or forged anchors are to be properly heat treated; fully annealed; normalised or normalised and tempered in accordance with Part 2, Chapter 5, SECTION 2 and Part 2, Chapter 4, SECTION 2. Fabricated anchors may require stress relief after welding depending upon weld thickness. Stress relief is to be carried out as indicated in the approved welding procedure. Stress relief temperatures are not to exceed the tempering temperature of the base material.

1.3.4 Freedom from defects

All parts are to have a clean surface consistent with the method of manufacture and be free from cracks, notches, inclusions and other defects that would impair the performance of the product.

1.3.5 Repairs

Any necessary repairs to forged and cast anchors are to be agreed by the Surveyor and carried out in accordance with the repair criteria indicated in Part 2, Chapter 5, SECTION 2 and Part 2, Chapter 4, SECTION 2. Repairs to fabricated anchors are to be agreed by the Surveyor and carried out in accordance with qualified weld procedures, by qualified welders, following the parameters of the welding procedures used in construction.

1.3.6 Anchor assembly

Assembly and fitting are to be done in accordance with the design details. Securing of the anchor pin, shackle pin or swivel nut by welding is to be done in accordance with an approved procedure.

1.4 Testing and certification

1.4.1 Proof load test

Proof load tests are to be carried out by an approved testing facility.

Proof load testing for Ordinary, HHP and SHHP anchors is to be carried out in accordance with the pertinent requirements of Part 3, Chapter 17, SECTION 3, 3.3.

1.4.2 Product tests

1.4.2.1 Product Test Programs

LHR can request that either program A or program B be applied.

Table 8.1.1: Applicable programs for each product form

Product test	Product form		
	Cast components	Forged components	Fabricated/Welded components
Programme A	Applicable	Not applicable	Not applicable
Programme B	Applicable (1)	Applicable	Applicable

Notes:

(1) CVN impact tests are to be carried out to demonstrate at least 27 joules average at 0ºC. Refer to 2.1 a).

Table 8.1.2: Product test requirements for program A and B

Program A	**Program B**
Drop test	---
Hammering test	---
Visual inspection	Visual inspection
General NDE	General NDE
---	Extended NDE

1.4.2.2 Drop test

Each anchor fluke and shank is individually raised to a height of 4 m and dropped on to a steel slab without fracturing. The steel slab is to be suitable to resist the impact of the dropped component.

1.4.2.3 Hammering test

After the drop test, hammering tests are carried out on each anchor fluke and shank, which is slung clear of the ground, using a non-metallic sling, and hammered to check the soundness of the component. A hammer of at least 3 kg mass is to be used.

1.4.2.4 Visual inspection

After proof loading visual inspection of all accessible surfaces is to be carried out.

1.4.2.5 General non-destructive examination

After proof loading general NDE is to be carried out as indicated in the following Table 8.1.3 and Table 8.1.4.

Table 8.1.3: General NDE for Ordinary and HHP anchors

Location	Method of NDE
Feeders of castings	PT or MT
Risers of castings	PT or MT
Weld repairs	PT or MT
Forged components	Not required
Fabrication welds	PT or MT

Table 8.1.4: General NDE for SHHP anchors

Location	Method of NDE
Feeders of castings	PT or MT and UT
Risers of castings	PT or MT and UT
All surfaces of castings	PT or MT
Weld repairs	PT or MT
Forged components	Not required
Fabrication welds	PT or MT

Part 2, Chapter 4, SECTION 9 "Guidelines for non-destructive examination of marine steel castings" is regarded as an example of an acceptable standard for surface and volumetric examination.

1.4.2.6 Extended non-destructive examination

After proof loading general NDE is to be carried out as indicated in the following Table 8.1.5.

Table 8.1.5: Extended NDE for Ordinary, HHP and SHHP anchors

Location	Method of NDE
Feeders of castings	PT or MT and UT
Risers of castings	PT or MT and UT
All surfaces of castings	PT or MT
Random areas of castings	UT
Weld repairs	PT or MT
Forged components	Not required
Fabrication welds	PT or MT

Part 2, Chapter 4, SECTION 9 "Guidelines for non-destructive examination of marine steel castings" is regarded as an example of an acceptable standard for surface and volumetric examination.

1.4.2.7 Repair criteria

If defects are detected by NDE, repairs are to be carried out in accordance with 1.3.5 of this SECTION. For fracture and unsoundness detected in a drop test or hammering test, repairs are not permitted and the component is to be rejected.

1.4.3 Mass and dimensional inspection

Unless otherwise agreed, the verification of mass and dimensions is the responsibility of the manufacturer. The Surveyor is only required to monitor this inspection. The mass of the anchor is to exclude the mass of the swivel, unless this is an integral component.

1.4.4 Retests

Mechanical retest are permitted in accordance with the requirements of Part 2, Chapter 3, SECTIONS 1-5.

1.5 Marking

Anchors which meet the requirements are to be stamped on the shank and the fluke. The markings on the shank are to be approximately level with the fluke tips. On the fluke, these markings are to be approximately at a distance of two thirds from the tip of the bill to the center line of the crown on the right-hand fluke looking from the crown towards the shank. The markings are to include:

- Mass of anchor
- Identification, e.g., test No. or certificate No.
- LHR's stamp
- Manufacturer's mark

Additionally, the unique cast identification is to be cast on the shank and the fluke.

1.6 Certification

Anchors which meet the requirements are to be certified by LHR at least with the following items:

- Manufacturer's name
- Type
- Mass
- Fluke and Shank identification numbers
- Grade of materials
- Proof test loads
- Heat treatment
- Marking applied to anchor

1.7 Painting

All types of anchor are not to be painted until all tests and inspections have been completed.

SECTION 2 Anchor chain cables and accessories including chafing chain for emergency towing arrangements (IACS UR W18 Rev.6 (2021))

2.1. Scope

2.1.1 These rules apply to the materials, design, manufacture and testing of stud link anchor chain cables and accessories used for ships. Where, in exceptional cases, studless short link chain cables are used with the consent of LHR, they must comply with recognized national or international standards. The requirements for chafing chain for Emergency Towing Arrangements (ETA) are given in 2.23.

2.1.2 Depending on the nominal tensile strength of the chain cable steel used for manufacture, stud link chain cables are to be subdivided into Grades LHR-1, LHR-2 or LHR-3.

2.2. Approval of chain cable manufacturers

2.2.1 Anchor chain cables and accessories are to be manufactured only by works approved by LHR. For this purpose, approval tests are to be carried out, the scope of which is to be agreed with LHR.

2.2.2 Applications for approval are to be made to LHR, stating the method of manufacture used, the grades of materials, the nominal dimensions and, where applicable, the material specification. A procedure test carried out on a high-strength chain cable may cover approval of lesser grades, provided that the material type, method of manufacture and the nature of the heat treatment are the same.

2.3. General requirements for materials

2.3.1 These Rules apply to rolled steels, forgings and castings used for the manufacture of anchor chain cables and accessories.

2.3.2 All materials used for the manufacture of anchor chain cables and accessories are to be supplied by manufacturers approved by LHR. LHR’s approval is not required for Grade LHR-1 steel bars.

2.3.3 Material suppliers or chain cable manufacturers are to submit specifications for Grade LHR-3 steel bars. These specifications should contain all necessary details, such as manufacturing procedure, deoxidation practice, specified chemical composition, heat treatment and mechanical properties.

2.3.4 Mechanical tests representing the steel bars are normally to be carried out by the steel mill, and the results are to meet the requirements in Table 8.2.1. The test coupons are to be in a heat treatment condition equivalent to that of the finished chain cable and accessories.

Table 8.2.1: Mechanical properties of rolled steel bars

Grade	R_{eH} [N/mm²] min	R_m [N/mm²]	A_5 (%) min.	Z (%) min.	Charpy V-notch impact test	
					Test temp. in °C	Absorbed energy in Joules, min.
LHR-1	-	370-490	25	-	-	-
LHR-2	295	490-690	22	-	0	27 [(1)]
LHR-3	410	min. 690	17	40	0[(2)] -20	60 35

Notes:
1. The impact test of Grade LHR-2 materials may be waived, if the chain cable is to be supplied in a heat treated condition as per Table 8.2.5.
2. Testing is normally to be carried out at 0°C.

2.4. Rolled steel bars

2.4.1 Unless otherwise stipulated, the steels will be supplied in as rolled condition.

2.4.2 The chemical composition of the steel bars is to be generally within the limits given in Table 8.2.2.

Table 8.2.2: Chemical composition of rolled steel bars

Grade	Chemical composition in maximum percent, unless specified					
	C	Si	Mn	P	S	Al tot [(1)] min.
LHR-1	0,20	0,15-0,35	min. 0,40	0,040	0,040	-
LHR-2 [(2)]	0,24	0,15-0,55	1,60	0,035	0,035	0,020
LHR-3 [(3)]	In accordance with an approved specification					

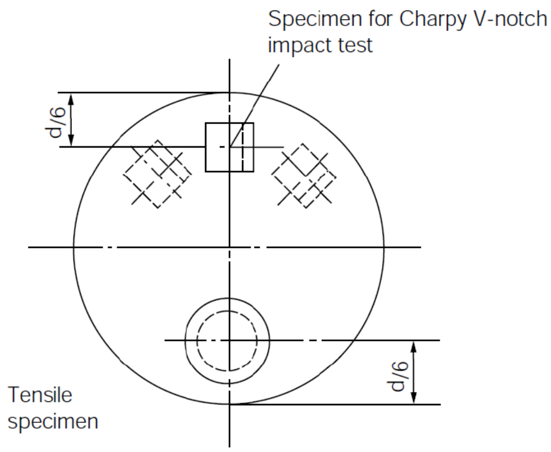
Notes:
1. Aluminum may be replaced partly by other grain refining elements.
2. If LHR agrees, additional alloying elements may be added.
3. To be killed and fine grain.

2.4.3 For performance of the mechanical tests the steel bars shall be sorted according to heats and diameters into test units not exceeding 50 tons each. From each test unit a test sample will be taken for the tests mentioned in 2.4.5 and 2.4.6. Prior to sampling, the test samples must be subjected to the heat treatment provided for the finished chain cable, see 2.8 in this SECTION. Details of the heat treatment must be indicated by the chain cable manufacturer.

2.4.4 Tensile and Charpy V-notch impact test specimens shall be taken from the test sample in the longitudinal direction at a distance of 1/6 diameter from the surface or as close as possible to this position (see Figure 8.2.1).

2.4.5 For the tensile test, one specimen shall be taken from each test unit and tested in accordance with Part 2, Chapter 2.

Figure 8.2.1: Sampling locations



2.4.6 One set of longitudinal Charpy V-notch test specimens shall be taken from each test unit and tested at the temperature prescribed in Table 8.2.1, all in accordance with Part 2, Chapter 2. The specimen transverse axis is to be radial to the steel bar. The average value obtained from one set of three impacts specimens is to comply with the requirements given in Table 8.2.1. One individual value only may be below the specified average value provided it is not less than 70% of that value.

2.4.7 Re-test requirements for tensile tests are to be in accordance with Part 2, Chapter 2 with specimens taken from the same sample. Failure to meet the specified requirements of either of both additional tests will result in rejection of the test unit represented unless it can be clearly attributable to improper simulated heat treatment, see 2.4.9.

2.4.8 Re-test requirements for Charpy impact tests are to be in accordance with Part 2, Chapter 2. Specimens are to be selected from the same sample. Failure to meet the requirements will result in rejection of the test unit represented unless it can be clearly attributable to improper simulated heat treatment, see 2.4.9.

2.4.9 If failure to pass the tensile test or the Charpy V-notch impact test is definitely attributable to improper heat treatment of the test sample, a new test sample may be taken from the same piece and reheat-treated. The complete test (both tensile and impact test) is to be repeated and the original results obtained may be disregarded.

2.4.10 The diameter and roundness shall be within the tolerances specified in Table 8.2.3 unless otherwise agreed.

2.4.11 The materials have to be free from internal and surface defects that might impair proper workability and use. Surface defects may be repaired by grinding, provided the admissible tolerance is not exceeded.

Table 8.2.3: Dimensional tolerance of rolled steel bars

Nominal diameter mm	Tolerance on diameter mm	Tolerance on roundness (d_{max} - d_{min}) mm
Less than 25	-0 + 1,0	0,6
25 - 35	-0 + 1,2	0,8
36 - 50	-0 + 1,6	1,1
51 - 80	-0 + 2,0	1,5
81 - 100	-0 + 2,6	1,95
101 - 120	-0 + 3,0	2,25
121 - 160	-0 + 4,0	3,00

2.4.12 Manufacturers are to effectively operate an identification system ensuring traceability of the material to the original cast.

2.4.12 The minimum markings required for the steels are the manufacturers' brandmark, the steel grade and an abbreviated symbol of the heat. Steel bars having diameters of up to and including 40 mm and combined into bundles, may be marked on permanently affixed labels.

2.4.13 Bar material for Grade LHR-2 or Grade LHR-3 is to be certified by LHR. For each consignment manufacturers shall hand to the Surveyor a certificate containing at least the following data:

1. Manufacturer's and/or purchaser's order No.
2. Number and dimensions of bars and weight of consignment.
3. Steel specification and chain grade.
4. Heat number.
5. Manufacturing procedure.
6. Chemical composition.
7. Details of heat treatment of the test sample (where applicable).
8. Results of mechanical tests (where applicable).
9. Number of test specimens (where applicable).

2.5. Forged steels for chain cables and accessories

2.5.1 Forged steels used for the manufacture of chain cables and accessories must be in compliance with Part 2, Chapter 5, SECTION 2, unless otherwise specified in the following paragraphs.

2.5.2 The chemical composition is to comply with the specification approved by LHR. The steel manufacturer must determine and certify the chemical composition of every heat of material.

2.5.3 The stock material may be supplied in the as rolled condition. Finished forgings are to be properly heat treated, i.e. normalized, normalized and tempered or quenched and tempered, whichever is specified for the relevant steel grade in Table 8.2.4.

2.6. Cast steels for chain cables and accessories

2.6.1 Cast steels used for the manufacture of chain cables and accessories are to be in compliance with Part 2, Chapter 4, Section 2, unless otherwise specified in the following paragraphs.

2.6.2 The chemical composition is to comply with the specification approved by LHR. The foundry is to determine and certify the chemical composition of every heat.

2.6.3 All castings must be properly heat treated, i.e. normalized, normalized and tempered or quenched and tempered, whichever is specified for the relevant cast steel grade in Table 8.2.4.

2.7. Materials for studs

2.7.1 The studs are to be made of steel corresponding to that of the chain cable or from rolled, cast or forged mild steels. The use of other materials, e.g. grey or nodular cast iron is not permitted.

2.8. Design and manufacturing process

2.8.1 Stud link chain cables should preferably be manufactured by flash butt welding using Grade LHR-1, LHR-2 or LHR-3 bar material. Manufacture of the links by drop forgings or castings is permitted. On request, pressure butt welding may also be approved for studless, Grade LHR-1 and LHR-2 chain cables, provided that the nominal diameter of the chain cable does not exceed 26 mm.

2.8.2 Accessories such as shackles, swivels and swivel shackles are to be forged or cast in steel of at least Grade LHR-2. The welded construction of these parts may also be approved.2.8.3 Chain cables must be designed according to a standard recognized by LHR, such as ISO 1704:2008 as amended. A length of chain cable must comprise an odd number of links. Where designs do not comply with this and where accessories are of welded construction, drawings giving full details of the design, the manufacturing process and the heat treatment are to be submitted to LHR for approval.

2.9. Heat treatment

2.9.1 According to the grade of steel, chain cables and accessories are to be supplied in one of the conditions specified in Table 8.2.4. The heat treatment shall in every case be performed before the proof load test, the breaking load test, and all mechanical testing.

Table 8.2.4:	**Condition of supply of chain cables and accessories**	
Grade	Condition of supply	Accessories
LHR-1	As-welded or normalized condition	-
LHR-2	As-welded or normalized condition (1)	Normalized
LHR-3	Normalized, normalized and tempered or quenched and tempered condition	Normalized, normalized and tempered or quenched and tempered condition

NOTE:

1. Grade LHR-2 chain cables made by forging or casting are to be supplied in the normalized condition.

2.10. Mechanical properties

2.10.1 The mechanical properties of finished chain cables and accessories, are to be in accordance with Table 8.2.7.

2.11. Freedom from defects

2.11.1 The materials have to be free from internal and surface defects that might impair proper workability and use. Surface defects may be repaired by grinding, provided the admissible tolerance is not exceeded.

2.11.2 All individual parts must have a clean surface consistent with the method of manufacture and be free from cracks, notches, inclusions and other defects impairing the performance of the product. The flashes produced by upsetting or drop forging must be properly removed.

2.11.3 Minor surface defects may be ground off so as to leave a gentle transition to the surrounding surface. Remote from the crown local grinding up to 5% of the nominal link diameter may be permitted.

2.12. Dimensions and dimensional tolerances

2.12.1 The shape and proportions of links and accessories must conform to a recognized standard, such as ISO 1704:2008 as amended or the designs specially approved.

2.12.2 The following tolerances are applicable to links:

a) Diameter measure at the crown (Two measurements are to be taken at the same location: one in the plane of the link (see dp in Figure 8.2.2), and one perpendicular to the plane of the link:

up to 40mm nominal diameter	: -1 mm
over 40mm up to 84 mm nominal diameter	: -2 mm
over 84mm up to 122mm nominal diameter	: -3 mm
over 122mm nominal diameter	: -4 mm

The plus tolerance may be up to 5% of the nominal diameter. The cross sectional area of the crown must have no negative tolerance.

b) Diameter measured at locations other than nominal:

The diameter is to have no negative tolerance. The plus tolerance may be up to 5% of the nominal diameter. The approved manufacturer's specification is applicable to the plus tolerance of the diameter at the flush-butt weld.

c) The maximum allowable tolerance on assembly measured over a length of 5 links may equal +2,5%, but may not be negative (measured with the chain under tension after proof load test).

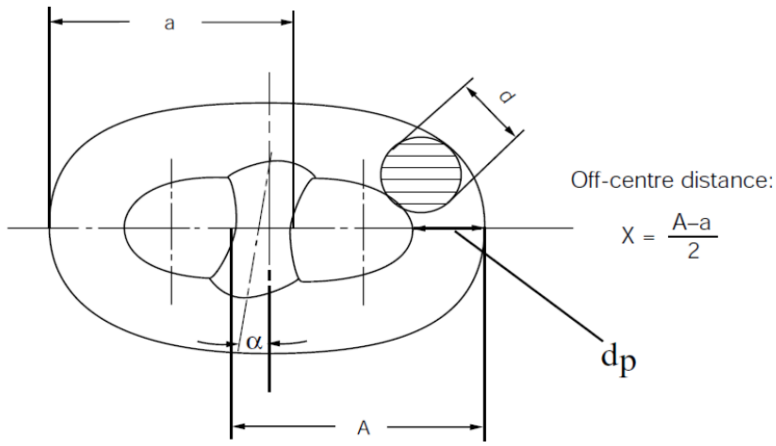
d) All other dimensions are subject to a manufacturing tolerance of ±2,5%, provided always that all parts of the final link parts of the chain cable fit together properly.

e) Studs must be located in the links centrally and at right angles to the sides of the link, although the studs at each end of any length may also be located off-centre to facilitate the insertion of the joining shackle. The following tolerances are regarded as being inherent in the method of manufacture and will not be objected to provided that the stud fits snugly and its ends lie practically flush against the inside of the link.

- Maximum off-centre distance "X" : 10% of the nominal diameter d
- Maximum deviation "a" from the 90°-position : 4°

The tolerances are to be measured in accordance with Figure 8.2.2.

Figure 8.2.2: Manufacturing tolerances



2.12.3 The following tolerances are applicable to accessories:

- nominal diameter : +5%, -0%
- other dimensions : ±2,5%

2.13. Welding of studs

2.13.1 The welding of studs is to be in accordance with an approved procedure subject to the following conditions:

- The studs must be of weldable steel; cf. 2.7.
- The studs are to be welded at one end only, i.e. opposite to the weldment of the link. The stud ends must fit the inside of the link without appreciable gap.
- The welds, preferably in the horizontal position, shall be executed by qualified welders using suitable welding consumables.
- All welds must be carried out before the final heat treatment of the chain cable.
- The welds must be free from defects liable to impair the proper use of the chain. Under-cuts, end craters and similar defects shall, where necessary be ground off.

LHR reserves the right to call for a procedure test for the welding of chain studs.

2.14. Proof and breaking load tests of finished chain cables

2.14.1 Finished chain cables are to be subjected to the proof load test and the breaking load test in the presence of the Surveyor, and shall not fracture or exhibit cracking. Special attention is to be given to the visual inspection of the flash-butt weld, if present. For this purpose, the chain cables must be free from paint and anti-corrosion media.

2.14.2 Each chain cable length (27,5 m) is to be subjected to a loading test at the proof load appropriate to the particular chain cable as shown in Table 8.2.6 and using an approved testing machine.

2.14.3 For the breaking load test, one sample comprising at least of three links is to be taken from every four lengths or fraction of chain cables and tested at the breaking loads shown in Table 8.2.6. The breaking load is to be maintained for a minimum of 30 seconds. The links concerned shall be made in a single manufacturing cycle together with the chain cable and must be welded and heat-treated together with it. Only after this may they be separated from the chain cable in the presence of the Surveyor.

2.14.4 If the tensile loading capacity of the testing machine is insufficient to apply the breaking load for chain cables of large diameter, another equivalent testing method shall be agreed with LHR.

2.15. Re-tests

2.15.1 Should a breaking load test fail, a further test specimen may be taken from the same length of chain cable and tested. The test shall be considered successful if the requirements are then satisfied.

If the re-test fails, the length of chain cable concerned shall be rejected. If the manufacturer so wishes, the remaining three lengths belonging to the unit test quantity may then be individually subjected to test at the breaking load. If one such test fails to meet the requirements, the entire unit test quantity is rejected.

2.15.2 Should a proof load test fail, the defective link(s) is (are) to be replaced, a local heat treatment to be carried out on the new link(s) and the proof load test is to be repeated. In addition, an investigation is to be made to identify the cause of the failure.

2.16. Mechanical tests on Grade LHR-2 and LHR-3 finished chain cables

2.16.1 For Grade LHR-2 and LHR-3 chain cables, mechanical test specimens required in Table 8.2.5 are to be taken from every four lengths in accordance with 2.16.2. For forged or cast chain cables where the batch size is less than four lengths, the sampling frequency will be by heat and heat treatment charge. Mechanical tests are to be carried out in the presence of the Surveyor. For the location of the test specimens see 2.4.4 and Figure 8.2.1. Testing is to follow 2.4.5 and 2.4.6. Retesting is to follow 2.4.7 and 2.4.8.

2.16.2 An additional link (or where the links are small, several links) for mechanical test specimen removal is (are) to be provided in a length of chain cable not containing the specimen for the breaking test. The specimen link must be manufactured and heat treated together with the length of chain cable.

2.16.3 The mechanical properties must be in accordance with the values indicated in Table 8.2.7.

Table 8.2.5:	**Number of mechanical test specimens for finished chain cables and accessories**				
Grade	**Manufacturing method**	**Condition of supply (1)**	**Number of test specimens**		
			Tensile test for base metal	**Charpy v-notch impact test**	
				Base metal	**Weldment**
LHR-1	Flush-butt welded	AW N	NR	NR	NR
LHR-2	Flush-butt welded Forged or Cast	AW N N	1 NR 1	3 NR 3 (2)	3 NR NA
LHR-3	Flush-butt welded	N NT QT	1	3	3
	Forged or Cast	N NT QT	1	3	NA

Notes:

1. AW = As Welded, N = Normalized, NT = Normalized and tempered, QT Quenched and tempered
2. For chain cables, Charpy V-notch impact test is not required
3. NR = Not Required, NA = Not Applicable

Table 8.2.6: Formulas for proof load and breaking load tests

Test	Grade 1	Grade 2	Grade 3
Proof load (kN)	$0{,}00686d^2 \cdot (44-0{,}08d)$	$0{,}00981d^2 \cdot (44-0{,}08d)$	$0{,}01373d^2 \cdot (44-0{,}08d)$
Breaking load (kN)	$0{,}00981d^2 \cdot (44-0{,}08d)$	$0{,}01373d^2 \cdot (44-0{,}08d)$	$0{,}01961d^2 \cdot (44-0{,}08d)$

Note: d= nominal diameter, in mm

Table 8.2.7: Mechanical properties of finished chain cables and accessories

Grade	R_{eH} N/mm^2 min.	R_m N/mm^2	A_5 % min.	Z % min.	Charpy V-notch impact test		
					Test temperature, in °C	Absorbed energy, in Joules min.	
						Base metal	Weldment
1	-	-	-	-	-	-	-
2	295	490-690	22	-	0	27	27
3	410	690 min.	17	40	0 (1)	60	50
					-20	35	27

Notes:

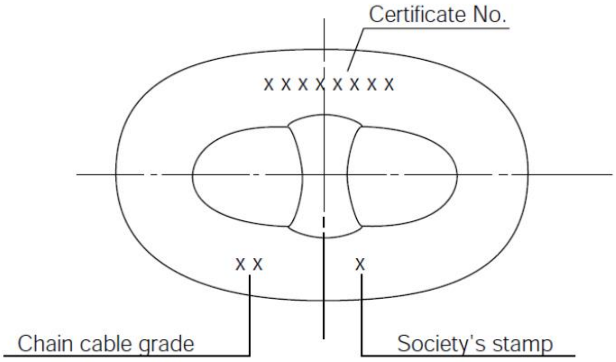
1. Testing is normally to be carried out at 0°C.

2.17. Marking

2.17.1 Chain cables which meet the requirements are to be stamped at both ends of each length at least with the following marks, cf. Figure 8.2.3:

1. Chain cable grade.
2. Certificate number.
3. LHR's stamp “LHR”.

Figure 8.2.3: Marking of chain cables



2.18. Proof load test of accessories

2.18.1 All accessories are to be subjected to the proof load test at the proof load specified for the corresponding chain given in Table 8.2.6, and in accordance with the provisions of 2.14, as appropriate.

2.19. Breaking load test of accessories

2.19.1 From each manufacturing batch (same accessory type, grade, size and heat treatment charge, but not necessarily representative of each heat of steel or individual purchase order) of 25 units or less of detachable links, shackles, swivels, swivel shackles, enlarged links and end links, and from each manufacturing batch of 50 units or less ofkenter shackles, one unit is to be subjected to the breaking load test at the break load specified for the corresponding chain given by Table 8.2.6 and in accordance with the provisions of 2.14, as appropriate. Parts tested in this way may not be put to further use. Enlarged links and end links need not be tested provided that they are manufactured and heat treated together with the chain cable.

2.19.2 LHR may waive the breaking load test if:

- the breaking load has been demonstrated on the occasion of the approval testing of parts of the same design, and
- the mechanical properties and impact energy of each manufacturing batch are proved, and
- the parts are subjected to suitable non-destructive testing.

2.19.3 Notwithstanding the above, the accessories which have been successfully tested at the prescribed breaking load appropriate to the chain may be used in service at the discretion of LHR where the accessories are manufactured with the following:

- the material having higher strength characteristics than those specified for the part in question (e.g. Grade LHR-3 material for accessories for Grade LHR-2 chain)
- or alternatively, the same grade material as the chain but with increased dimensions subject to the successful procedure tests that such accessories are so designed that the breaking strength is not less than 1,4 times the prescribed breaking load of the chain for which they are intended.

2.20. Mechanical properties and tests

2.20.1 Unless otherwise specified, the forging or casting must at least comply with the mechanical properties given in Table 8.2.7, when properly heat treated. For test sampling, forgings or castings of similar dimensions originating from the same heat treatment charge and the same heat of steel are to be combined into one test unit.

Mechanical tests are to be carried out in the presence of the Surveyor depending on the type and grade of material used. From each test unit, one tensile test specimen and three Charpy V-notch impact test specimens are to be taken in accordance with Table 6 and tested in accordance with Part 2, Chapter 2.

For the location of the test specimens see 2.4.4 and Figure 8.2.1. Testing is to follow 2.4.5 and 2.4.6. Retesting is to follow 2.4.7 and 2.4.8. Enlarged links and end links need not be tested provided that they are manufactured and heat treated together with the chain cable.

2.21. Marking

2.21.1 Accessories which meet the requirements are to be stamped as follows:

- Chain cable grade.
- Certificate number.
- LHR's stamp “LHR”.

2.22. Certification

2.22.1 Chain cables and accessories which meet the requirements are to be certified by LHR at least with the following items:

- Manufacturer's name
- Grade
- Heat Number
- Chemical composition (including total aluminum content)
- Nominal diameter/weight
- Proof/break loads
- Heat treatment
- Marks applied to chain or accessory
- Length (for chain)
- Mechanical properties, where applicable

2.23. Chafing Chain for Emergency Towing Arrangements

2.23.1 General

These requirements apply to the chafing chain for chafing gear of two types of Emergency Towing Arrangement (ETA) with specified safe working load (SWL) of 1000 kN (ETA1000) and 2000 kN (ETA 2000). Chafing chains other than those specified can be used subject to special agreement with LHR.

2.23.2 Approval of manufacturing

The chafing chain is to be manufactured by works approved by LHR according to 2.2 of this SECTION.

2.23.3 Materials

The materials used for the manufacture of the chafing chain are to satisfy the requirements of 2.3, 2.4, 2.5, 2.6 and 2.7 of this SECTION.

2.23.4 Design, manufacture, testing and certification of chafing chain

The chafing chain is to be designed, manufactured, tested and certified in accordance with the requirements of 2.8 to 2.22 of this SECTION.

The arrangement at the end connected to the strongpoint and the dimensions of the chafing chain are determined by the type of ETA. The other end of the chafing chain is to be fitted with a pear-shaped open link allowing connection to a shackle corresponding to the type of ETA and chain cable grade. A typical arrangement of this chain end is shown in Figure 8.2.4.

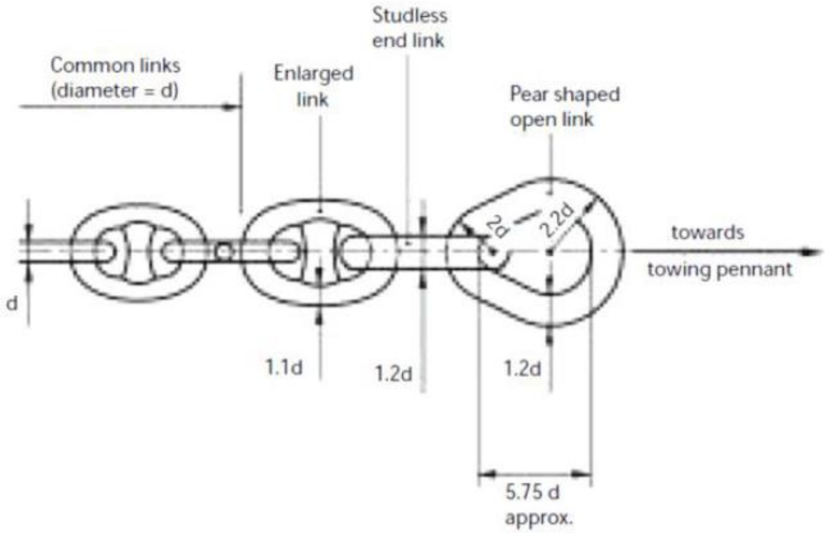
The common link is to be of stud link type Grade LHR-2 or LHR-3.

The chafing chain is to be able to withstand a breaking load not less than twice the SWL. For each type of ETA, the nominal diameter of common link for chafing chains is to comply with the value indicated in Table 8.2.8.

Table 8.2.8: Nominal diameter of common link for chafing chains

Type of ETA	Nominal Diameter of common link, d min.	
	Grade LHR-2	Grade LHR-3
ETA 1000	62 mm	52 mm
ETA 2000	90 mm	76 mm

Figure 8.2.4: Typical outboard chafing chain end



SECTION 3 Short link chain cables

3.1. General

3.1.1 Short link chain cables are to be manufactured by works approved by LHR and are to comply with the requirements of ISO/R 1834-1971, ISO/R 1835-1971 and ISO/R 1836-1971, as appropriate. Short link chain may be galvanized provided that the proof test requirements are accomplished after galvanizing is completed.

3.2. Testing and inspection

3.2.1 All chain cables having a diameter 12,5 mm or above, as well as steering chains, are to be tested at approved establishments according to the requirements stated in this Section; attention must also be given to any relevant statutory requirements of the National Authority of the country in which the ship or other marine structure is to be registered. The test loads for ISO Grade 40 cable are given in Table 8.3.1. Each length of chain is to be carefully examined after proof loading and is to be free from significant defects.

Table 8.3.1: Test loads for ISO Grade 40 chains

Nominal diameter dc (mm)	Proof load (kn)	Breaking load (kN)	Energy absorption factor[1] (kJ/m)
6,3	12,5	24,9	4,50
7,1	15,8	31,6	5,70
8	20,1	40,2	7,25
9	25,4	50,9	9,18
10	31,4	62,8	11,3
11,2	39,4	79,0	14,2
12,5	49,2	98,4	17,7
14	61,8	124	22,2
16	80,4	161	29,0
18	102	204	37,7
20	126	252	45,3
22,4	158	316	56,8
25	197	394	70,7
28	246	492	89,0

[1] Defined in ISO/R 1834-1971

32	322	644	116
36	407	814	147
40	503	1010	181

3.3. Marking and certification

3.3.1 All lengths of cable are to be stamped with the following marks:

- Inspector's mark, or the LHR mark "LHR" if the inspection has been performed under the LHR's supervision.
- Number of certificate.
- Manufacturer's mark.

3.3.2 The manufacturer of the chain cable is to supply the Surveyor with a certificate stating compliance with the appropriate ISO/R standards referred in 3.1.1.

3.3.3 In the event the test and inspection were not performed under LHR's supervision, the manufactures are to supply the Surveyor a certificate stating that the test and inspection requirements have been complied with at recognized facilities.

SECTION 4 Steel wire ropes

4.1. Manufacture and testing

4.1.1 Steel wire ropes are to be manufactured in works approved by LHR. The Surveyors are to be allowed access to all relevant parts of the works.

4.1.2 Steel wire ropes for stream wires, towlines and mooring lines are to be constructed as in Table

8.4.1. Other types of wire ropes will be specially considered by LHR on the basis of their suitability for the proposed application.

Table 8.4.1: Recommended rope construction

Purpose	Construction of rope			Construction of strands
	Strands	Wires	Core	
Stream wires, towlines and mooring lines	6	24	Fibre	15 over 9 over fibre core
	6	37	Fibre	18 over 12 over 6 over 1
	6	26	Fibre	10 over (5+5) over 5 over 1
	6	31	Fibre	12 over (6+6) over 6 over 1
	6	36	Fibre	14 over (7+7) over 7 over 1
	6	41	Fibre	16 over (8+8) over 8 over 1
	6	30	Fibre	18 over 12 over fibre core
Towlines and mooring lines used in association with mooring winches	6	31	7x7 wire rope	12 over (6+6) over 6 over 1
	6	36	7x7 wire rope	14 over (7+7) over 7 over 1
	6	41	7x7 wire rope	16 over (8+8) over 8 over 1

4.1.3 The tensile tests are to be performed in accordance with the requirements of Chapter 2. The specified tests are to be carried out by the manufacturer and, unless otherwise agreed, do not require to be witnessed by the Surveyor.

4.2. Steel wire for ropes

4.2.1 The wires are to be drawn from steel manufactured by the open hearth, electric or basic oxygen furnace. Other processes may be specially approved by LHR. The wires are to be of homogeneous quality, consistent strength and free from visual defects likely to impair the performance of the rope.

4.2.2 The tensile strength is generally to be within the ranges 1420 to 1570 N/mm², 1570 to 1770 N/mm² or 1770 to 1960 N/mm².

4.2.3 The wire is to be galvanized by a hot dip or electrolytic process to give a continuous uniform coating which may be any of the following grades:

– Grade 1-heavy coating, drawn after galvanizing

– Grade 2-heavy coating, finally galvanized

– Grade 3-light coating, drawn after galvanizing

4.2.4 Torsion and zinc coating tests are to be carried out on wire samples taken from a suitable length of the completed rope. After unstranding and straightening, six wires are to be subjected to both a torsion test and a wrap test for adhesion of coating. Moreover, tests to determine the mass and uniformity of the zinc coating are to be carried out.

4.2.5 As an alternative to test specimens taken as detailed in 4.2.4, tests may be carried out on the wire before the rope is stranded.

4.2.6 For the torsion test, the length of the sample is to be such as to allow a length between the grips of 100 times the wire diameter or 300 mm, whichever is less. The wire is to be twisted by causing one or both of the vices to be revolved until fracture occurs. The speed of testing is not to exceed, for a length equal to 100 times the diameter, that given in Table 8.4.2 (a tensile load not exceeding 2 per cent of the breaking load of the wire may be applied to keep the wire stretched). The wire is to withstand, without fracture on a length of 100 times the diameter of wire, the number of complete twists given in Table 8.4.3.

Table 8.4.2: Torsion test: speed of testing

Diameter of coated wire (mm)	Maximum speed of testing (twists per minute)
< 1,5	90
1,5 ≤ ... < 3,0	60
3,0 ≤ ... < 4,0	30

Table 8.4.3: Torsion test

Diameter of coated wire (mm)	Minimum number of twists			
	Grade 2		Grade 1 or 3	
	Tested before stranding	Tested after stranding	Tested before stranding	Tested after stranding
< 1,3	15	13	27	24
1,3 ≤ ... < 2,3	15	13	26	23
2,3 ≤ ... < 3,0	14	12	23	20
3,0 ≤ ... < 4,0	12	10	21	18

4.3. Zinc coating tests

4.3.1 The mass per unit area of the zinc coating is to be determined in accordance with a recognized standard and is to comply with the minimum values given in Table 8.4.4.

4.3.2

4.3.2 The uniformity of the zinc coating is to be determined by a dip test carried out in accordance with the requirements of a recognized standard.

Table 8.4.4: Zinc coating

Diameter of coated wire (mm)	Zinc coating, minimum (g/m^2)	
	Grade 1 or 2	Grade 3
0,40 ≤ ... < 0,50	75	40
0,50 ≤ ... < 0,60	90	50
0,60 ≤ ... < 0,80	110	60
0,80 ≤ ... < 1,00	130	70
1,00 ≤ ... < 1,20	150	80
1,20 ≤ ... < 1,50	165	90
1,50 ≤ ... < 1,90	180	100
1,90 ≤ ... < 2,50	205	110
2,50 ≤ ... < 3,20	230	125
3,20 ≤ ... < 4,00	250	135

4.3.3 The adhesion of the coating is to be tested by wrapping the wire round a cylindrical mandrel for 10 complete turns. The ratio between the diameter of the mandrel and that of the wire is to be as in

Table 8.4.5. After wrapping on the appropriate mandrel, the zinc coating is to have neither flaked nor cracked to such an extent that any zinc can be removed by rubbing with the bare fingers.

Table 8.4.5: Wrap test for adhesion of coating

Coating	Diameter of coated wire (mm)	Maximum ratio of mandrel to wire diameter
Grade 1 and 2	< 1,5	4
	≥ 1,5	6
Grade 3	< 1,5	2
	≥ 1,5	3

4.4. Tests of completed ropes

4.4.1 The breaking load is to be determined by testing to destruction a sample cut from the completed rope. This sample is to be of sufficient length to provide a clear test length of at least 36 times the rope diameter between the grips.

4.4.2 Not more than four-fifths of the nominal braking load may be applied quickly, and thereafter the load is to be applied slowly and steadily until the maximum load is obtained. Tests in which a breakage occurs adjacent to the grips may, at the option of the manufacturer, be neglected. The actual braking load is to be not less than that given in an appropriate national standard.

4.4.3 If facilities are not available for making a breaking test on completed ropes, consideration will be given to the acceptance of the determination of the breaking load by the summation of the tests of individual wires. A percentage deduction is to be applied to the calculated breaking load to compensate for laying up. This percentage is to be not less than that given in Table 8.4.6.

Table 8.4.6: Laying up deduction on the calculated breaking load

Construction of rope	Percentage deduction (see Note 1)
6x24	13
6x37	17,5

NOTE:

1. Percentage deductions for other constructions should either be in accordance with a recognized national standard or are to be established by breaking tests carried out on completed ropes.

4.4.4 Manufacturers desiring to adopt the method of testing described in 4.4.3 may be required to arrange for check breaking tests to be carried out on completed ropes.

4.5. Marking

4.5.1 All completed ropes are to be identified with attached labels detailing the rope type, diameter and length.

4.5.2 Where ropes have been tested in the presence of the Surveyor, each rope length is to be additionally identified with a lead seal stamped with the Surveyor's personal marking.

4.6. Certification

4.6.1 When tests have not been witnessed by the Surveyor, manufacturers are authorized to complete and issue LHR's printed certificate forms. These forms are available on request.

4.6.2 In cases where purchasers require tests to be witnessed by the Surveyor, certificates will be issued by LHR.

SECTION 5 Fiber ropes

5.1. Manufacture

5.1.1 Fiber ropes intended as mooring lines may be made of coir, hemp, manila or sisal, or may be composed of synthetic fibers. They may be three-strand (hawser laid), four-strand (shroud laid) or nine-strand (cable laid), but other constructions will be specially considered.

5.1.2 Each length of rope is to be manufactured from suitable material of good and consistent quality. Rope materials should, in general, comply with a recognized national standard.

5.1.3 Synthetic fiber ropes are to be suitable for the purpose intended and should comply with a recognized standard.

5.1.4 Weighting and loading matter is not to be added, and any lubricant is to be kept to a minimum. Any rot-proofing or water repellence treatment is not to be deleterious to the fibre nor is it to add to the weight or reduce the strength of the rope.

5.2. Tests of completed ropes

5.2.1 The breaking load is to be determined by testing to destruction a sample cut from the completed rope.

5.2.2 The minimum test length and the initial test load are to be as given in Table 8.5.1. After application of the initial load, the diameter and evenness of lay up of the sample are to be checked. The sample is then to be uniformly strained at the rate given in Table 8.5.1 until it breaks.

Table 8.5.1: Breaking load test

Material	Test length (mm) minimum	Initial load (%) (see Note 1)	Rate of straining (mm/min)
Natural fiber	1800	2	150 ± 50
Synthetic fiber	900	1	100 max

NOTE:

1. Percentage of specified minimum breaking load.

5.2.3 The actual breaking load is to be not less than that given in an appropriate national standard.

5.2.4 If the sample is held by grips and the break occurs within 150 mm of the grips, the test may be repeated, but not more than two tests may be made on any one coil.

5.2.5 Where difficulty is experienced in testing a sample of a completed synthetic fiber rope, LHR will consider alternative methods of testing.

5.3. Marking

5.3.1 Each coil of rope is to be identified with an attached label detailing the material, construction, diameter and length.

5.4. Certification

5.4.1 Printed certificates issued by the manufacturer or a competent governmental, municipal or similar responsible body will be accepted. These certificates are to give the breaking load, test length and rate of straining.

CHAPTER 9 General Welding Requirements

CONTENTS

SECTION 1 General

1.1 Scope

1.1.1 Part 2, Chapters 9, 10, 11 and 12 contain the rules to be applied to all welding work carried out on ship constructions or machinery installations which are subject to LHR's Rules for the Classification and Construction of Steel Vessels.

1.1.2 Where exception to the above-mentioned rules is requested, this is left upon the discretion of LHR on a case by case consideration.

1.1.3 The standards mentioned in these rules for welding constitute an integral part of them and require no special consent by LHR. The version current at the time when the welding rules are issued shall be applied. New editions of standards may be used in the absence of an expressed objection by LHR.

1.1.4 The application of other rules, guidelines or standards not specifically mentioned in the rules for welding, requires the agreement of LHR after special consideration.

1.1.5 Where the other rules, guidelines or standards mentioned in 1.1.3 and 1.1.4 contradict these rules for welding, the latter take precedence over all others.

1.2 Welding terminology

1.2.1 In order to ensure that the description and evaluation of welding processes and positions, test results, etc. are as clear and as uniform as possible, use shall be made of the terminology given in the relevant standards, e.g. EN 287-1, "Approval testing of welders - Fusion welding - Part 1: Steels" and ISO 4063-1978 "Welding, brazing, braze welding and soldering of metals - List of processes for symbolic representation on drawings"

1.2.2 The following welding processes are defined:

- metal-arc welding with covered electrode,
- flux-cored wire metal-arc welding without gas shield,
- submerged arc welding,
- metal-arc inert gas welding (MIG welding),
- metal-arc active gas welding (MAG welding),
- flux-cored wire metal-arc welding with active gas shield,
- tungsten inert gas arc welding (TIG welding),
- plasma arc welding,
- oxy-acetylene welding.

1.2.3 Welding positions for plates and pipes are as defined in EN 287-1.

1.3 Materials

1.3.1 Welding work may only be performed on materials of the proper weldability as it is ensured by the Carbon content, derived from the chemical analysis, or the Carbon Equivalent. Materials are to be selected in accordance with Part 2, Chapter 3 , Chapter 4, Chapter 5, Chapter 6, Chapter 7 and Chapter 8 which contain rules for materials. Their mechanical characteristics are to be attested by material test certificates, as required.

1.3.2 Where it is intended to weld materials whose properties are not described in the rules of materials, material standards or specifications are to be submitted to LHR for consideration and must, in doubtful cases, provide special proof of the weldability of the material concerned.

1.4 Welding consumables

1.4.1 Welding consumables are to be capable of producing a weld compatible with the parent metal and the operating conditions and are to undergo a qualification test covering the particular application concerned in accordance with the requirements of Part 2, Chapter 10.

1.4.2 Where qualification testing by LHR is not expressly stipulated, the test may be performed by a recognized testing authority independent of the filler manufacturer.

1.4.3 The welding workshop must ensure that only qualification tested consumables are used.

1.5 Inspections and tests

1.5.1 Inspections and tests are to be performed under the supervision of LHR on the manufacturer's or user's premises or, with the agreement of LHR, on the premises of a neutral testing body recognized by LHR (a Materials Testing Authority, a training and research establishment for welding technology or similar).

1.5.2 The testing machines and appliances used must conform to recognized standards and at least once a year they must be examined by a neutral testing authority. On demand, the relevant certificates are to be presented to LHR.

1.5.3 All tests and inspections are to be performed by established methods and by suitably trained and experienced personnel. LHR may demand proof of qualifications.

1.5.4 Detailed and complete reports shall be prepared for all inspections and tests and must be signed by the tester and the testing supervisor. These are to be submitted to LHR.

1.5.5 Test pieces and specimens together with test documentation are to be kept until all the inspections and tests are concluded by the confirmation of approval by LHR.

1.6 Welding workshop

1.6.1 The welding workshop is responsible to comply with these rules and with any other conditions which may be agreed or stated in the order specification or imposed in connection with approval. The welding workshop is further responsible for ensuring that the manufacturing conditions and qualitative characteristics (e.g. as these relate to welding consumables, auxiliary materials or welding processes) conform to those at the time of the approval tests. LHR does not guarantee that products, welding processes, etc. which have undergone an approval test or random testing during fabrication comply with these rules throughout the entire fabrication process. However, LHR inspections and tests do not relieve the welding workshop of any responsibility.

1.6.2 Welding workshops are to have at their disposal adequate and suitable facilities, equipment, machines and appliances to ensure that the welding work is to be properly performed. The workshop must also be provided with facilities for storing and drying filler materials, preheating and heat treatment equipment, test equipment, and appliances for weather protection.

1.6.3 Welders for manual or semi-automatic welding operations must possess adequate manual skill and experience and must have been qualification tested in accordance with SECTION 3. The scope of testing must cover the welding process, parent metal, filler metal and welding position relevant to the work to be undertaken.

1.6.4 Welding workshops are to have at least one expert welding supervisor who is responsible for the competent execution of the welding work.

SECTION 2 Welding procedure qualification tests of steels for hull construction and marine structures (IACS UR W28 Rev.2 (2012))

2.1 Scope

This document gives requirements for qualification tests of welding procedures intended for the use of weldable steels as specified in Part 2, Chapter 3, Chapter 4 and Chapter 5 for hull construction and marine structures.

For material and welding procedure for ships carrying liquefied gases in bulk and ships using gases or other low-flashpoint fuels see 2.6 in this SECTION.

This Section does not invalidate welding procedure qualification tests made and accepted by LHR before 1 July 2007 provided the welding procedure qualification tests are considered by LHR to meet the technical intent of this Section or have been qualified in accordance with the recognized standards such as ISO, EN, AWS, JIS or ASME.

2.2 General

2.2.1 Welding procedure qualification tests are intended to verify that a manufacturer is adequately qualified to perform welding operations using a particular procedure.

2.2.2 In general, welding procedure tests are to reflect fabrication conditions in respect to welding equipment, inside or outside fabrication, weld preparation, preheating and any post-weld heat treatment. It is to be the manufacturer’s responsibility to establish and document whether a procedure is suitable for the particular application.

2.2.3 For the welding procedure approval the welding procedure qualification test is to be carried out with satisfactory results. Welding procedure specifications are to refer to the test results achieved during welding procedure qualification testing.

2.2.4 Welding procedures qualified at a manufacturer are valid for welding in workshops under the same technical and quality management.

2.3 Preliminary welding procedure specification and welding procedure specification

2.3.1 A welding procedure specification (WPS) is to be prepared by the shipyard or manufacturer which intends to perform the welding procedure qualification test. This document is also referred to as a preliminary welding procedure specification (pWPS). The pWPS can be modified and amended during procedure tests as deemed necessary however it is to define all relevant variables as mentioned in the WPS (refer to ISO 15614 as amended or other recognized standards).

2.3.2 The shipyard or manufacturer is to submit to LHR a pWPS for review prior to the tests. In case that the test pieces welded according to the pWPS show unacceptable results the pWPS is to be adjusted by the shipyard or manufacturer. The new pWPS is to be prepared and the test pieces welded in accordance with the new pWPS.

2.3.3 The WPS is to be used as a basis for the production welds, and upon satisfactory completion of the tests based on the pWPS, LHR may approve it as a WPS. In case that a WPS is approved by LHR the approval range is to be in compliance with 2.5.

2.4 Qualification of welding procedures

2.4.1 General

a) Preparation and welding of test pieces are to be carried out in accordance with the pWPS and under the general condition of production welding which it represents.

b) Welding of the test assemblies and testing of test specimens are to be witnessed by the Surveyor.

c) If tack welds and/or start and stop points are a condition of the weld process they are to be used into the joint and are to be included in the test assemblies.

2.4.2 Butt weld

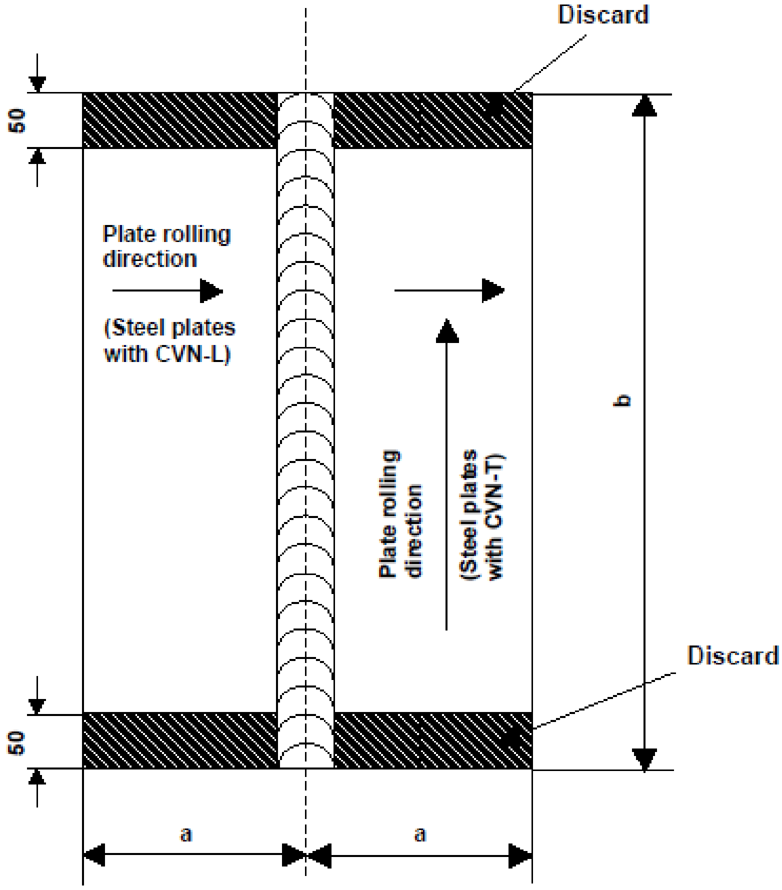
2.4.2.1 Assembly of test pieces

The test assembly is to be of a size sufficient to ensure a reasonable heat distribution and according to Figure 9.2.1 with the minimum dimensions:

- manual or semi-automatic welding:
  width = 2a, a = 3 x t, min 150 mm
  length b = 6 x t, in 350 mm

- automatic welding:
  width = 2a, a = 4 x t, min 200 mm
  length b = 1000 mm

Figure 9.2.1: Test assembly for butt weld



For hull structural steel plates impact tested in the longitudinal direction (CVN-L) in Part 2, Chapter 3, SECTION 3, the butt weld of the test piece is perpendicular to the rolling direction of the two plates.

For high strength quenched and tempered steel plates impact tested in the transverse direction (CVN-T) in Part 2, Chapter 3, SECTION 9, the butt weld of the test piece is parallel to the rolling direction of the two plates.

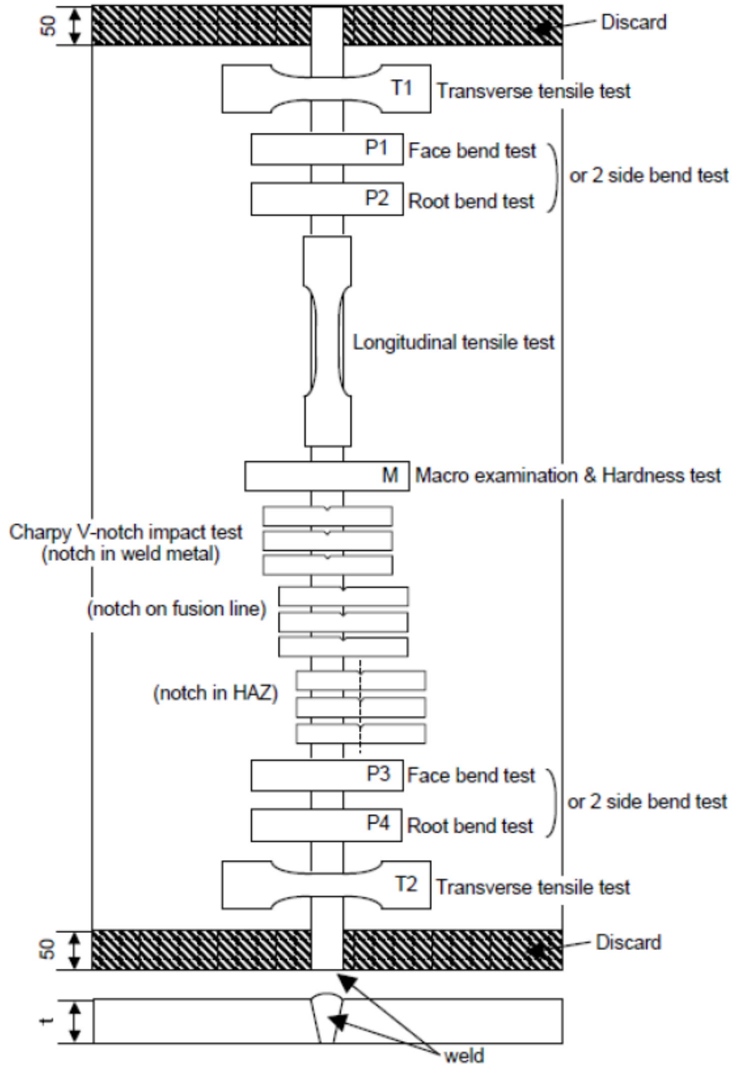
2.4.2.2 Examinations and tests

Test assemblies are to be examined non-destructively and destructively in accordance with the following and Figure 9.2.2:

- Visual testing	100%
- Surface crack detection	100% (dye penetrant testing or magnetic particle testing)
- Radiographic or Ultrasonic testing	100%
- Transverse tensile test	two specimens as per 2.4.2.2(B)
- Longitudinal tensile test	required as per 2.4.2.2(C)
- Transverse bend test	four specimens as per 2.4.2.2(D)
- Charpy V-notch impact test	required as per 2.4.2.2(E)

- Macro examination — one specimen as per 2.4.2.2(F)
- Hardness test — required as per 2.4.2.2(G)

Figure 9.2.2: Test sampling



A. Non-destructive testing

Test assemblies are to be examined by visual and by non-destructive testing prior to the cutting of test specimen. In case that any post-weld heat treatment is required or specified, non-destructive testing is to be performed after heat treatment. For steels according to Part 2, Chapter 3, SECTION 9, with specified minimum yield strength of 420 N/mm^2 and above the non-destructive testing is to be delayed for a minimum of 48 hours, unless heat treatment has been carried out. NDT procedures are to be agreed with the LHR. Imperfections detected by visual or non-destructive testing are to be assessed in accordance with ISO 5817, class B, as amended, except for excess weld metal and excess of penetration for which the level C applies.

B. Transverse tensile test

The testing is to be carried out in accordance with Part 2, Chapter 2, SECTION 3, 3.1. The tensile strength recorded for each specimen is not to be less than the minimum required for the base metal. When butt welds are made between plates of different grades, the tensile strength to be obtained on the welded assembly is to be in accordance with the requirements relating to the steel grade having lower strength.

C. Longitudinal tensile test

Longitudinal tensile test of deposited weld metal taken lengthways from the weld is required for cases where the welding consumable is not approved by the LHR.

The testing is to be carried out in accordance with Part 2, Chapter 2, SECTION 3, 3.1. The tensile properties recorded for each specimen are not to be less than the minimum required for the approval of the appropriate grade of consumable.

Where more than one welding process or type of consumable has been used to make the test weld, test specimens are to be taken from the area of the weld where each was used with the exception of those processes or consumables used to make the first weld run or root deposit.

D. Bend test

Transverse bend tests for butt joints are to be in accordance with Part 2, Chapter 2, SECTION 6. The mandrel diameter to thickness ratio (i.e. D/t) is to be that specified for the welding consumable (Part 2, Chapter 10, SECTIONS 1-8) approvals + 1.

The bending angle is to be 180°. After testing, the test specimens are not to reveal any open defects in any direction greater than 3 mm. Defects appearing at the corners of a test specimen during testing are to be investigated case by case.

Two root and two face bend specimens are to be tested. For thickness 12 mm and over, four side bend specimens may alternatively be tested.

For butt joints in heterogeneous steel plates, face and root longitudinal bend test specimens may be used instead of the transverse bend test specimens.

E. Impact test

(i) Normal and higher strength hull structural steels according to Part 2, Chapter 3, SECTION 3. The positions of specimens are to be in accordance with these requirements. Dimensions and testing are to be in accordance with the requirements of Part 2, Chapter 2, SECTION 4.

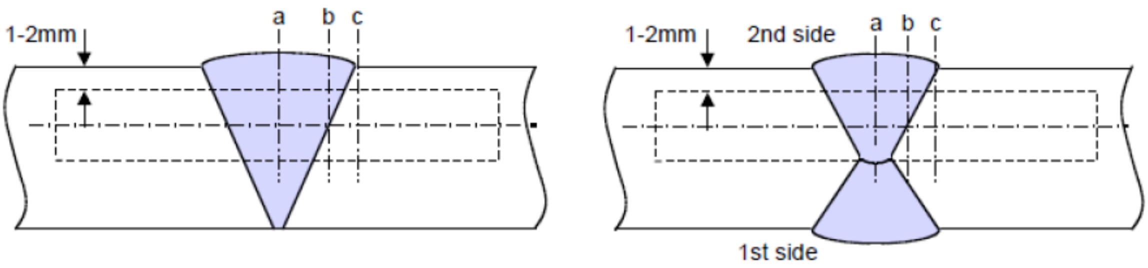
Test specimen with Charpy-V-notch are to be used and sampled from 1 to 2 mm below the surface of the base metal, transverse to the weld and on the side containing the last weld run.

V-notch specimens are located in the butt-welded joint as indicated in Figure 9.2.3 and Figure 9.2.4 and the V-notch is to be cut perpendicular to the surface of the weld.

Test temperature and absorbed energy are to be in accordance with Table 9.2.1.

Figure 9.2.3: Locations of V-notch for butt weld of normal heat input (heat input ≤ 50 kJ/cm)

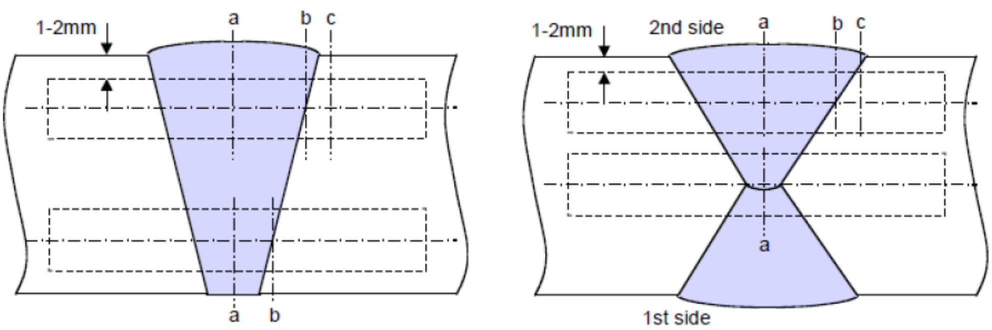
(a) t ≤ 50 mm (1)



NOTE:

For one side single run welding over 20mm notch location “a” is to be added on root side.

(b) t > 50mm



Notch locations:

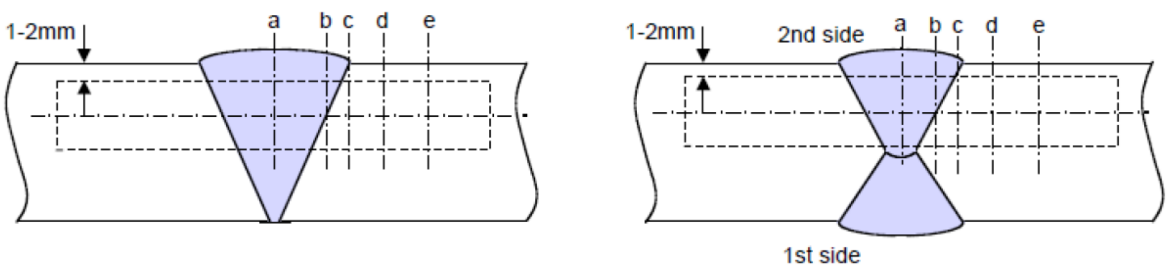
center of weld “WM”

on fusion line “FL”

in HAZ, 2 mm from fusion line

Figure 9.2.4: Locations of V-notch for butt weld of high heat input (heat input > 50kJ/cm)

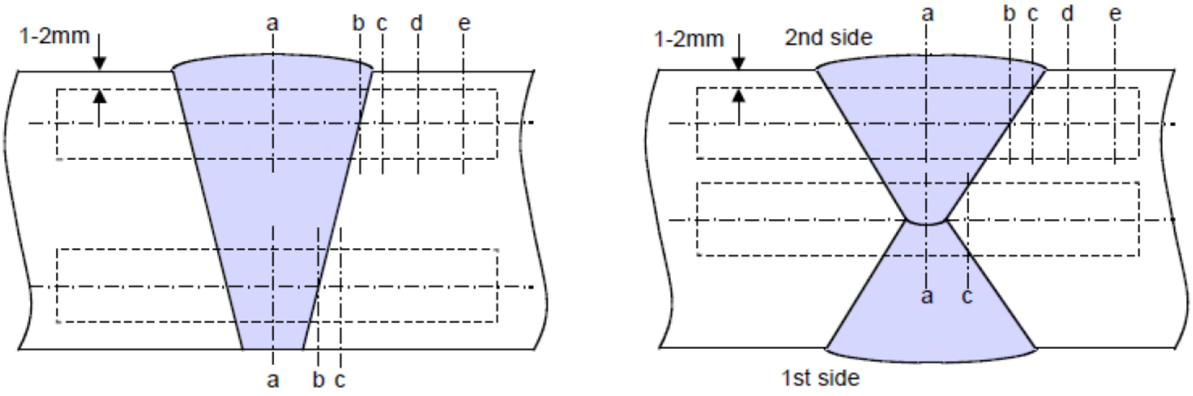
(a) t ≤ 50 mm [(1)]



NOTE:

1. For one side single run welding over 20mm notch locations “a”, “b” and “c” are to be added on root side.

(b) t > 50 mm



Notch locations:

a: center of weld "WM"

b: on fusion line "FL"

c: in HAZ, 2 mm from fusion line

d: in HAZ, 5 mm from fusion line

e: in HAZ, 10 mm from fusion line in case of heat input > 200 kJ/cm

<table>
<tr><th colspan="5">Table 9.2.1: Impact test requirements for butt joints (t ≤ 50 mm)(1), (2)</th></tr>
<tr><td rowspan="3">Grade of steel</td><td rowspan="3">Testing Temperature (°C)</td><td colspan="3">Value of minimum average absorbed energy (J)</td></tr>
<tr><td colspan="2">For manually or semi-automatically welded joints</td><td rowspan="2">For automatically welded joints</td></tr>
<tr><td>Downhand, Horizontal, Overhead</td><td>Vertical upward, Vertical downward</td></tr>
<tr><td>A(3)</td><td>20</td><td rowspan="11">47</td><td rowspan="7">34</td><td rowspan="7">34</td></tr>
<tr><td>B(3), D</td><td>0</td></tr>
<tr><td>E</td><td>-20</td></tr>
<tr><td>A32, A36</td><td>20</td></tr>
<tr><td>D32, D36</td><td>0</td></tr>
<tr><td>E32, E36</td><td>-20</td></tr>
<tr><td>F32, F36</td><td>-40</td></tr>
<tr><td>A40</td><td>20</td><td rowspan="4">39</td><td rowspan="4">39</td></tr>
<tr><td>D40</td><td>0</td></tr>
<tr><td>E40</td><td>-20</td></tr>
<tr><td>F40</td><td>-40</td></tr>
</table>

Note:

1. For thickness above 50 mm impact test requirements are to be agreed by LHR.

2. These requirements are to apply to test piece of which butt weld is perpendicular to the rolling direction of the plates.

3. For Grade A and B steels average absorbed energy on fusion line and in heat affected zone is to be minimum 27 J.

When butt welds are made between different steel grades/types, the test specimens are to be taken from the side of the joint with lower toughness of steel. Temperature and absorbed energy results are to be in accordance with the requirements for the lower toughness steel.

Where more than one welding process or consumable has been used to make the test weld, impact test specimens are to be taken from the respective areas where each was employed. This is not to apply to the process or consumables used solely to make the first weld run or root deposit. The testing of sub - size specimen is to be in accordance with Part 2, Chapter 2, SECTION 4, 4.2.

(ii) High strength quenched and tempered steels according to Part 2, Chapter 3, SECTION 9.

Impact test is to be performed as described in the above (i). V-notch specimens are located in the butt welded joint as indicated in Figure 9.2.3 and Figure 9.2.4 and the V-notch is to be cut perpendicular to the surface of the weld.

Test temperature and absorbed energy are to be in accordance with the requirements of base metal as specified in Part 2, Chapter 3, SECTION 9.

(iii) Weldable C and C-Mn hull steel castings and forgings according to Part 2, Chapter 5, SECTION 2 and Part 2, Chapter 4, SECTION 2.

For base metal with specified impact values test temperature and absorbed energy are to be in accordance with the requirements of the base metal to be welded.

F. Macro examination

The test specimens are to be prepared and etched on one side to clearly reveal the weld metal, the fusion line and the heat affected zone. Macro examination is to include about 10 mm unaffected base metal. The examination is to reveal a regular weld profile, through fusion between adjacent layers of weld and base metal and the absence of defects such as cracks, lack of fusion etc.

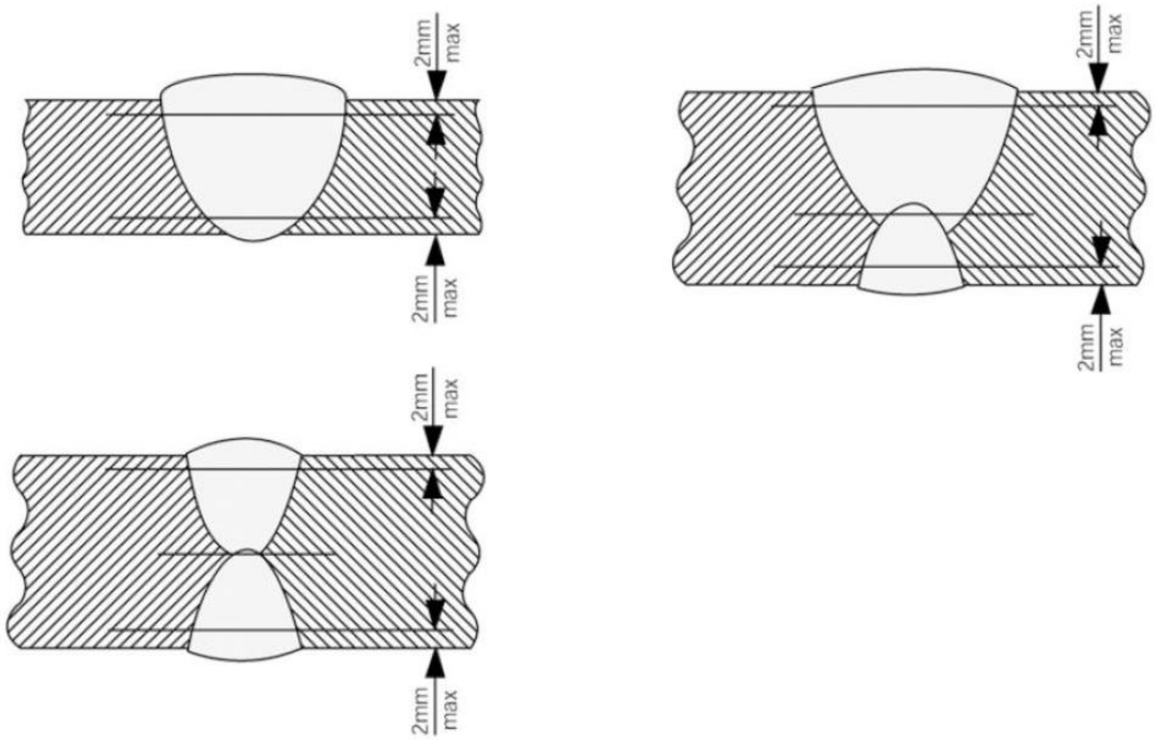
G. Hardness test

Hardness test is required for steels with specified minimum yield strength of $R_{eH} \geq 355$ N/mm². The Vickers method HV 10 is normally to be used. The indentations are to be made in the weld metal, the heat affected zone and the base metal measuring and recording the hardness values. At least two rows of indentations are to be carried out in accordance with Figure 9.2.5 and Figure 9.2.6.

For each row of indentations there is to be a minimum of 3 individual indentations in the weld metal, the heat affected zones (both sides) and the base metal (both sides). A typical example is shown in Figures 9.2.6, 9.2.9 and 9.2.10. The results from the hardness test are not to exceed the following:

- Steel with a specified minimum yield strength $R_{eH} \leq 420$ N/mm² ;350 HV 10
- Steel with a specified minimum yield strength 420 N/mm² < $R_{eH} \leq 690$ N/mm² ;420 HV 10

Figure 9.2.5: Examples of hardness test with rows of indentations (R) in butt welds



Recommended distances *l* between indentations for hardness test in the heat affected zone

Vickers hardness Symbol	Distance between indentations *l* (mm)
HV 10	1

The distance of any indentation from the previous indentation is not to be less than the value allowed for the previous indentation by ISO 6507/1 as amended.

Figure 9.2.6: Example showing the position of the indentations for hardness test in the weld metal, the heat affected zone and the base metal of a butt weld (dimensions in mm)

2.4.3 Fillet welds

2.4.3.1 Assembly of test pieces

The test assembly is to be of a size sufficient to ensure a reasonable heat distribution and according to Figure 9.2.7 with the minimum dimensions:

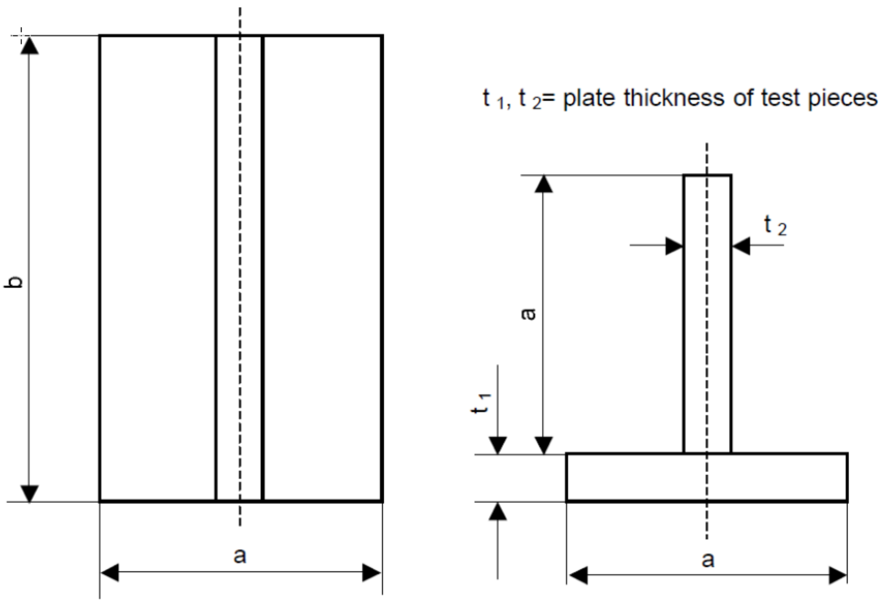
- manual and semi-automatic welding:

  width a = 3 x t, min. 150 mm
  length b = 6 x t, min. 350 mm

- automatic welding:

  width a = 3 x t, min. 150 mm
  length b = 1000 mm

Figure 9.2.7: Test assembly for fillet weld



2.4.3.2 Welding of test pieces

The test assembly is welded on one side only. For single run manual and semi-automatic welding, a stop/restart is to be included in the test length and its position is to be clearly marked for subsequent examination.

2.4.3.3 Examinations and tests

Test assemblies are to be examined non-destructively and destructively in accordance with the following:

- Visual testing	100%
- Surface crack detection	100%
	(dye penetrant testing or magnetic particle testing)
- Macro examination	two specimen as per 2.4.3.3(b)
- Hardness test	required as per 2.4.3.3(c)
- Fracture test	required as per 2.4.3.3(d)

a) Non-destructive testing

Test assemblies are to be examined by visual and by non-destructive testing prior to the cutting of test specimen. In case that any post-weld heat treatment is required or specified non-destructive testing is to be performed after heat treatment. For steels according to Part 2, Chapter 3, SECTION 9 with specified minimum yield strength of 420 N/mm² and above the non-destructive testing is to be delayed for a minimum of 48 hours, unless heat treatment has been carried out. NDT procedures are to be agreed with LHR.

Imperfections detected by visual or non-destructive testing are to be assessed in accordance with ISO 5817, class B, as amended, except for excess convexity and excess throat thickness for which the level C applies.

b) Macro examination

The test specimens are to be prepared and etched on one side to clearly reveal the weld metal, fusion line, root penetration and the heat affected zone. Macro examination is to include about 10 mm unaffected base metal. The examination is to reveal a regular weld profile, through fusion between adjacent layers of weld and base metal, sufficient root penetration and the absence of defects such as cracks, lack of fusion etc.

c) Hardness test

Hardness test is required for steels with a specified minimum yield strength of $R_{eH} \geq 355$ N/mm². The Vickers method HV 10 is normally to be used. The indentations are to be made in the weld metal, the heat affected zone and the base metal measuring and recording the hardness values. At least two rows of indentations are to be carried out in accordance with Figure 9.2.8, Figure 9.2.9 and Figure 9.2.10.

For each row of indentations there is to be a minimum of 3 individual indentations in the weld metal, the heat affected zone (both sides) and the base metal (both sides). The results from the hardness test are not to exceed the following:

- Steel with a specified minimum yield strength $R_{eH} \leq 420$ N/mm² ;350 HV 10
- Steel with a specified minimum yield strength 420 N/mm² < $R_{eH} \leq 690$ N/mm² ;420 HV 10

Figure 9.2.8: Examples of hardness test with row indentation (R) in fillet welds and in T-joint welds

(a) Fillet weld (b) T-joint weld

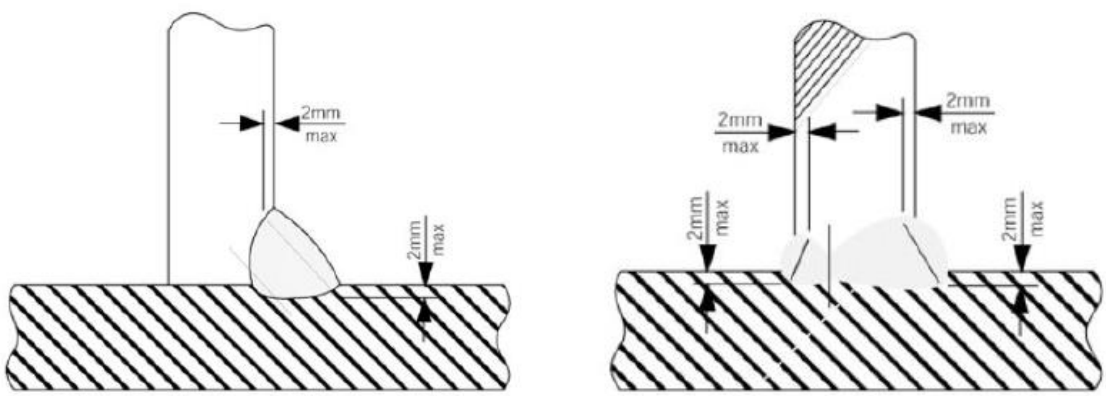


Figure 9.2.9: Example showing the position of the indentations for hardness test in the weld metal, the heat affected zone and the base metal of a fillet weld (dimensions in mm)

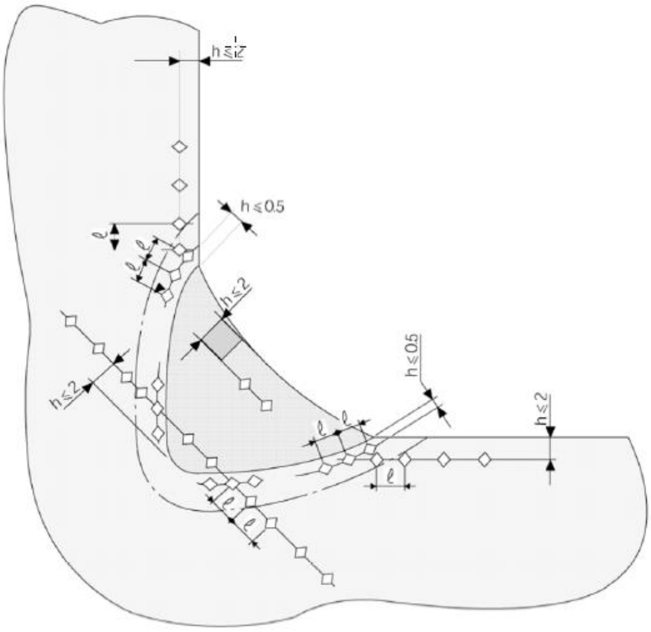
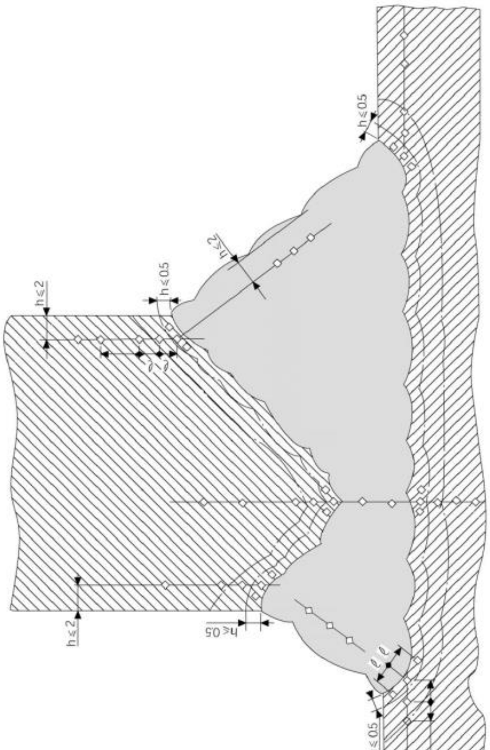


Figure 9.2.10: Example showing the position of the indentations for hardness test on the weld metal, the heat affected zone and the base metal of a T-joint weld (dimensions in mm)



d) Fracture test

The fracture test is to be performed by folding the upright plate onto the through plate. Evaluation is to concentrate on cracks, porosity and pores, inclusions, lack of fusion and incomplete penetration. Imperfection that are detected is to be assessed in accordance with ISO 5817, class B, as amended.

2.4.4 Re-testing

a) If the test piece fails to comply with any of the requirements for visual or non-destructive testing one further test piece is to be welded and subjected to the same examination. If this additional test piece does not comply with the relevant requirements, the pWPS is to be regarded as not capable of complying with the requirements without modification.

b) If any test specimens fail to comply with the relevant requirements for destructive testing due to weld imperfections only, two further test specimens are to be obtained for each one that failed. These specimens can be taken from the same test piece if there is sufficient material available or from a new test piece, and are to be subjected to the same test. If either of these additional test specimens does not comply with the relevant requirements, the pWPS is to be regarded as not capable of complying with the requirements without modification.

c) If a tensile test specimen fails to meet the requirements, the re-testing is to be in accordance with Part 2, Chapter 2, SECTION 3, 3.1.11.

d) If there is a single hardness value above the maximum values allowed, additional hardness tests are to be carried out (on the reverse of the specimen or after sufficient grinding of the tested surface). None of the additional hardness values is to exceed the maximum hardness values required.

e) The re-testing of Charpy impact specimens are to be carried out in accordance with Part 2, Chapter 2, SECTION 4, 4.4.

f) Where there is insufficient welded assembly remaining to provide additional test specimens, a further assembly is to be welded using the same procedure to provide the additional specimens.

2.4.5 Test record

a) Welding conditions for test assemblies and test results are to be recorded in welding procedure test record. Forms of welding procedure test records can be taken from LHR's rules or from relevant standards.

b) A statement of the results of assessing each test piece, including repeat tests, is to be made for each welding procedure test. The relevant items listed for the WPS of these requirements are to be included.

c) A statement that the test piece was made according to the particular welding procedure is to be signed by the Surveyor witnessing the test and is to include the LHR's identification.

2.5 Range of approval

2.5.1 General

a) All the conditions of validity stated below are to be met independently of each other.

b) Changes outside of the ranges specified are to require a new welding procedure test.

c) Shop primers may have an influence on the quality of fillet welds and is to be considered. Welding procedure qualification with shop primer will qualify those without but not vice versa.

2.5.2 Base metal

i. Normal and higher strength hull structural steels according to Part 2, Chapter 3, SECTION 3.

a) For each strength level, welding procedures are considered applicable to the same and lower toughness grades as that tested.
b) For each toughness grade, welding procedures are considered applicable to the same and two lower strength levels as that tested.
c) For applying the above (a) and (b) to high heat input processes above 50kJ/cm, e.g. the two-run technique with either submerged arc or gas shielded metal arc welding, electro slag and electro gas welding, welding procedure is applicable to that toughness grade tested and one strength level below.

Where steels used for construction are supplied from different delivery conditions from those tested LHR may require additional tests.

ii. High strength quenched and tempered steels according to Part 2, Chapter 3, SECTION 9.

a) For each strength level, welding procedures are considered applicable to the same and lower toughness grades as that tested.
b) For each toughness grade, welding procedures are considered applicable to the same and one lower strength level as that tested.
c) The approval of quenched and tempered steels does not quality thermo-mechanically rolled steels (TMCP steels) and vice versa.

iii. Weldable C and C-Mn hull steel forgings according to Part 2, Chapter 5, SECTION 2.

a) Welding procedures are considered applicable to the same and lower strength level as that tested.
b) The approval of quenched and tempered hull steel forgings does not quality other delivery conditions and vice versa.

iv. Weldable C and C-Mn hull steel castings according to Part 2, Chapter 4, SECTION 2.

a) Welding procedures are considered applicable to the same and lower strength level as that tested.
b) The approval of quenched and tempered hull steel castings does not quality other delivery conditions and vice versa.

2.5.3 Thickness

a) The qualification of a WPS carried out on a test assembly of thickness t is valid for the thickness range given in Table 9.2.2.

Table 9.2.2: Approval range of thickness for butt and T-joint welds and fillet welds

Thickness of test piece t [(1)] (mm)	Range of approval	
	Butt and T-joint welds with single run or single run from both sides	Butt and T-joint welds with multi-run and fillet welds [(2)]
3 < t ≤ 12	0.7 x t to 1,1 x t	3 to 2 x t
12 < t ≤ 100	0.7 x t to 1,1 x t [(3)]	0,5 x t to 2 x t (Max. 150)

NOTE:

1. For multi process procedures, the recorded thickness contribution of each process is to be used as a basis for the range of approval for the individual welding process.

2. For fillet welds, the range of approval is to be applied to both base metals.

3. For high heat input processes over 50kJ/cm, the upper limit of range of approval is to be 1,0 x t.

b) In addition to the requirements of Table 9.2.2, the range of approval of throat thickness “a” for fillet welds is to be as follows:

- Single run ; “0,75 x a” to “1,5 x a”
- Multi-run ; as for butt welds with multi-run (i.e. a=t)

c) For the vertical-down welding, the test piece thickness “t” is always taken as the upper limit of the range of application.

d) For unequal plate thickness of butt welds the lesser thickness is ruling dimension.

e) Notwithstanding the above, the approval of maximum thickness of base metal for any technique is to be restricted to the thickness of test assembly if three of the hardness values in the heat affected zone are found to be within 25 HV of the maximum permitted, as stated 2.4.2.2(G) and 2.4.3.3(c).

2.5.4 Welding position

Approval for a test made in any position is restricted to that position (Figure 9.2.11 and Figure 9.2.12). To qualify a range of positions, test assemblies are to be welded for highest heat input position and lowest heat input position and all applicable tests are to be made on those assemblies.

Figure 9.2.11: Welding positions according to ISO Standard

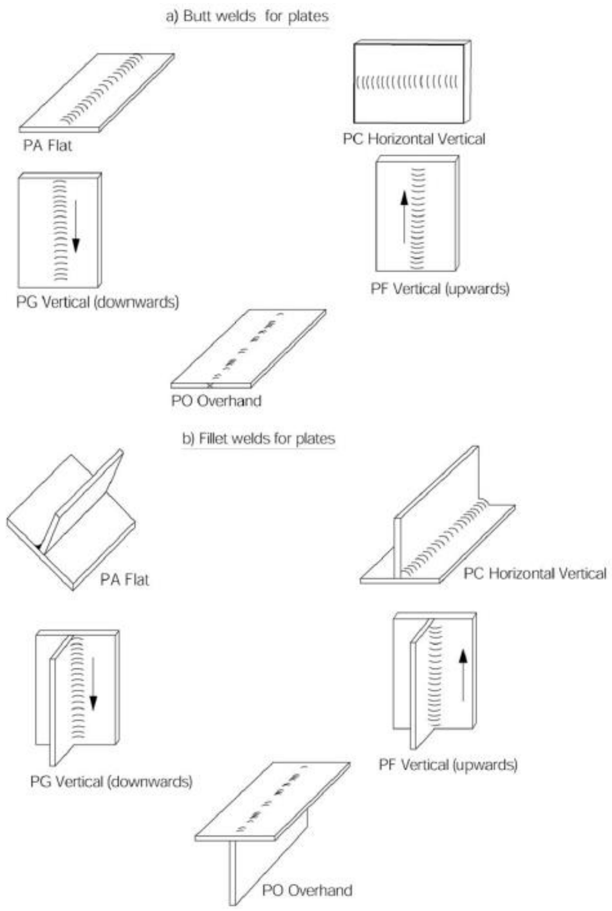
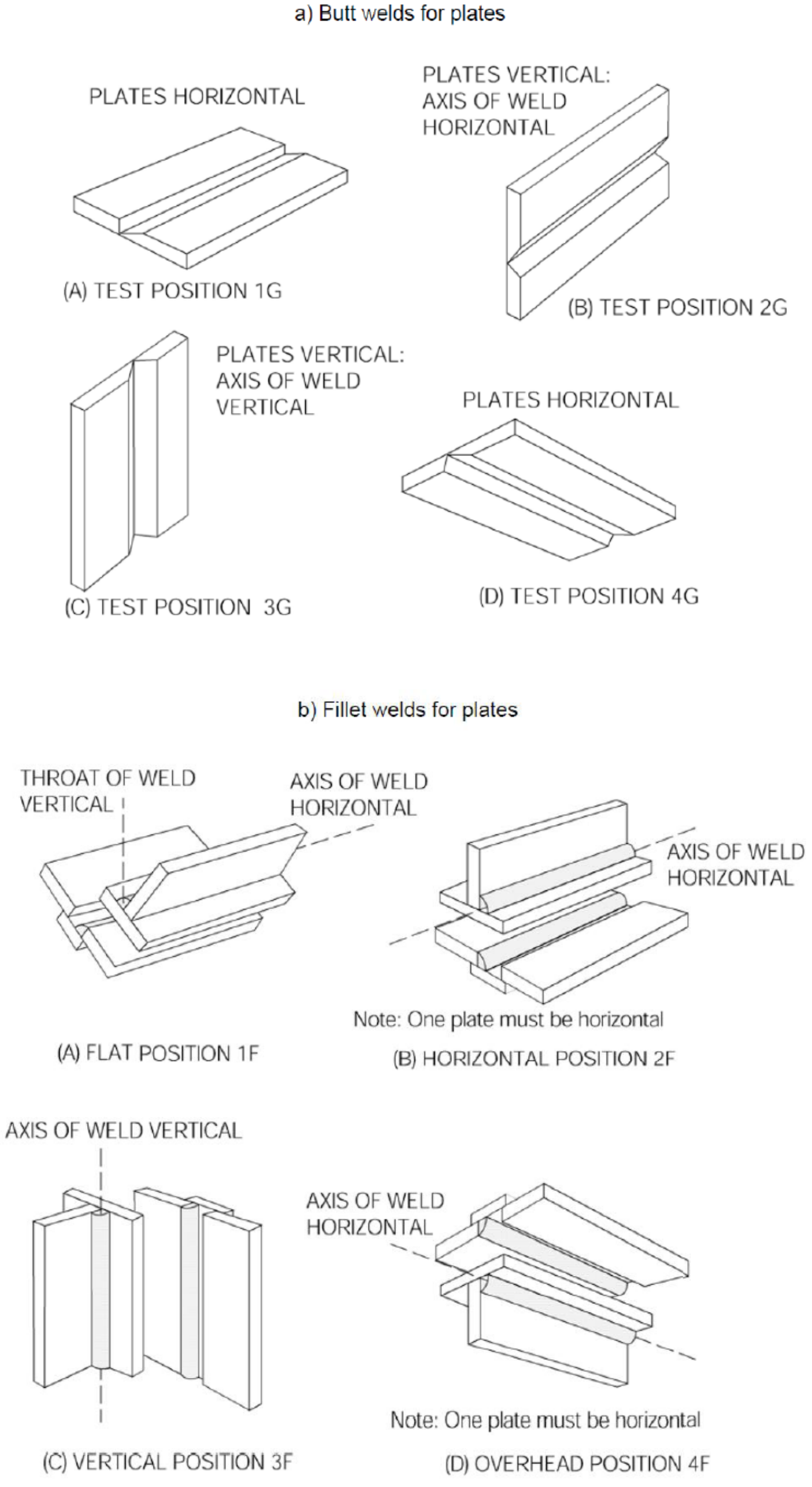


Figure 9.2.12: Welding positions according to AWS-Code



2.5.5 Welding process

a) The approval is only valid for the welding process(es) used in the welding procedure test. It is not permitted to change from a multi-run to a single run.

b) For multi-process procedures the welding procedure approval may be carried out with separate welding procedure tests for each welding process. It is also possible to make the welding procedure test as a multi-process procedure test. The approval of such a test is only valid for the process sequence carried out during the multi-process procedure test.

2.5.6 Welding consumable

Except high heat input processes over 50kJ/cm, welding consumables cover other approved welding consumables having the same grade mark including all suffixes specified in Part 2, Chapter 10, SECTIONS 1-7 and Part 2, Chapter 10, SECTION 8 with the welding consumable tested.

2.5.7 Heat input

a) The upper limit of heat input approved is 25% greater than that used in welding the test piece or 55kJ/cm whichever is smaller, except that the upper limit is 10% greater than that for high heat input processes over 50kJ/cm.

b) The lower limit of heat input approved is 25% lower than that used in welding the test piece. 2.5.8

2.5.8 Preheating and interpass temperature

a) The minimum preheating temperature is not to be less than that used in the qualification test.

b) The maximum interpass temperature is not to be higher than that used in the qualification test.

2.5.9 Post-weld heat treatment

The heat treatment used in the qualification test is to be maintained during manufacture. Holding time may be adjusted as a function of thickness.

2.5.10 Type of joint

(i) Range of approval depending on type of welded joints for test assembly is to be specified in Table 9.2.3.

(ii) A qualification test performed on a butt weld will also qualify for fillet welding within the thickness ranges specified for fillet welds specified in 2.5.3 above.

Table 9.2.3: Range of approval for type of welded joint

Type of welded joint for test assembly				Range of approval
Butt welding	One side	With backing	A	A, C
		Without backing	B	A, B, C, D
	Both side	With gouging	C	C
		Without gouging	D	C, D

2.5.11 Other variables

The range of approval relating to other variables may be taken according to LHR requirements.

2.6 Material and welding for ships carrying liquefied gases in bulk and ships using gases or other low-flashpoint fuels (IACS UR W1 Rev.4 (2021))

2.6.1 This document gives additional requirements to the ones prescribed in the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC Code) or International Code of Safety for Ships using Gases or other low-flashpoint Fuels (IGF Code).

2.6.2 The manufacture, testing, inspection and documentation shall be in accordance with the general practice of LHR.

2.6.3 In addition to IGC Code Table 6.1 or IGF Code Table 7.1 for design temperature not lower than 0°C, the following applies:

Table 9.2.4: Plates, pipes (seamless and welded), sections and forgings for cargo tanks, fuel tanks and process pressure vessels for design temperatures not lower than 0°C.

CHARPY V-NOTCH IMPACT TEST REQUIREMENTS		
TEST TEMPERATURE	Thickness t (mm)	Test temperature (°C)
	$40 < t \leq 50$ (1)	-20 (2)
	$40 < t \leq 50$ (1)	-30 (3)

Notes:

1. A further set of impact test at mid thickness for products with t > 40 mm is required except rolled steels specified in Part 2, Chapter 3, SECTION 3 or Part 2, Chapter 3, SECTION 9.
2. Applies to type C independent tanks and process pressure vessels. In addition, post-weld stress relief heat treatment shall be performed. Exemption to post-weld stress relief heat treatment based on alternative approach (e.g. Engineering Critical Assessment) shall be approved by LHR or shall be to recognized standards.
3. Applies to cargo tank or fuel tank other than type C.

2.6.4 In addition to IGC Code Table 6.2 or IGF Code Table 7.2, the following applies:

Table 9.2.5: Plates, sections and forgings for cargo tanks, fuel tanks, secondary barriers and process pressure vessels for design temperatures below 0°C and strictly down to -10°C

CHARPY V-NOTCH IMPACT TEST REQUIREMENTS		
TEST TEMPERATURE	Thickness t (mm)	Test temperature (°C)
	40 < t ≤ 50 (1)	5°C below design temperature or -20°C, whichever is lower (2)
	40 < t ≤ 45 (1)	25 °C below design temperature (3)
	45 < t ≤ 50 (1)	30 °C below design temperature (3)

Notes:

1. A further set of impact test at mid thickness for products with t > 40 mm is required except rolled steels specified in Part 2, Chapter 3, SECTION 3 or Part 2, Chapter 3, SECTION 9.
2. Applies to type C independent tanks and process pressure vessels. In addition, post-weld stress relief heat treatment shall be performed. Exemption to post-weld stress relief heat treatment based on alternative approach (e.g. Engineering Critical Assessment) shall be approved by LHR or shall be to recognized standards.
3. Applies to cargo tank or fuel tank other than type C.

Table 9.2.6: Plates, sections and forgings for cargo tanks, fuel tanks, secondary barriers and process pressure vessels for design temperatures below -10°C and down to -55°C

	Thickness t (mm)	Test temperature (°C)
TEST TEMPERATURE	40 < t ≤ 50 (1)	5°C below design temperature or -20°C, whichever is lower (2)
	40 < t ≤ 45 (1)	25 °C below design temperature (3)
	45 < t ≤ 50 (1)	30 °C below design temperature (3)

Notes:

1. A further set of impact test at mid thickness for products with t > 40 mm is required except rolled steels specified in Part 2, Chapter 3, SECTION 3 or Part 2, Chapter 3, SECTION 9.
2. IGC code section 6.6.2.2 applies with regards to post-weld stress relief heat treatment. Exemption to post-weld stress relief heat treatment based on alternative approach (e.g. Engineering Critical Assessment) shall be approved by LHR or shall be to recognized standards.
3. Applies to cargo tank or fuel tank other than type C.

2.6.5 In addition to IGC Code Table 6.3 or IGF Code Table 7.3, the following applies:

Table 9.2.7: Plates, sections and forgings for cargo tanks, fuel tanks, secondary barriers and process pressure vessels for design temperatures below -55°C and down to -165°C.

CHARPY V-NOTCH IMPACT TEST REQUIREMENTS	
40 < t ≤ 45 (1)	25°C below design temperature
45 < t ≤ 50 (1)	30°C below design temperature

Notes:

1. A further set of impact test at mid thickness for products with t > 40 mm is required except rolled steels specified in Part 2, Chapter 3, SECTION 3 or Part 2, Chapter 3, SECTION 9.

SECTION 3 Aluminium weldings and welding procedures

3.1 Application

3.1.1 The requirements of this Section are applicable to mono-hull and multi-hull craft of aluminium construction.

3.1.2 This Section includes the general requirements for the construction of aluminium craft under the use of two welding processes: the metal inert gas (MIG) and the tungsten inert gas (TIG). Where alternative methods of construction are proposed, additional documentation is to be submitted for consideration by LHR.

3.2 General design principles

3.2.1 Any abrupt change in the general contour of the structure increases the stress level of the adjacent area well above the average stress level. For that reason, it is important to eliminate, as far as it is practicable, details such as groove welds, small insert plates and drain holes in the vicinity of significant structural discontinuities. Measures are to be taken to provide as smooth a stress flow in the structural contour as it is possible by using, for instance, connecting brackets.

3.2.2 Where a rigid member terminates abruptly in the middle of a plate panel which is inherently flexible, a point of stress concentration is produced. Such points are to be avoided.

3.2.3 Welds are to be located in a way so as to avoid the creation of high restraints against weld shrinkage, e.g. the welding of small thick insert plates. Therefore, the use of small inserts for reinforcement of openings should be avoided.

3.2.4 When designing weld joints, factors concerned with material special characteristics are to be taken into account, such as the reduced strength values of rolled plates in the through thickness direction. Material properties and the specific location of weld joints should be specially considered in order to avoid dangerous phenomena such as lamellar tearing.

3.2.5 The design of welded joints and the sequence of welding should enable residual welding stresses to be kept to a minimum. Welded joints are not to be over-dimensioned.

3.2.6 Weld joints, and especially heavily loaded weld joints, are to be so designed that the most suitable method of testing for defects can be used (radiography, ultrasonic, surface crack inspection) in order that a reliable examination may be carried out.

3.2.7 Welded joints are to be designed to ensure that the proposed weld type and quality can be satisfactorily achieved under the given fabricating conditions.

3.2.8 Where different types of materials are welded and operate in sea water or any other electrolytic medium, i.e. weld joints made between unalloyed and stainless steels in the wear linings of jet rudders and the built-up welds on rudderstocks, attention is to be paid to the increased tendency towards corrosion, especially at the weld, due to the differences in electrochemical potential. Where necessary, the welded joints should be located at points where there is less danger of corrosion (e.g. outside tanks) or special corrosion protection should be provided (e.g. coating or catholic protection).

3.3 Welding consumables

3.3.1 All welding consumables used have to be approved by LHR or other recognized Classification Society and are to be suitable for the type of joint and grade of material.

3.3.2 Alloys such as 5083 and 5086 are normally welded using the 5356, 5556 or 5183 consumables and alloys such as 6061 and 6082 are normally welded using the 4043 consumables.

3.3.3 Cast aluminium alloys are not in general to be welded directly to wrought high magnesium alloys unless the welding is carried out in accordance with an agreed procedure.

3.3.4 The distribution, storage and handling of all welding consumables is a very important matter and should be dealt with special care. The aluminium filler metals must be kept in a heated and dry storage place with a relatively uniform temperature. The metal surface should remain clear of condensation during storage and use. Welding studs and bare wire are to be stored in dry places to prevent corrosion.

3.4 Welder qualifications

3.4.1 The welders should be experienced and well-qualified. The Builders have to keep records of tests and qualifications of each welder, which will be available to the Surveyors, in order to check if the personnel involved in the construction procedure are capable of achieving the required standard of workmanship.

3.5 Documentation to be submitted

3.5.1 The documentation submitted for approval has to indicate clearly details of the welded connections of the main structural members. In addition to this, it is also to include the type, size and disposition of welds.

3.5.2 The following information is to be submitted:

a) Grades, tempers and thicknesses of materials to be welded

b) Weld throat thickness or leg lengths

c) Locations, types of joints and angles of abutting members

d) Sequence of welding of assemblies and joining up of assemblies

e) Reference to welding procedures to be used

3.6 Butt welding

3.6.1 Butt welding is to be used for plates and section butts and is mandatory for heavily stressed butts such as those of the bottom, keel, side shell, sheerstrakes and strength deck plating, joints and butts of bulkheads (especially those bulkheads located in areas where vibrations occur).

3.6.2 Wherever possible, joints in girders and sections are not to be located in areas of high bending stress. Joints at the buckling points of the flanges are to be avoided.

3.6.3 The transition between differing component dimensions are to be smooth and gradual. Where the depth of web of girders or sections differs, the flanges or bulbs are to be bevelled and the web is to be slit and expanded or pressed together to equalise the depths of the members. The length of the transition should be at least equal with twice the difference in depth.

3.6.4 To provide smooth stress flow, the transition between differing thickness of plates is to be gradual. Where the differences in thickness exceeds 3 mm, the thicker plate to be welded is to be tapered with a maximum slope of $^1/_3$. Differences in thickness of 3 mm or less may be accommodated within the weld. In the assembly of two plates of different thicknesses, the weld must be followed by a backweld.

3.6.5 For the welding on plates or other relatively thin-walled elements, steel castings and forgings must be appropriately tapered or provided with integrally cast or forged welding flanges.

3.6.6 Where stiffening members are going to be attached to plating by continuous fillet welds and to cross completely finished butt welds, the weld reinforcements of butt welds are to be removed and the welds are to be made flush with the adjacent surface. Where butt welding of stiffeners is made prior to continuous fillet welding on plating, the weld reinforcement is also to be removed. Care is to be taken so that the ends of the flush portion not to have notches liable to impair the soundness of the continuous fillet welding. Where these conditions cannot be complied with, a scallop is to be arranged in the web of a stiffening member. A scallop is also used where a butt weld of a stiffener or girder is made after the members have been assembled in place. Scallops shall have a minimum radius of 25mm or twice the plate thickness whichever is the greater. Because an improperly cut scallop is potentially dangerous, scallops should be shaped in such a way so as to provide a gentle transition to the adjoining surface.

3.6.7 Where butt welds form a T-junction, the leg of the T is, where practicable, to be completed first including any back run. During the welding operation special attention is to be given to the completion of the weld at the junction, which is to be chipped back to remove crater cracks, etc., before the table is welded.

3.6.8 In Table 9.3.1 and Table 9.3.2 a number of typical joint preparations for TIG and MIG welding is shown respectively.

Table 9.3.1: Typical joint preparations for TIG welding of aluminium alloys

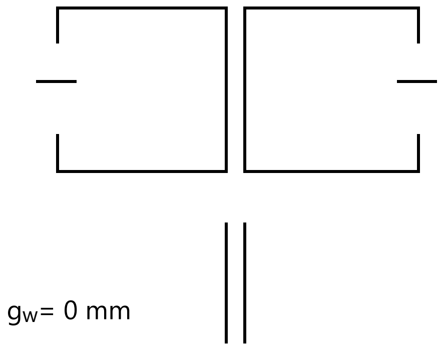
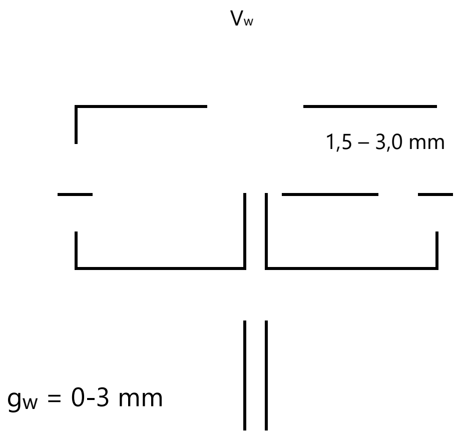
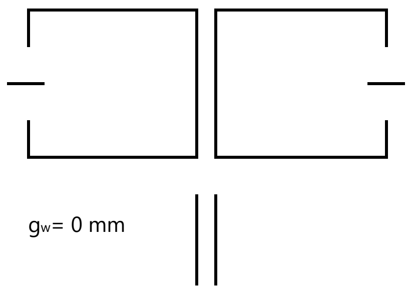
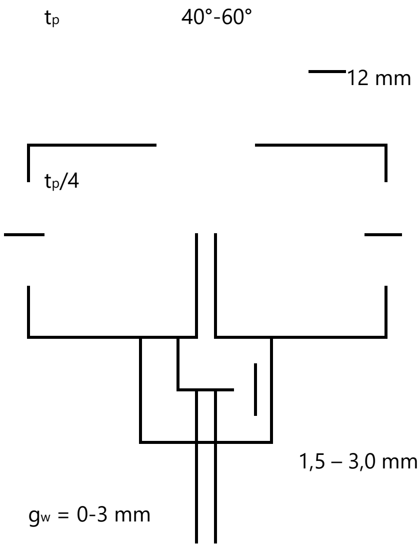
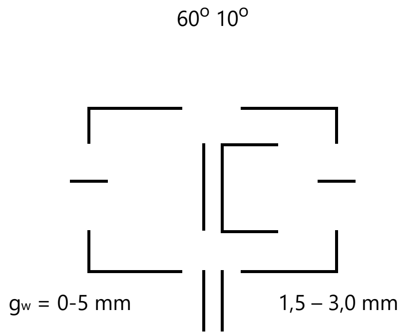
Thickness (mm)	Joint design	Welding position/comments
2,5 – 3,0		Flat Horizontal Vertical Overhead
3,0 – 10,0		Flat and Vertical V = 60° Horizontal and Overhead V = 90° - 110°
Symbols and definitions		
g_W = weld gap, mm V_W = weld preparation angle, degrees		

Table 9.3.2: Typical joint preparations for semi-automatic MIG welding

Thickness (m)	Joint design	Welding position/comments
5,0 – 6,5		Flat
7,0 – 15,0		Flat and Vertical Horizontal Vertical Overhead One sided welding with Temporary backing
12,0 – 25,0		All positions

3.7 Fillet welds

3.7.1 T-connections are generally to be made by fillet welds on both sides of the abutting plate, the dimensions and spacing of which are shown in Figure 9.3.1. Where the connection is highly stressed full penetration welding may be required. Where full penetration welding is required, the abutting plate may need to be bevelled.

3.7.2 The throat thickness a of fillet welds is to be determined from:

$$a = t_p \times \beta \times \left(\frac{d}{s}\right)$$

where:

s = the length of correctly proportioned weld fillet, clear of end craters, mm, and is to be 10 plate thickness, t_p, or 75 mm whichever is the lesser, but in no case to be taken less than 40 mm.

d= the distance between successive weld fillets, in mm

t_p = plate thickness, mm, on which weld fillet size is based

β= weld factor

Weld factors are contained in Table 9.3.3

NOTE:
For double continuous fillet welding (d/s) is to be taken as 1 (see 3.10.1).

3.7.3 For ease of welding, it is suggested that the ratio of the web height to the flange breadth be greater than or equal to 1,5 (see Figure 9.3.2).

3.7.4 Where an approved automatic deep penetration procedure is used, the weld factors given in Table 9.3.3 may be reduced by 15%.

3.7.5 The leg length of the weld is to be not less than $\sqrt{2}$ times the specified throat thickness.

3.7.6 The plate thickness t_p to be used in 3.7.2 is generally to be that of the thinner of the two parts being joined. Where the difference in thickness is considerable, the size of fillet will be specially considered.

3.8 Throat thickness limits

3.8.1 The throat thickness limits given in Table 3.3.4 are to be complied with.

3.9 Single sided welding

3.9.1 Where the main welding is carried out from one side only a back sealing run is to be applied to all butt welds, after suitable back gouging, unless the welding process and consumables have been specially approved for one-side welding.

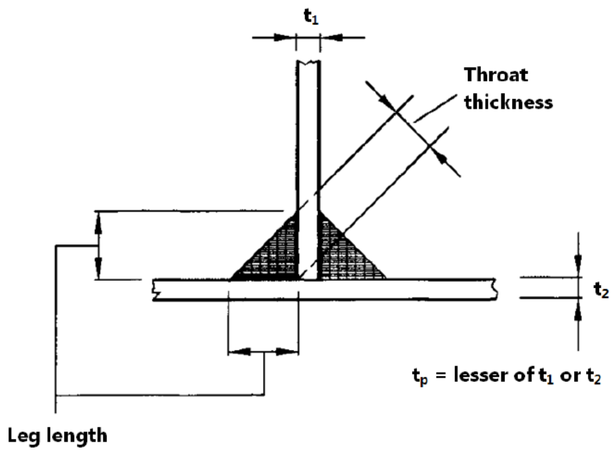
3.9.2 Where internal access for welding is impracticable, backing bars are to be fitted in way of butt and fillet welds, or alternative means of obtaining full penetration welds are to be agreed. Backing bars are to be permanent or temporary.

3.9.3 Permanent backing bars are to be of the same material as the base metal and of thickness not less than the thickness of the plating being joined or 4 mm, whichever is the lesser. The weld is to be thoroughly fused to the backing bar.

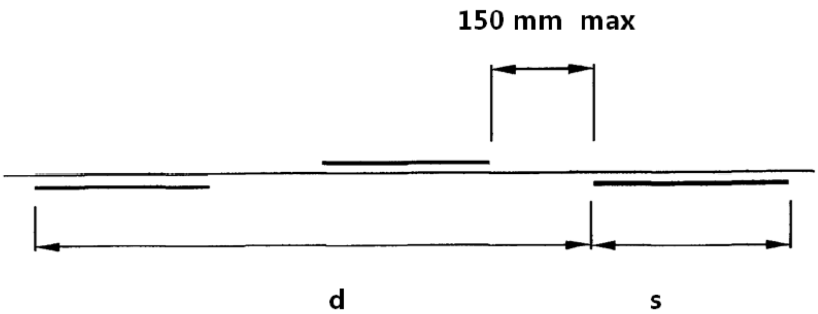
3.9.4 Backing bars are to be continuous for the full length of the weld and joints in the backing bar are to be by full penetration welds, ground smooth.

Figure 9.3.1: Weld types

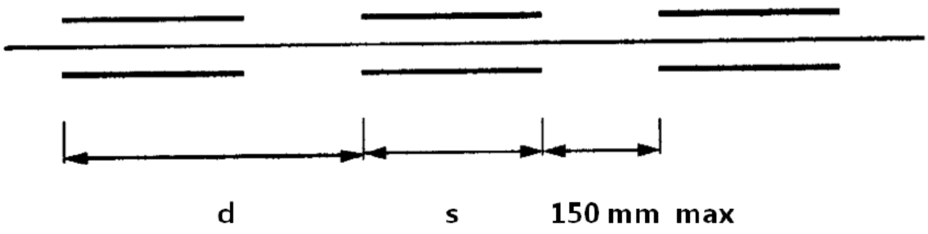
a) Weld fillet dimensions



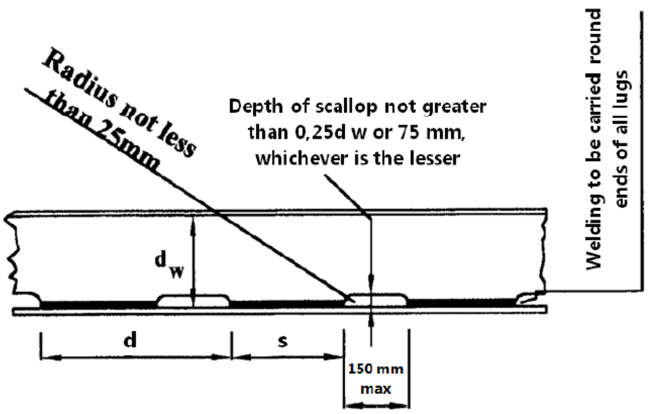
b) Staggered intermittent



c) Chain intermittent



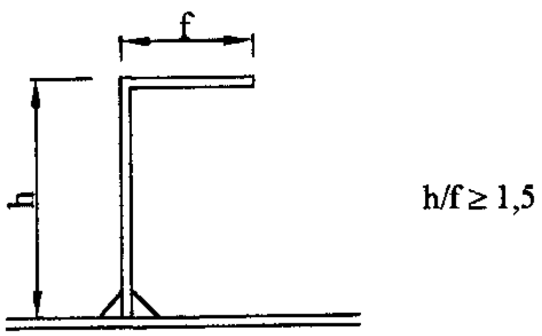
d) Scalloped construction



3.9.5 Temporary backing bars for single sided welding may be austenitic stainless steel, glass tape, ceramic, or anodized aluminium of the same material as the base metal. Backing bars are not to be made of copper to avoid weld contamination and corrosion problems.

3.9.6 Temporary backing bars are to be suitably grooved in way of the weld to ensure full penetration.

Figure 9.3.2: Web height/flange breadth ratio



3.10 Double continuous welding

3.10.1 Where double continuous fillet welding is proposed the throat thickness is to be in accordance with 3.7.2 taking (d/s) equal to 1.

3.10.2

3.10.2 Double continuous welding is to be adopted in the following locations and may be used elsewhere if desired:

- Main engine seatings
- Boundaries of tank and watertight compartments.
- Boundaries of weathertight decks and erections, including hatch coamings, companionways and other openings.
- Bottom framing structure of high-speed craft in way of machinery and jet room spaces as appropriate.
- Structure in way of ride control systems, stabilisers, thrusters, bilge keels, foundations and other areas subject to high stresses.
- The side and bottom shell structure in the impact area of high-speed motor craft.
- The underside of the cross-deck structure in the impact area of high-speed multi-hull craft. Stiffening members to plating in way of end connections, and of end brackets to plating in the case of lap connections.
- Face flats to webs of built-up/fabricated stiffening members in way of knees/end brackets and for a distance beyond such knees / end brackets of not less than the web depth of stiffener in way.
- The shell structure in the vicinity of the propeller blades.
- Primary and secondary members to plating in way of end connections, and end brackets to plating in the case of lap connections.

Table 9.3.3: Weld factors

Item	Weld Factor β	Remarks
(1) General application:		except as required below
Watertight plate boundaries	0,34	
Non-tight plate boundaries	0,13	
Longitudinals, frames, beams, and other secondary members to shell, deck or bulkhead plating	0,10	
	0,13	in tanks
	0,21	in way of end connections
Panel stiffeners	0,10	
Overlap welds generally	0,27	
Longitudinals of the flat-bar type to plating		see 3.10.2
(2) Bottom construction:		
Non-tight centre girder: to keel to	0,27	no scallops
inner bottom	0,21	
Non-tight boundaries of floors, girders and brackets	0,21	in way of 0,2 span at ends
	0,27	in way of brackets at lower end of main frame
Inner bottom longitudinals, or face flat to floors reverse frames	0,13	
Connection of floors to inner bottom where bulkhead supported on tank top. The supporting floors are to be continuously welded to the inner bottom	0,44	Weld size based on floor thickness Weld material compatible with floor material
(3) Hull framing:		
Webs of web frames and stringers:		
~ to shell	0,16	
~ to face plate	0,13	
(4) Decks and supporting structure:		
Weather deck plating to shell	0,44	
Other decks to shell and	0,21	generally continuous

bulkheads (except where forming tank boundaries)		
Webs of cantilevers to deck and to shell in way of root bracket	0,44	
Webs of cantilevers to face plate	0,21	
Girder webs to deck clear of end brackets	0,10	
Girder webs to deck in way of end brackets	0,21	
Web of girder to face plate	0,10	
Pillars: fabricated	0,10	
~ end connections	0,34	

Item	Weld Factor β	Remarks
~ end connections (tubular)	full penetration	
Girder web connections and brackets in way of pillar heads and heels	0,21	Continuous
(5) Bulkheads and tank construction:		
Plane and corrugated watertight bulkhead boundary at bottom, bilge, inner bottom, deck and connection to shelf plate, where fitted.	0,44	Weld size to be based on thickness of bulkhead plating Weld material to be compatible with bulkhead plating material
Secondary members where acting as pillars	0,13	
Non-watertight pillar bulkhead boundaries	0,13	
Perforated flats and wash bulkhead boundaries	0,10	
Deep tank horizontal boundaries at vertical corrugations	full penetration	
(6) Structure in machinery space:		
Centre girder to keel and inner bottom	0,27	no scallops to inner bottom
Floors to centre girder in way of engine thrust bearers	0,27	
Floors and girders to shell and inner bottom	0,21	
Main engine foundation girders: to top plate to hull structure	deep penetration to depend on design	edge to be prepared with maximum roote $0,33t_p$ deep penetration generally
Floors to main engine Foundation girders	0,27	
Brackets, etc., to main engine foundation girders	0,21	

Transverse and longitudinal framing to shell	0,13	
(7) Superstructures and deckhouses: Connection of external bulkheads to deck Internal bulkheads	 0,34 0,21 0,13	 1st and 2nd tier erections elsewhere
(8) Steering control systems: Rudder: Fabricated mainpiece and mainpiece to side plates and webs Slot welds inside plates Remaining construction	 0.44 0.44 0.21	

Item	**Weld Factor β**	**Remarks**
Fixed and steering nozzles: Main structure Elsewhere Fabricated housing and structure of thruster units, stabilisers, etc.: Main structure Elsewhere	 0,44 0,21 0,44 0,21	
(9) Miscellaneous fittings and equipment: Rings for manhole type covers, to deck or bulkhead Frames of shell and weathertight bulkhead doors Stiffening of doors Ventilator, air pipes, etc., Coamings to deck Ventilator, etc., fittings	 0,34 0,34 0,21 0,34 0,21 0,21	 Load Line Position 1 and 2 elsewhere

Scuppers and discharges, to deck	0,44	
Masts, crane pedestals, etc., to deck	0,44	full penetration welding may be required
Deck machinery seats to deck	0,21	generally
Mooring equipment seats	0,21	generally , but increased or full penetration may be required
Bulwark stays to deck	0,21	
Bulwark attachment to deck	0,34	
Guard rails, stanchions, etc., to deck	0,34	
Bilge keel ground bars to shell	0,34	continuous fillet weld , minimum throat thickness 4mm
Bilge keels to ground bars	0,21	light continuous or staggered intermittent fillet weld , minimum throat thickness 3mm
Fabricated anchors	full penetration	

3.11 Full penetration welding

3.11.1 Where full penetration welding is required in accordance with 3.6 and 3.7, these are to be made by welding from both sides with the root of the first weld back gouged to sound metal before welding the second side. The weld on the second side may be a sealing run .

3.11.2 Where access to the second side for welding is impracticable, backing bars are to be used in accordance with 3.9.

Table 3.3.4: Throat thickness limits

Item	Throat thickness a (mm)	
	Minimum	Maximum
(1) Double continuous welding	0,21 t_p	0,44 t_p
(2) Intermittent welding	0,27 t_p	0,44 t_p or 4,5
(3) Overriding minimum		
(a) Continuous welds	2,5	
(b) Intermittent welds		
(i) Plate thickness t_p 7,5mm		
Hand or automatic welding	3,0	
Automatic deep penetration welding	3,0	
(ii) Plate thickness t_p 7,5 mm		
Hand or automatic welding	3,25	
Automatic deep penetration welding	3,0	

NOTES

1. In all cases the limiting maximum value is to be taken as the greatest of the applicable values above.
2. The maximum throat thicknesses shown are intended only as a design limit for the approval of fillet welded joints. Any welding in excess of these limits is to be to the Surveyor's satisfaction.

3.12 Intermittent welding (chain)

3.12.1 Chain intermittent welding may be used, outside of the impact area in the bottom shell or crossdeck structure of high-speed craft.

3.13 Intermittent welding (staggered)

3.13.1 Where intermittent welding is used, the welding is to be made continuous round the ends of brackets, lugs, scallops, etc.

3.13.2 Staggered intermittent welding is not to be used in the bottom shell or crossdeck structure of high-speed craft.

3.14 Stud welding

3.14.1 Where permanent or temporary studs are to be attached by welding to main structural parts in areas subject to high stress, the proposed location of the studs and the welding procedures adopted are to be to the satisfaction of the Surveyors.

3.15 Slot welding

3.15.1 The connection of plating to internal webs is usually difficult, and the access for welding is not practicable. In such a case the closing plating is to be attached by continuous full penetration welds, or by slot fillet welds to face plates fitted to the webs. Slots are, in general, to have a minimum length of ten times the plating thickness or 75 mm, whichever is the lesser, but in no case to be taken as less than 40 mm, and a minimum width of twice the plating thickness or 15 mm whichever is the greater, with well rounded ends. Slots cut in plating are to have smooth, clean and square edges and the distance between the slots is, in general, not to exceed 150 mm. Slots are not to be filled with welding. Alternative proposals for length, width and spacing of slot welds will be specially considered.

3.16 Lap connections

3.16.1 The connection of plates, which may be subjected to compressive loading or high tensile, is usually not being made by overlaps. In case, however, that plates overlaps are used, the width of the overlap is not, in general, to exceed four times nor be less than three times the thickness of the thinner plate and the joints are to be positioned so as to allow adequate access for completion of sound welds. The faying surfaces of lap joints are to be in close contact and both edges of the overlap are to have continuous fillet welds.

3.17 Connections of primary structure

3.17.1 Connections of primary structure need a full penetration welding.

3.17.2 Special care must be taken of the material lost in the notch, where longitudinals or stiffeners pass through the member, when welding connections to shell, deck or bulkhead. Where the width of notch exceeds 15% of the stiffener spacing, the weld factor is to be multiplied by:

$$\frac{\text{stiffener plating} \times 0.85}{\text{length of web plating between notches}}$$

3.17.3 Where direct calculation procedures have been adopted, the weld factors for the 0,2 overall length at the ends of the members will be considered in relation to the calculated loads.

3.18 Primary and secondary member end connection welds

3.18.1 Welding of end connections of primary members is to be such that the area of welding is not less than the cross-sectional area of the member, and the weld factor is to be not less than 0,34 in tanks or 0,27 elsewhere.

3.18.2 The welding of secondary member end connections is to be not less than as required by Table 3.3.5. Where two requirements are given the greater is to be complied with.

3.18.3 The area of weld, A_w, is to be applied to each arm of the bracket or lapped connection.

3.18.4 Where a longitudinal strength member is cut at a primary support and the continuity of strength is provided by brackets, the area of weld is to be not less than the cross-sectional area of the member.

Table 3.3.5: Primary and secondary member end connection welds

Connection	Weld area, A_W, (cm^2)	Weld factor β
(1) Stiffener welded direct to plating	$0{,}25A_S$ or 6,5 cm^2, whichever is the greater	0,34
(2) Bracketless connection of stiffeners or stiffener lapped to bracket or bracket lapped to stiffener:		
(a) in dry space	$1{,}2\sqrt{SM}$	0.27
(b) in tank	$1{,}4\sqrt{SM}$	0.34
(c) main frame to tank side bracket in $0{,}15L_R$ forward	As (a) or (b)	0.34
(3) Bracket welded to face of stiffener and bracket connection to plating		0.34
(4) Stiffener to plating for 0,1 span at ends, or in way of the end bracket if that be geater		0.34
Symbols:		
A_s = cross section area of the stiffener, in cm^2 A_w = the area of the weld, in cm^2, and is calculated as total length of weld, in cm, throat thickness, in cm SM= the section modulus, cm^3, of the stiffener on which the scantlings of the end bracket are based		
NOTE: 1. For maximum and minimum weld fillet sizes, see Table 3.3.4		

3.19 Weld connection of strength deck plating to sheerstrake

3.19.1 The connection of strength deck plating to sheerstrake is being made by using double continuous fillet welding with a weld factor of 0,44. The welding procedure, including joint preparation, is to be specified and the procedure qualified and approved for individual Builders.

3.20 Notches and scallops

3.20.1 Notches and scallops are to be kept clear of the toes of brackets, etc. Openings are to be well rounded with smooth edges.

3.20.2 The size and position of the scallops are such, that a satisfactory weld can be made around the ends of openings.

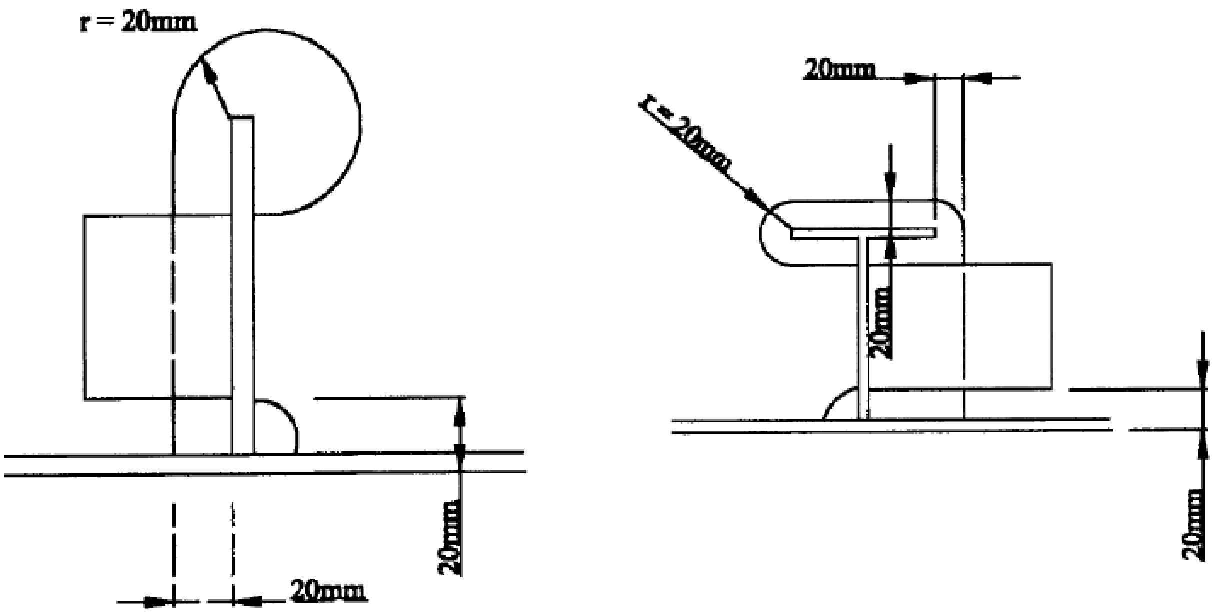
3.21 Watertight collars

3.21.1 Watertight collars are to be fitted, where stiffeners are continuous through watertight or oiltight boundaries.

3.22 Lug connections

3.22.1 The area of the weld connecting secondary stiffeners to primary structure in the bottoms of the hulls and cross-deck structure in areas subjected to impact pressures is to be not less than the shear area from the Rules. This area is to be obtained by fitting two lugs or by other equivalent arrangements. In Figure 9.3.3 and Figure 9.3.4 are shown some typical lug connections.

Figure 9.3.3: Typical lug connections



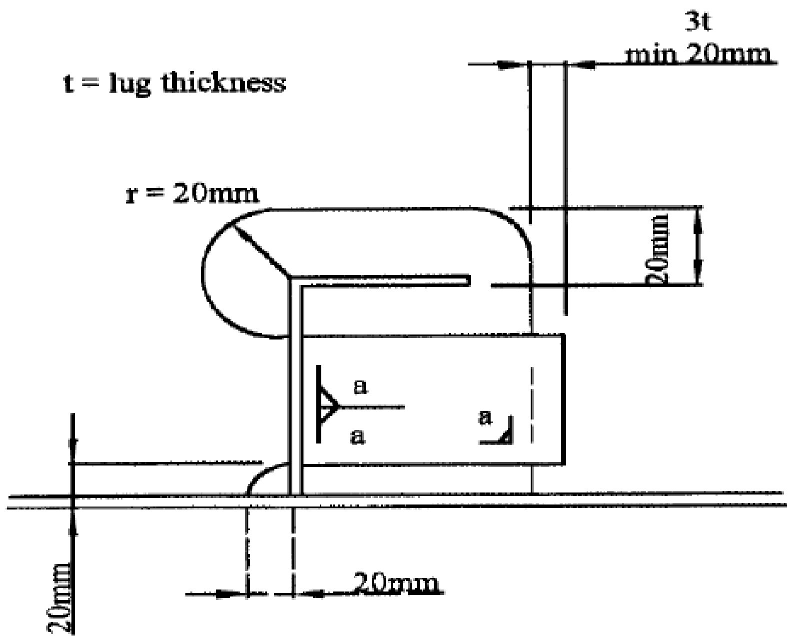
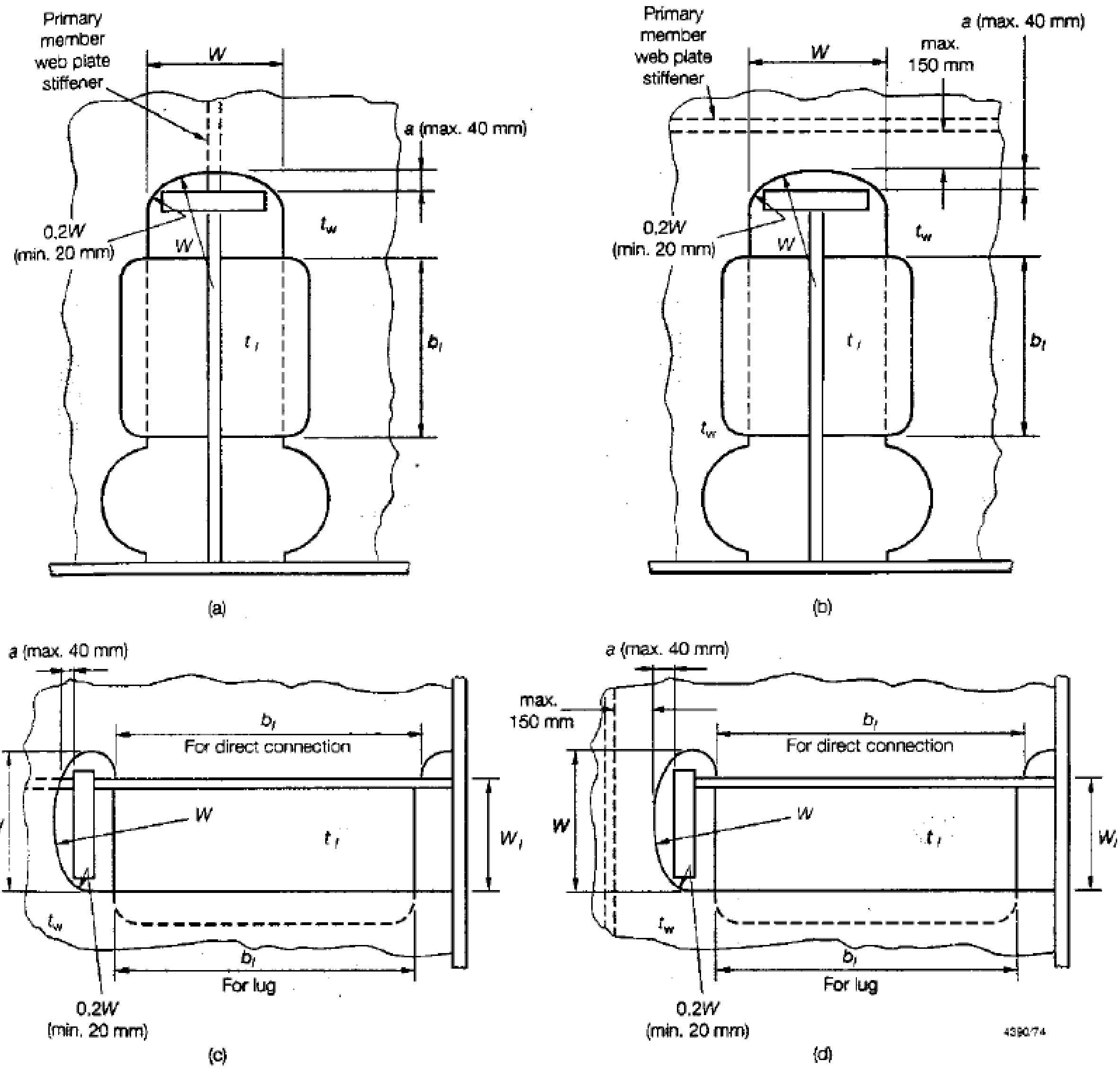


Figure 9.3.4: Cut-outs and connections



3.22.2 Lugs or tripping brackets are to be fitted where shell longitudinals are continuous through web frames in way of highly stressed areas of the side shell.

3.22.3 Lugs or tripping brackets are also to be fitted where continuous secondary stiffeners are greater than half the depth of the primary stiffeners.

3.23 Insert plates

3.23.1 Where thick insert plates are butt welded to thin plates, the edge of the thick plate may require to be tapered. The slope of the taper is generally not to exceed one in three.

3.23.2 The corners of insert plates are to be suitably radiused.

3.24 Doubler plates

3.24.1 It is usually preferable doubler plates to be avoided in areas, which are easily affected by corrosion and present difficulty in inspection and maintenance.

3.24.2 Where doubler plates are fitted, they are to have well radiused corners and the perimeter is to be continuously welded. Large doubler plates are also to be suitably slot welded, the details of which are to be submitted for consideration.

3.25 Joint preparation

3.25.1 The preparation of plate edges is to be accurate and free from blemishes. All joints are to be properly aligned and closed or adjusted before welding. In case of excessive gaps between surfaces or edges to be joined, the corrective measures adopted are to be to the satisfaction of the Surveyor.

3.25.2 The contraction stresses between the welded parts are to be kept to a minimum. Due to this fact the parts are to be set up and welded very carefully.

3.25.3 Before a manual sealing run is applied to the back of a weld the original root run is to be cut back to sound metal.

3.25.4 In order to remove oxide or adhering films of dirt and filings from the joint edges, an acceptable method should be used, such as scratch brushing, immediately before welding.

3.25.5 In Table 9.3.1 and Table 9.3.2 are shown typical butt joints.

3.26 Triaxial stresses

3.26.1 Poor joint design may result in triaxial stresses, which are considered to be an undesirable case. Detailed joint design can be a great help in order to avoid triaxial stress problems.

3.27 Aluminium / Wood connection

3.27.1 The corrosion of aluminium, caused by its contact to wood in a damp or marine environment, can be minimized by priming and painting the timber. Alternatively, the surface of the aluminium in contact with the timber is to be coated with a substantial thickness of a suitable sealant.

3.27.2 Timbers such as western red cedar, oak and chestnut are not, unless well seasoned, to be directly in contact with aluminium.

3.27.3 The following types of timber preservatives should be avoided: copper napthanate, copper-chrome-arsenate, borax-boric acid.

3.28 Aluminium / Steel connection

3.28.1 Provision is made in this Subsection for explosion bonded composite aluminium/steel transition joints used for connecting aluminium structures to steel plating. Such joints are to be used in accordance with the manufacturer's requirements.

3.28.2 Transition joints are to be manufactured by an approved producer in accordance with an approved specification which is to include the maximum temperature allowable at the interface during welding.

3.28.3 The aluminium material is to comply with LHR's requirements and the steel is to be of an appropriate grade complying with the relevant LHR requirements.

3.28.4 Intermediate layers between the aluminium and steel may be used, in which case the material of any such layer is to be specified by the manufacturer and is to be recorded in the approval certificate. Any such intermediate layer is then to be used in all production transition joints.

3.28.5 Bimetallic joints where exposed to seawater or used internally within wet spaces are to be suitably protected to prevent galvanic corrosion.

SECTION 4 Approval testing of welders

4.1 General

4.1.1 The purpose of this Section is to provide with essential requirements, ranges of approval, test conditions, acceptance requirements and certification for the approval testing of welders on fusion welding of steels. This Section covers the approval testing of welders either for welding plates or for pipe welding.

4.1.2 Approval testing of welder or welder's qualification test is required for all manual or partly mechanized welding and where the quality of the welded joints depends to a considerable degree on the manual skill of the welder.

4.1.3 Approval testing of welders may only be carried out by welders who have received appropriate previous training and who have had sufficient opportunity to practice the craft. Moreover, the welders must also possess the professional knowledge to enable them to perform the welding work competently taking all the necessary precautions for safety and showing the required care. During the approval testing the welder should be required to show adequate practical experience and job knowledge of the welding processes, materials and safety requirements for which he is to be approved.

4.1.4 Welding workshops are required to maintain lists, which at all times can provide with complete information about the number, the names, the ranges of approvals and the dates of the initial and repeat tests taken by the welders.

4.1.5 The approval testing of welders is to be carried out in the welding workshop, conducted by the welding supervisory staff in the presence of the Surveyor.

4.1.6 Welder's approval testing conducted by other testing bodies independent of the works and acceptable to LHR will be recognized upon submittance of the relevant test certificates and appropriate documentation, e.g. assessment sheets.

4.2 General requirements for testing the welders

4.2.1 The welder's approval test is to be carried out on test pieces and is independent of the type of construction. The test piece shall be marked with the identification of the examiner, the Surveyor and the welder before start welding.

4.2.2 The test may be stopped if the welding conditions are not correct or if it appears that the welder does not have the technical competence to achieve the required standard, e.g. where there is the need for excessive and/or systematic repairs.

4.2.3 The approval test for the welder shall correspond to the conditions used in production and is to be carried out in accordance with a WPS prepared in accordance with SECTION 2.

4.2.4 For the preparation of the WPS the conditions specified in EN 287-1 should apply.

4.3 Test methods

4.3.1 Each completed weld shall be examined visually in the as welded condition. Major defects in appearance, such as appreciable undercuts, craters, irregular depositions, excessive thicknesses or weaknesses, may entail rejection of the test piece presented. Where the weld passes the visual inspection, additional tests are to be carried out as shown in Table 9.4.1.

4.3.2 Prior to mechanical testing, temporary backing strips, where used, are to be removed. The test piece can be sectioned by thermal cutting or by mechanical means discarding the first and last 25 mm of the test piece at the end of the plates.

Table 9.4.1: Test methods

Test method	Butt weld plate	Butt weld pipe	Fillet weld
Visual examination	*	*	*
Radiography	* (Notes 1, 5)	* (Notes 1, 5)	+
Bend	* (Note 2)	* (Note 2)	+
Fracture	* (Note 1)	* (Note 1)	* (Notes 3, 4)
Macro (without polishing)	—	+	* (Note 4)
Magnetic particle/ dye penetrant	—	+	+

NOTES:

1. Radiography or fracture tests shall be used, but not both.
2. When radiography is used, then bend tests shall always be applied to butt welds made by metal -arc inert gas welding or metal - arc active gas welding or oxyacetylene welding.
3. The fracture tess are to be supported by magnetic particle or dye penetrant when required.
4. The fracture test may be replaced by a macroexamination of at least 4 sections. The macro specimens shall be prepared and etched on one side to reveal the weld.
5. The radiographic test may be replaced by an ultrasonic test for thickness ≥ 12 mm on ferritic steels only

key:

* indicates that the test method is mandatory

+ indicates that the test method is not mandatory

4.4 Butt welds in plate

4.4.1 The test piece for approval testing of welders in butt welding of plates is to be as required by EN 287-1. The inspection length is the whole weld length apart from 25 mm on each end.

4.4.2 When radiography is used, the whole inspection length of the weld is to be radiographed in the as welded condition in accordance with ISO 1106-1:1984 "Recommended practice for radiographic examination of fusion welded joints - Part 1: Fusion welded butt joints in steel plates up to 50 mm thick" or ISO 1106-2: 1985 "Recommended practice for radiographic examination of fusion welded butt joints in steel plates thicker than 50 mm and up to and including 200 mm in thickness" using Class B technique.

4.4.3 When fracture testing is used, the full test piece inspection length shall be tested. The test piece shall be cut into an even-numbered quantity of test specimens of approximately the same length of 40 mm. The weld reinforcement of the test specimen may be removed and additionally the weld edges may be notched to a depth of approximately 5 mm to facilitate fracture in the weld metal. In the case of single sided welding without backing, half of the inspection length shall be tested against the face side and the other half against the root side.

4.4.4 When transverse bend testing is used for plate thickness larger than 3 mm, two root bend test specimens and two face bend test specimens shall be tested in accordance with 4.5. The diameter of the former is to be 4t and the bending angle 120° unless the low ductility of the parent metal or filler metal impose other limitations. For plate thicknesses larger than 12 mm the transverse bend tests may be substituted by four side bend tests in accordance with SECTION 4.

4.5 Fillet welds in plate

4.5.1 The test piece for approval testing of welders in fillet welding of plates is o be as required by EN 287-1. The inspection length is the whole weld length apart from 25 mm on each end.

4.5.2 The fracture tests are to be performed as required by EN 287-1.

4.5.3 To carry out macroexamination, four test specimens are to be taken equally spaced in the inspection length.

4.6 Butt welds in pip

4.6.1 The test piece for approval testing of welders in butt welding of pipes is so be as required by EN 287-1.

4.6.2 The radiographic test is to be performed on the whole inspection length of the weld. The test piece is to be radiographed in the as-welded condition in accordance with ISO 1106-3: 1984 "Recommended practice for radiographic examination of fusion welded joints: Part 3: Fusion welded circumferential joints in steel pipes of up to 50 mm wall thickness".

4.6.3 In fracture testing, the whole inspection length is to be examined. The test piece shall be cut into at least four test specimens, depending on the pipe diameter. If the pipe diameter is too small for testing, two or more test pieces are to be welded. The inspection length of any test specimen is to be approximately 40 mm. The weld reinforcement of the test specimen may be removed and additionally the weld edges may be notched to a depth of 5 mm to facilitate fracture in the weld metal. In the case of single-side welding without backing half of the inspection length of the test piece is to be tested against the face side and the other half against the root side.

4.6.4 When transverse bend testing is used for wall thickness larger than 3 mm, two root bend test specimens and two face bend test specimens are to be tested. The diameter of the former is to be 4t and the bending angle 120° unless the low ductility of the parent metal or filler metal imposes other limitations. For the sectioning of test pieces welded in position PF, PG and H-LO45, test specimens shall be taken form different welding positions. Definition of welding positions is mentioned in Section

For wall thickness larger than 12 mm the transverse bend tests may be substituted by four side bend tests.

4.7 Fillet weld on pipe

4.7.1 The test piece for approval testing of welders is to be as required by EN 287-1.

4.7.2 To carry out fracture tests, the test piece is to be cut into four or more test specimens and to be fractured.

4.7.3 When macro examination is used, at least four test specimens shall be taken equally around the pipe.

4.8 Acceptance requirements for test pieces

4.8.1 Test pieces are to be evaluated in accordance with the acceptance requirements specified for relevant types of imperfections. The acceptance requirements for imperfections found by test methods according to these rules, unless otherwise agreed, be assessed in accordance with EN 25817 "Arc-welded joints in steel-Fusion welding-Guidance on quality levels for imperfections (ISO 5817: 1991)". A welder is approved if the imperfections in the test piece are within the specified limits of quality level B in EN 25817, except that for imperfections "excess weld metal", "excessive convexity", "fillet weld having a throat thickness greater than the nominal value", "excessive penetration", quality level C is to be applied. If the imperfections in the welder's test piece exceed the permitted maximum specified, then the welder shall not be approved.

4.9 Re-tests

4.9.1 If any test piece fails to comply with these requirements, the welder is to produce a new test piece. If it is proved that failure is attributed to the welder's lack of skill, the welder shall be regarded as incapable of complying with these requirements without further training before re-testing. If it is proved that failure is due to metallurgical or other extraneous causes and cannot be directly attributed to the welder's lack of skill, an additional test is required in order to assess the quality and integrity of the new test material and/or new test conditions.

4.9.2 Additional test specimens shall be taken as required by EN 287-1.

4.10 Period of validity

4.10.1 Beginning from the date when all required tests are satisfactorily completed, the welder is considered approved. This date may be different from the date of issue marked on the certificate.

4.10.2 The welder's approval is to remain valid for a period of two years, provided that the relevant certificate is signed at six months intervals by the supervisor and that all the following conditions are fulfilled:

The welder shall be engaged with reasonable continuity on welding work within the extent of the current approval. An interruption for a period no longer than six months is permitted.

The welder's work shall be in general accordance with the technical conditions under which the approval test is carried out.

There shall be no specific reason to question the welder's skill and knowledge.

If any of these conditions are not fulfilled, the approval shall be canceled.

4.11 Prolongation of validity

4.11.1 The validity of the approval on the certificate may be prolonged for a further period of two years, within the original extent of approval, provided each of the following conditions are fulfilled:

The production welds made by the welder are of the required quality.

The relative records of tests, e.g. documentation about x-ray or ultrasonic inspections or test

reports about fracture tests or comments of the appointed supervisors, shall be maintained on file with the welder's approval certificate.

LHR shall verify compliance with the above conditions and sign the prolongation of the welder's approval test certificate.

4.12 Certification

4.12.1 The certificate is to be a proof for the welder's approval, meaning that no certificate is issued when the welder has not passed successfully the approval test. All relevant test conditions are to be recorded on the certificate.

4.12.2 The welder's approval test certificate is issued by LHR. The format should be in accordance with a recognized standard, e.g. EN 287-1.

4.12.3 If a testing body different to LHR, has issued approval certificates for the welder, the information given in those certificates is to be in accordance with that required in 4.12.2.

4.12.4 Each change of the essential variables for the approval testing beyond the permitted ranges requires a new test and a new approval certificate.

4.13 Ranges of approval

4.13.1 The test piece approves the welder not only for the conditions used in the test, but also for all joints which are considered easier to weld.

4.13.2 The ranges of approval regarding welding processes, joint types, material groups, welding positions, dimensions and consumables should follow the requirements of EN 287-1.

SECTION 5 Mechanical testing of welded joints

5.1 General

5.1.1 This Section provides the testing methods and appropriate test specimens for the mechanical testing of welded joints related to the welding procedure tests and approval testing of welders.

5.1.2 Test methods and forms of specimens conforming to national or international standards may also be used with the consent of LHR provided that the tests applied are considered equivalent to those mentioned in this Section.

5.2 Preparation of test pieces and specimens

5.2.1 The test pieces are to be welded in the presence of the Surveyor and are to be marked by him beforehand.

5.2.2 Each test specimen is to be marked by the Surveyor before being cut out of the test piece. The test specimen is to be marked in such a way that after it has been removed it is possible to identify its exact position in the joint from which it has been removed.

5.2.3 The test specimens are to be taken by appropriate means. Shearing is excluded for thicknesses of more than 8 mm. If thermal cutting or other cutting method which could affect the cut surfaces is used to cut the test specimens from the test piece, the cuts are to be made at a distance from the test specimen greater than or equal to 8 mm. Moreover, that distance is to be sufficient, according to the process used, so as not to induce any metallurgical effect which could modify the test results.

5.2.4 The final stages of preparation are to be obtained by machining or grinding. However, suitable precautions are to be taken to avoid superficial strain hardening or excessive heating of the material.

5.3 Performance of tests

5.3.1 All mechanical tests are to be performed in the presence of the Surveyor.

5.4 Transverse tensile test

5.4.1 This test is carried out to determine the tensile strength and the location of fracture of a welded butt joint. The yield stress or proof stress and the elongation may be required to be determined, if LHR considers it necessary. A tensile load is applied to a test specimen taken transversely from the welded joint, until rupture. The removal of the test specimen is to be done in such a way so that, after machining, the weld axis will remain in the middle of the parallel length of the test specimen. The surfaces are to be free from scratches and notches transverse to the test specimen direction. The surfaces of the test specimen are to be machined in such a way that the weld reinforcement, the penetration bead and irregularities at the surface between weld metal and parent metal are removed. After rupture of the test specimen, the fracture surfaces are to be examined and the existence of any defects are to be recorded, including their type and amount.

5.4.2 For test specimens machined from pipe, flattening of the gripped ends may be necessary. However, this flattening and the possible resulting variation in thickness is not, in any case, to affect the zone of the parallel length.

5.4.3 The dimensions are to conform to those given in Table 9.5.1 with reference to the symbols of Figure 9.5.1 and Figure 9.5.2.

5.4.4 Generally, the thickness of the test specimen is to be equal to the thickness of the parent metal near the welded joint. It is permissible, however, to take several test specimens from the welded joint to cover the full thickness of the joint, instead of a single test specimen having the full joint thickness; see Figure 9.5.3. In such cases, the position of the test specimen in the welded joint thickness is to be identified.

Table 9.5.1: Dimensions of the transverse tensile test specimen

Designation		Symbol	Remarks	
Maximum width of the weld after machining		L_s		
Total length of the test specimen		L_t	to suit particular testing machine	
Parallel length of the test specimen		L_c	> L_s + 60 mm	
Width of parallel length	plates	b_2	25 mm	Unless specified otherwise, this dimension may be reduced, if necessary, in the case of pipes
	pipes			
Width of gripped ends		b_2	b_2 + 12 mm	
Transition radius		R	> 25 mm	

Figure 9.5.1: Test specimen for plates

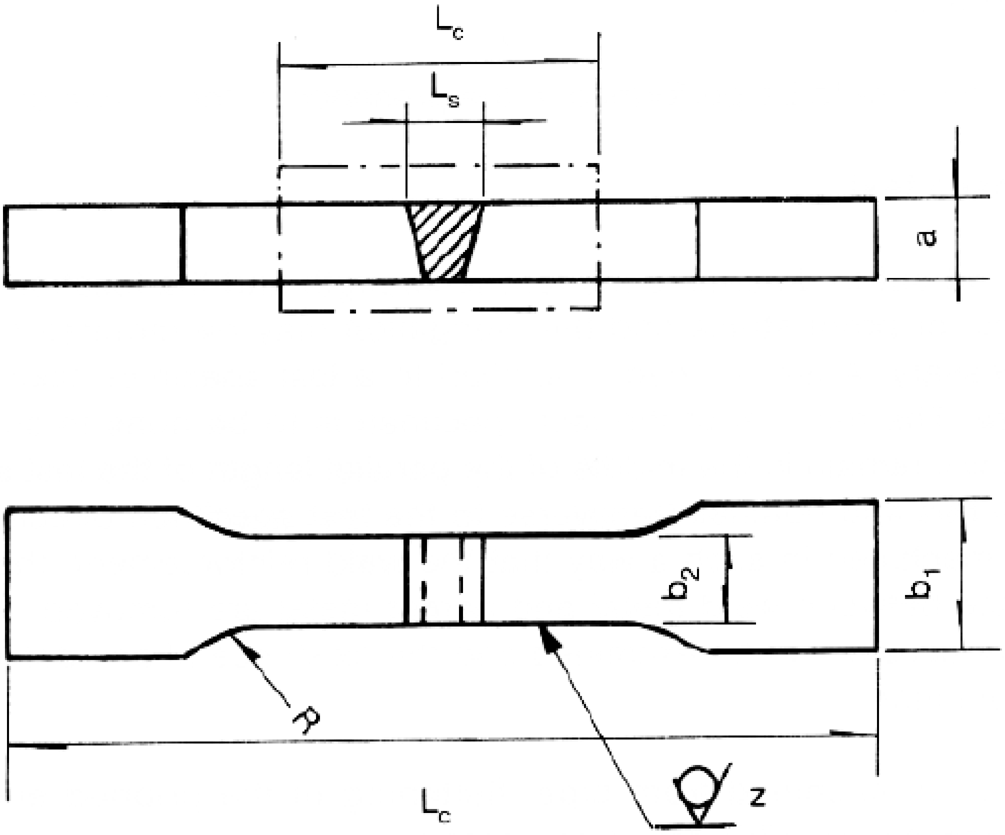


Figure 9.5.2: Test specimen for pipes

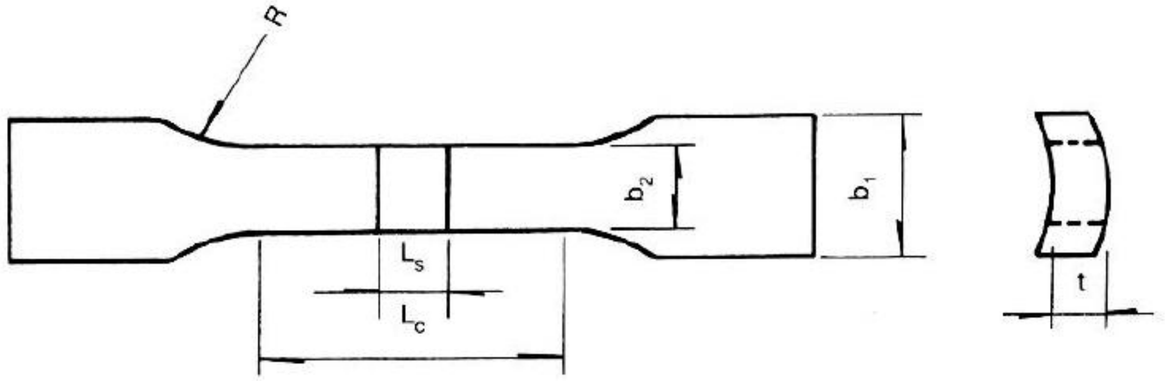
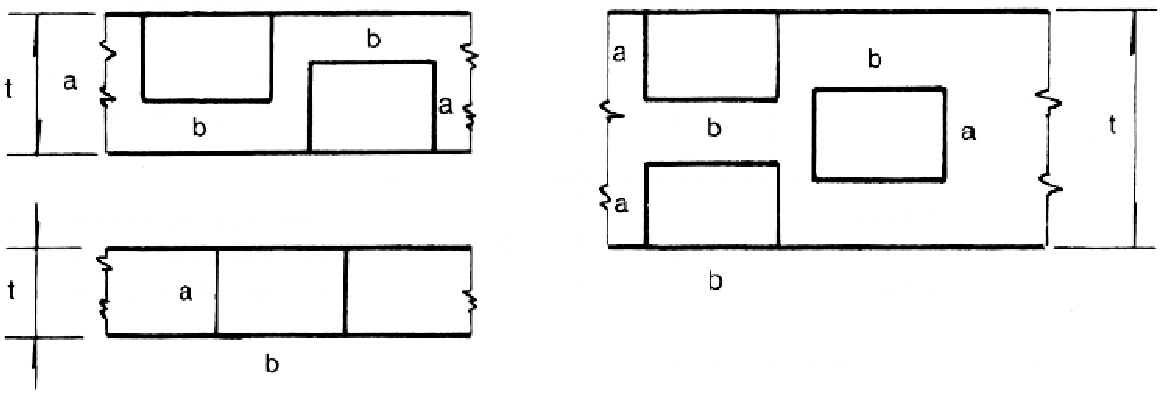


Figure 9.5.3: Position of specimens through thickness



5.5 Transverse root and face bend tests

5.5.1 Transverse root and face bend tests on test specimens taken form a welded butt joint intend to assess ductility and absence of imperfections on the surface in tension of the joint itself.

5.5.2 The test specimen is to be removed transversely from the welded joint of the manufactured product or from the welded test piece in such a way that after machining the weld axis remains in the middle of the test specimen. The upper and lower surfaces of the weld are to be dressed flush with the original surfaces of the parent metal. Machining of any undercuts is not permitted unless otherwise specified.

5.5.3 When the weld is made from one side only, the bend test specimens are called:

Face bend test specimens, when the surface in tension contains the largest width of the weld.

Root bend test specimens, when the surface in tension contains the root of the weld.

When the joint is made from both sides, then the side from which welding commenced first is called the face. The other side is called the root.

5.5.4 The test is to be carried out by placing the test specimen on two supports consisting of parallel rollers. The test piece is bent slowly and continuously by applying in the middle of the span, on the axis of the weld, a concentrated load (three-point bending) perpendicularly to the test specimen surface. The load is to be applied by means of a former having a specified diameter D. The test is completed when the bending angle α reaches a specified value. After bending, both the external surface and the side of the test specimen are to be examined; see Figure 9.5.4.

5.5.5 Generally, the test specimen thickness is to be equal to the thickness of the parent metal near the welded joint. Where the thickness exceeds 30 mm, several test specimens may be taken to cover the full thickness of the joint. In such a case, the position of the test specimens in the welded joint thickness are to be identified; see Figure 9.5.5.

5.5.6 The dimensions of the test specimens are prescribed in Table 9.5.2. The shapes of the test specimens are shown in Figure 9.5.6.

5.6 Transverse side bend test

5.6.1 Side bend tests intend also to assess ductility and absence of internal defects in the joint itself.

5.6.2 Side bend tests may be carried out when the joint thickness is at least 10 mm. The test specimen is taken transversely from a welded joint in such a way that, after machining, the weld cross-section remains in the middle of the length of the test specimen and corresponds to its width. The upper and lower surfaces of the weld are to be dressed flush with the original surfaces of the parent metal.

5.6.3 The shape of test specimen is shown in Figure 9.5.7. Generally, the width of the test specimen, b, is to be equal to the thickness of the parent metal of the welded joint, it is to be at least 10 mm and have a ratio $b > 1{,}5 \cdot a$, where a is the test specimen thickness. The ratio between a and the diameter of the former d is to be specified. When the joint thickness exceeds 40 mm, it is permissible to take several specimens from the welded joint, instead of one, provided the width b of each test specimen is in the range from 20 to 40 mm. In these cases the location of the test specimen in the welded joint thickness is to be identified. The total length of test specimens, the diameter of the former and the distance between the rollers are to be as mentioned in Table 9.5.2.

5.6.4 The test is to be carried out as shown in Figure 9.5.8 in a way similar to that described in 5.5.4.

Figure 9.5.4: Transverse face (or root) test

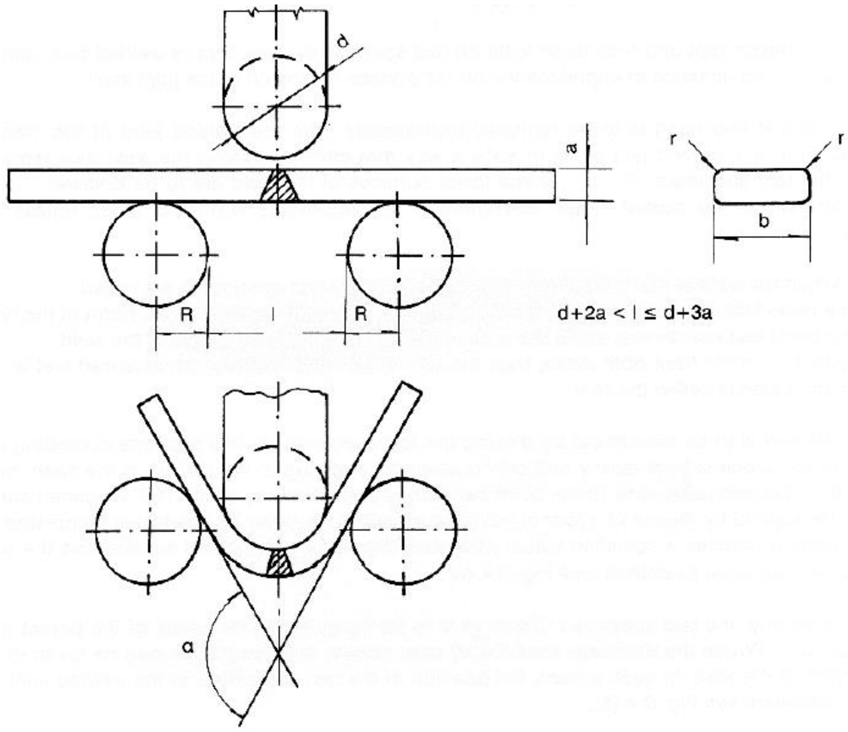


Figure 9.5.5: Position of specimens through thickness

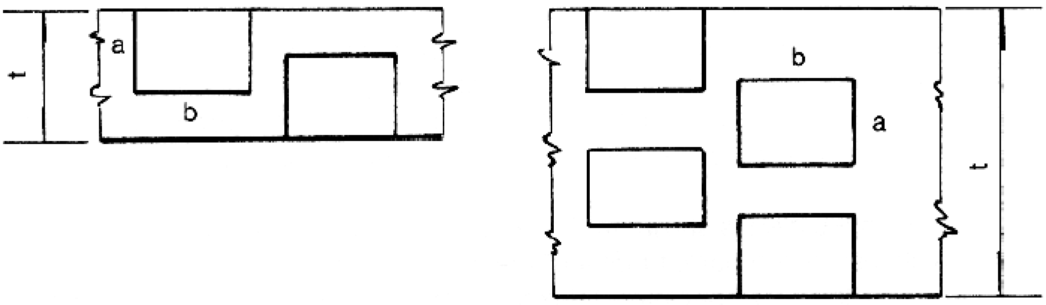


Figure 9.5.6: Transverse root and face bend test specimen

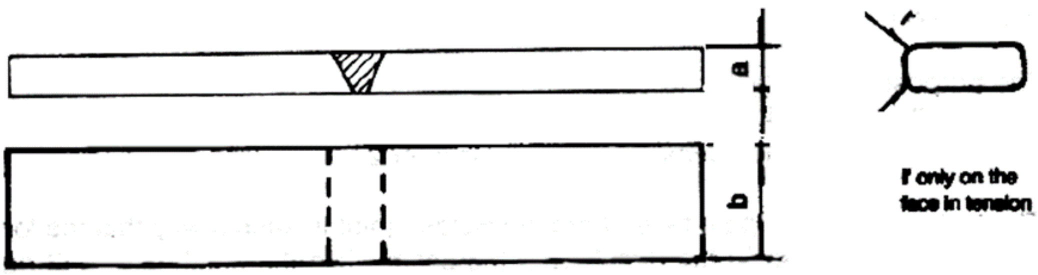
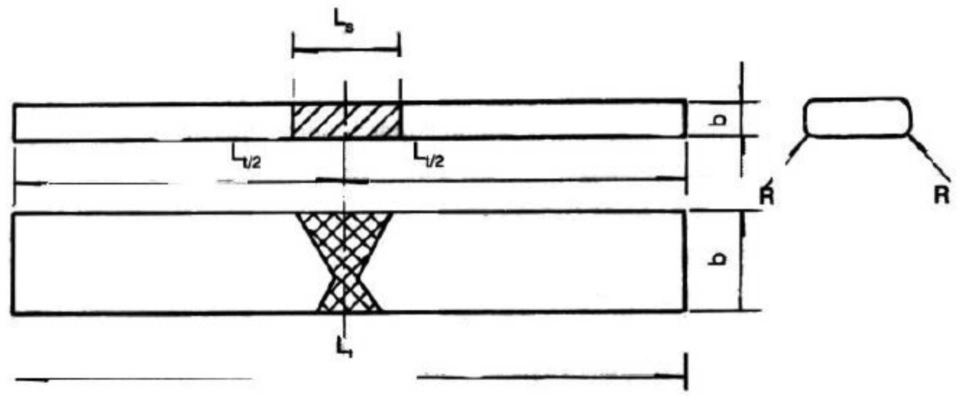


Table 9.5.2: Symbol designations and dimensions for transverse face and root bend test specimens

Designations	Symbols	Remarks
Thickness of the welded joint	t, mm	
Thickness of the test specimen	a, mm	
Diameter of the former	d, mm	d ≥ 20 mm
Radius of the roller	R, mm	
Radius of the test specimen edges on the face in tension	r, mm	r ≤ 0,2·a ≤ 3 mm
Distance between the rollers	l, mm	d + 2·a < l ≤ d + 3·a
Total length of test specimen	L_t	L_t ≥ l + 2·R
Width of the test specimen	b, mm	for plates: b ≥ 1,5·a ≥ 20 mm for pipes outs. diam. D_o < 50 mm: b = tube thickness + 0,1·D_o ≥ 8 mm outs. diam. D_o < 50 mm b = tube thickness + 0,05 D_o 8 mm ≤ b ≤ 40 mm
Bending angle	α, degrees	

Figure 9.5.7: Transverse side bend test specimen

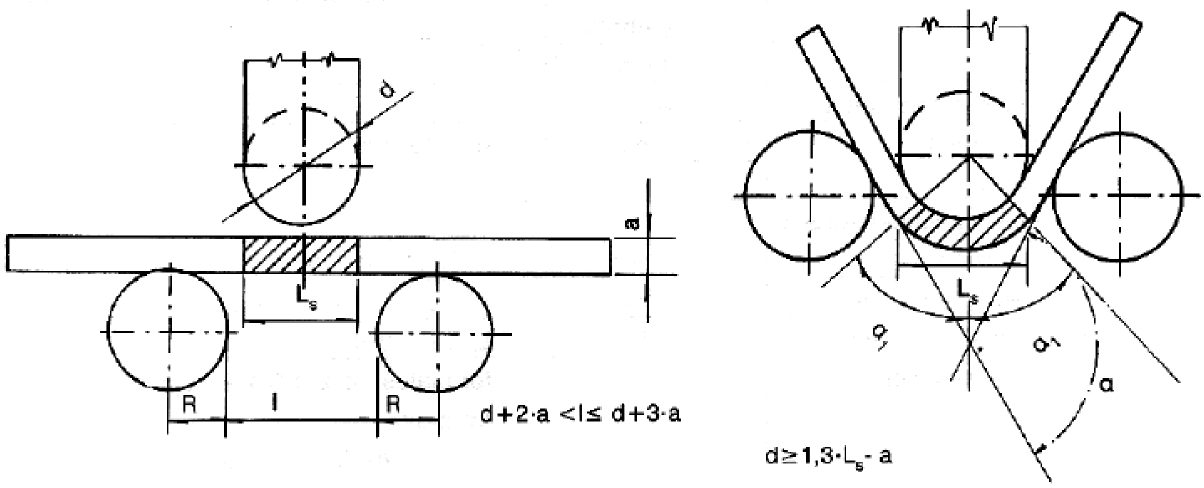


5.7 Impact test

5.7.1 The purpose of this test is to determine the impact energy in J. The test is to be carried out in the manner described in ISO 148-1983(E): "Steel - Charpy impact test (V-notch)". The dimensions of Charpy V-notch impact test specimens are given in Chapter 2.

5.7.2 The test specimen is to be taken from the welded joint in such a way that the longitudinal axis of the specimen is perpendicular to the direction of the seam while the notch axis is at right angles to the surface of the product. Depending on the test specification, the notch is to be located either at the center of the weld metal, on the fusion line or in the heat affected zone of the parent metal at a specified distance form the fusion line; see Figure 9.5.9.

Figure 9.5.8: Transverse side bend test

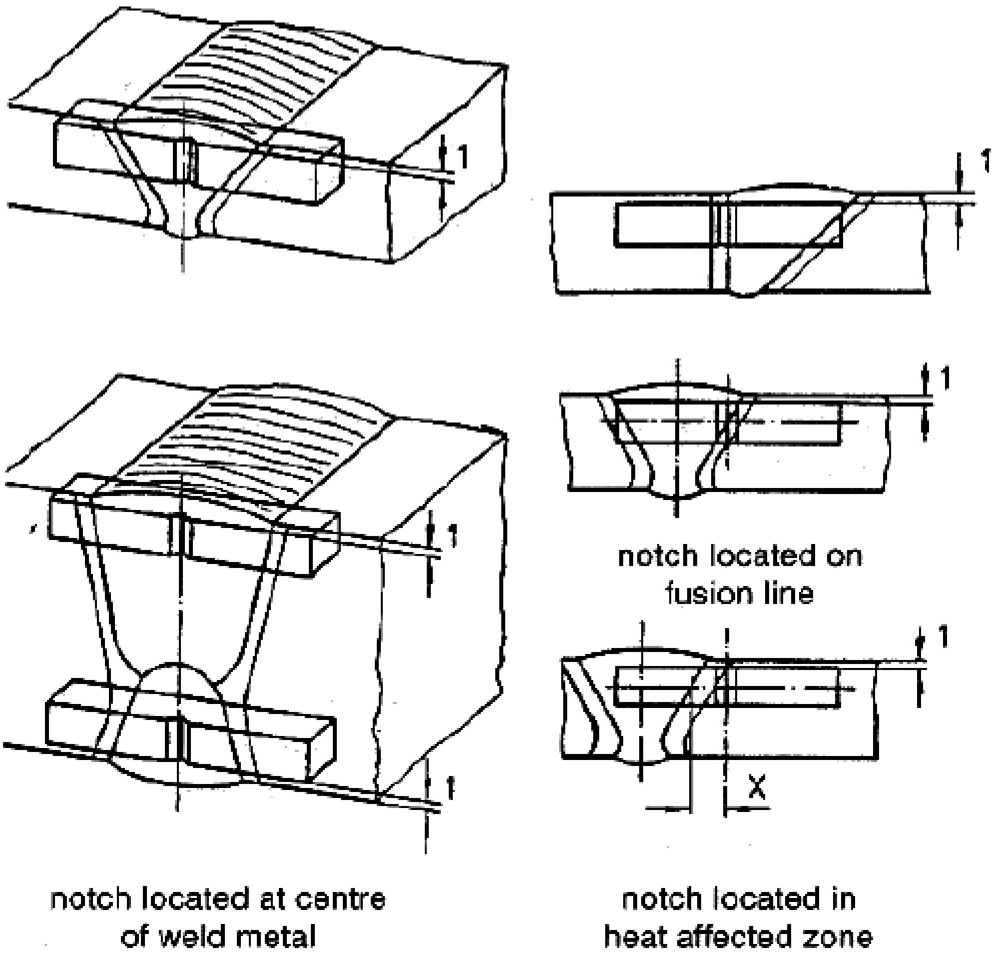


5.7.3 The test is to be carried out at a specified test temperature. The average value of the three impact test specimens, comprising one set, is not to be less than the specified impact energy in the requirements. Only one specimen may be below the required average value but not to be less than 70% of that value. Where the joint thickness is smaller than 10 mm, specimens measuring 7,5X10 mm, 5X10 mm an 2,5X10 mm should be used where possible. For these specimens the required impact energy E (J) in relation to the standard 10X10 mm test specimen is to be as indicated below:

Cross - section of specimen (mm x mm)	Mean impact energy specimen value required E
Standard specimen 10 x 10	E
Specimens of reduced section	
10 x 7,5	5/6 E
10 x 5	2/3 E
10 x 2,5	1/2 E

5.7.4 If in exceptional cases specimens of other shapes or different orientation are to be used, the test requirements must be specially agreed.

Figure 9.5.9: The location of specimens for notched bar impact testing



5.7.5 Where specimens are taken from only one side of a double V weld, they are to be taken from the side of the seam which was welded last, as shown in Figure 9.5.9.

5.8 Hardness test

5.8.1 Hardness testing on transverse sections of welded joints made of steel is to be performed to ensure that hardness falls below a maximum specified value. It is to be carried in accordance with ISO 6507/1: "Metallic materials - Hardness test - Vickers test - Part 1: HV5 to HV100" normally with test loads of approximately 49 or 98 N (HV 5 or HV 10).

5.8.2 Test specimens are to be taken by mechanical cutting of a cross-section, usually transverse to the welded joint. This operation and the subsequent preparation of the surface are to be carried out carefully so that the hardness of the face to be tested is not altered by either process. The surface to be tested is to be properly prepared and etched, in order to enable the correct identification of the different zones of the welded joint.

5.8.3 The hardness tests are to be carried out in the form of rows of indentations, as specified in ISO 6507/1. The number and spacing of indentations are to be sufficient to define any hardened or softened regions. A recommended spacing between indentations in the heat affected zone (excluding austenitic steels) is to be 0,7 mm for test load HV 5 and 1 mm for test load HV 10. Sufficient indentations are to be made to ensure that unaffected parent metal is tested. In the weld metal, the distance is to be selected so that the results obtained will enable assessment of the welded joint to be made. For metals which harden in the HAZ as a result of welding, two additional indentations in the HAZ are to be made at a distance less than 0,5 mm from the fusion line. For other metals, e.g. austenitic stainless steels and joint configurations special requirements may be given.

5.8.4 The test report should include information such as the kind of parent metal, thickness of product, type of weld, welding process, filler metal, post-weld heat treatment and/or ageing. A drawing designating the rows of indentations and giving the distance of rows of indentations from the reference line which may be the surface or fusion line, should be attached. The test report should include the hardness curve giving the hardness value for each point of measurement for each row of indentations.

5.9 Metallographic inspections

5.9.1 The scope of such inspections is to reveal the nature and structure of the crystallization of the weld metal and the heat affected zone, as well as the texture of the parent metal and in the case of micrographs, the grain boundaries in the area under examination.

5.9.2 These tests shall be carried out on polished sections perpendicular to the weld axis.

5.9.3 The metallographic specimens shall be photographed and the pictures appended to the test report. Micrographs shall normally be to a scale of 1:1. If the section of the weld is small, they may be enlarged. For micrographic specimens, at least three photographs shall be made of characteristic points within the areas referred to in 5.9.1. The scale used shall normally be 100:1.

5.10 Test reports

5.10.1 Reports on tests must be prepared by the manufacturer and submitted to the Surveyor. They should contain all the necessary details of the test piece, the welding process, the test method, the form of specimens used (including their dimensions and orientation) and the test results.

CHAPTER 10 Approval of Welding Consumables

CONTENTS

SECTION 1 General

1.1 Scope

1.1.1 These requirements give the conditions of approval and inspection of welding consumables used for hull structural steel welding as follows:

- Normal strength steels Grades A, B, D and E.
- Higher strength steels Grades AH-32, DH-32, EH-32, AH-36, DH-36, and EH-36.
- Higher strength steels with minimum yield strength 390 N/mm²: Grades A-40, D-40 and E-40,
- Higher strength steels for low temperature application: Grades FH-32, FH-36 and F-40.

Welding consumables for high strength steels for welded structures are to comply with the requirements of SECTION 8 of this Chapter.

These requirements are not applicable for welding procedure qualification tests at the shipyard.

1.1.2 The concerned welding consumables are divided into several categories as follows:

- covered electrodes for manual welding and gravity welding
- wire/flux combinations for two run or multi-run submerged arc welding
- solid wire/gas combinations for arc welding
- flux cored wires with or without gas for arc welding
- consumables for use in electroslag and electrogas vertical welding

1.2 Grading

1.2.1. Filler metals are divided into two groups:

- normal strength filler metals for welding normal strength hull structural steels
- higher strength filler metals for welding normal and higher strength hull structural steels with minimum yield strength up to 355 N/mm²
- higher strength filler metals for welding normal and higher strength hull structural steels with minimum yield strength up to 390 N/mm²

Each of the three groups is based upon corresponding tensile strength requirements. Each filler metal group is further divided into three grades:

- Grades 1, 2 and 3 for ordinary-strength filler metals
- Grades 1Y, 2Y, 3Y and 4Y for higher strength filler metals for steels up to 355 N/mm² yield strength
- Grades 2Y40, 3Y40 and 4Y40 for higher strength filler metals for steels up to 390 N/mm² yield strength

The Grade assignment is given in respect of Charpy V-notch impact test requirements. For each strength basic group, welding consumables, which have satisfied the requirements for a higher toughness grade are considered as complying with the requirements for a lower toughness grade.

1.2.2. The correlation between the hull steel grades and the welding consumable grades that must be used for the hull steel welding, is stated in Table 10.1.1.

1.2.3. Welding consumables of Grades 2 and 3 and of Grades 2Y, 3Y and 4Y and of Grades 2Y40, 3Y40 and 4Y40 for which the hydrogen content has been controlled in accordance with 4.5.3 are identified by the mark H15, H10 or H5.

Table 10.1.1: Correlation of welding consumables to hull structural steels

Grades of welding consumables (see notes)	Hull structural steel grades											
	LHR-A	LHR-B	LHR-D	LHR-E	A32/36	D32/36	E32/36	F32/36	A40	D40	E40	F40
1, 1S, 1T, 1M, 1TM, IV	X											
1YS, 1YT, 1YM, 1YTM, 1YV	X				(2)							
2, 2S, 2T, 2M, 2TM, 2V	X	X	X									
2Y, 2YS, 2YT, 2YM, 2YTM, 2YV	X	X	X		X	X						
2Y40, 2Y40S, 2Y40T, 2Y40M, 2Y40TM, 2Y40V	(1)	(1)	(1)		X	X			X	X		
3, 3S, 3T, 3M, 3TM, 3V	X	X	X	X								
3Y, 3YS, 3YT, 3YM, 3YTM, 3YV	X	X	X	X	X	X	X					
3Y40, 3Y40S, 3Y40T, 3Y40M, 3Y40TM, 3Y40V	(1)	(1)	(1)	(1)	X	X	X		X	X	X	
4Y, 4YS, 4YT, 4YM, 4YTM, 4YV	X	X	X	X	X	X	X	X				
4Y40, 4Y40S, 4Y40T, 4Y40M, 4Y40TM, 4Y40V	(1)	(1)	(1)	(1)	X	X	X	X	X	X	X	X
5Y40, 5Y40S, 5Y40T, 5Y40M, 5Y40TM, 5Y40V	(1)	(1)	(1)	(1)	X	X	X	X	X	X	X	X
(1): see note d) (2): see note e)												

NOTES:

a) When joining normal to higher strength structural steel, consumables of the lowest acceptable grade for either material being joined may be used.

b) When joining steels of the same strength level but of different toughness grade, consumables of the lowest acceptable grade for either material being joined may be used.

c) It is recommended that controlled low hydrogen type consumables are to be used when joining higher strength structural steel to the same or lower strength level, except that other consumables may be used at the discretion of LHR when the carbon equivalent is below or equal to 0,41%. When other than controlled low hydrogen type electrodes are used appropriate procedure tests for hydrogen cracking may be conducted at the discretion of LHR.

d) The welding consumables approved for steel Grades A40, D40, E40 and/or F40 may also be used for welding of the corresponding grades of normal strength steels subject to the special agreement with LHR.

e) When joining higher strength steels using Grade 1Y welding consumables, the material thicknesses should not exceed 25 mm.

1.3 Manufacture

1.3.1 The manufacturer's plant, methods of production and quality control of welding consumables are to be such as to ensure reasonable uniformity in manufacture.

SECTION 2 Approval procedure

2.1 Plant inspection

2.1.1 The Surveyor is to be satisfied that the manufacturer's plant, methods of production and quality control of welding consumables are to be such as to ensure a reasonable uniformity in manufacture, as mentioned in 1.3.1.

2.2 Test assemblies

2.2.1 The test assemblies are to be prepared under the supervision of the Surveyor, and all tests are to be carried out in his presence. When a welded joint is performed, the edges of the plates are to be bevelled either by mechanical machining or by oxygen cutting; in the latter case, a de-scaling of the bevelled edges is necessary.

2.2.2 The welding conditions used such as amperage, voltage, travel speed, etc. are to be within the range recommended by the manufacturer for normal good welding practice. Where a filler metal is stated to be suitable for both alternating current (AC) and direct current (DC), AC is to be used for the preparation of the test assemblies.

2.3 Firms with several factories - sister firms

2.3.1 When a filler product is manufactured in several factories of the same company, the complete series of approval tests should be carried out in one of the works only. In the other factories, a reduced test program at least equivalent to annual tests is permitted if the manufacturer can certify that the materials used and the fabrication process are identical with those used in the main works.

This requirement is applicable to all manufacturers of filler products under license (sister firms). However, should there be any doubt, complete test-series may be required.

NOTE:

Wire flux combination for submerged arc welding. If a unique powder flux is combined with different wires coming from several factories belonging to the same firm, it may be admitted to perform only one test-series if the different wires are conformable to the same technical specification, after approval of LHR.

2.4 Annual inspection and tests

2.4.1 The production techniques and associated quality control procedures at all establishments approved for the manufacture of welding consumables are to be subjected to an annual reappraisal. On these occasions, samples of the approved consumable are to be selected by the Surveyor and subjected to the tests detailed in subsequent SECTIONS of this Chapter. These are to be completed and reported within the one year period beginning at the initial approval date, and repeated annually so as to provide at least an average of one annual test per year. Equivalent alternative arrangements may be accepted subject to special agreement with LHR.

2.5 Alterations to approved consumables

2.5.1 Any alteration proposed by the maker to the approved consumable which may result in a change in the chemical composition and the mechanical properties of the deposited metal must be immediately notified to LHR. Additional tests may be necessary.

2.6 Upgrading and uprating

2.6.1 Upgrading and uprating of welding consumables will be considered only at the manufacturer's request, preferably at the time of annual testing. Generally, for this purpose, tests from butt weld assemblies will be required in addition to the normal annual approval tests.

2.7 Additional tests

2.7.1 LHR may request, in a particular case, additional tests or requirements as may be considered necessary.

SECTION 3 Mechanical testing procedure

3.1 Test specimens

3.1.1. Specimens dimensions.

Deposited metal and butt weld tensile, butt weld bend and Charpy V-notch impact test specimens are to be machined to the dimensions given in Part 2, Chapter 2.

3.1.2. Specimens location and preparation.

a) Deposited metal tensile

The longitudinal axis must coincide with the centre of the weld and:

i. the mid thickness of the weld in the deposited metal test assemblies
ii. the mid thickness of the 2nd run in the two-run welded test assemblies

The specimens may be heated to a temperature not exceeding 250°C for a period not exceeding 16 hours for hydrogen removal prior to testing.

b) Butt weld tensile

The upper and lower surfaces of the weld are to be filed, ground or machined flush with the surface of the plate.

c) Butt weld bend

The upper and lower surfaces of the weld are to be filed, ground or machined flush with the Surface of the plate and the sharp corners of the specimens rounded to a radius not exceeding 2 mm.

d) Charpy V-notch impact

The test specimens shall be cut with their longitudinal axes transverse to the weld length and:

i. at mid thickness of the weld in the deposit metal and butt weld test assemblies with multi-run technique
ii. on the 2nd run side, 2 mm maximum below the surface in the two-run welded test assemblies;
iii. 2 mm maximum below one surface in the electroslag or electrogas welded test assemblies.

The notch shall be cut in the face of the test piece perpendicular to the surface of the plate and shall be positioned in the centre of the weld and, for electroslag and electrogas welded test assemblies, also at 2 mm from the fusion line in the deposited metal.

3.2 Testing procedures

3.2.1 Tensile tests are to be carried out on an approved tensile testing machine. On deposited metal test specimens, the values of tensile strength, yield stress and elongation are to be recorded. On butt weld specimens, the values of tensile strength are to be recorded together with the position of fracture.

3.2.2 Bend test specimens are to be capable of withstanding, without fracture or crack, being bent through an angle of 120° over a former having a diameter three times the thickness of the specimen. However, superficial cracks of less than 3 mm long on the outer surface should not be taken into consideration. For each set of bend tests one specimen is to be tested with the face of the weld in tension and the other with the root of the weld in tension except in the electroslag or electrogas welded test assemblies, where side bend tests are carried out in lieu of face and root bend tests.

3.2.3 Impact tests are to be carried out on a Charpy impact machine of an approved type. A set of three test specimens is to be prepared and tested. The average absorbed energy value is to comply with the requirements of subsequent SECTIONS of this Chapter. One individual value may be less than the required average value provided that it is not less than 70% of this value. The test temperature for Grades 2, 2Y, 2Y40, 3, 3Y, 3Y40, 4Y, 4Y40 and 5Y40 test pieces is to be controlled to within ±2°C of the prescribed temperature.

3.3 Re-test procedures

3.3.1 Where the result of a tensile or bend test does not comply with the requirements, duplicate test specimens of the same type are to be prepared and satisfactorily tested. Where insufficient original welded assembly is available, a new assembly is to be prepared using welding consumables from the same batch. If the new assembly is made with the same procedure (particularly the number of runs) as the original assembly, only the duplicate re-test specimens needs to be prepared and tested. Otherwise, all test specimens should be prepared as for re-testing.

3.3.2 Re-test requirements for Charpy impact tests are to be in accordance with Part 2, Chapter 2, SECTION 4, 4.4. Further re-tests may be made at the Surveyor's discretion, but these must be made on a new welded assembly and must include all tests required for the original assembly, even those which were previously satisfactory.

SECTION 4 Covered electrodes for manual arc welding

4.1 General

4.1.1. Depending on the results of the Charpy V-notch impact tests, electrodes are divided into the following grades:

- for normal strength steel: Grades 1, 2 and 3
- for higher strength steel with minimum yield strength up to 355 N/mm²: Grades 2Y and 3Y and 4Y (Grade 1Y not applicable for manual welding)
- for higher strength steels with minimum yield strength up to 390 N/mm²: Grades 2Y40, 3Y40, 4Y40 and 5Y40

4.1.2. If the electrodes are in compliance with the requirements of the hydrogen test given in a suffix H15, H10 or H5 will be added to the Grade mark.

4.2 Deposited metal tests

4.2.1 Two deposited metal test assemblies are to be prepared in the downhand position as shown in Figure 10.4.1, one with 4 mm diameter electrodes and the other with the largest size manufactured. If an electrode is available in one diameter only, one test assembly is sufficient. Any grade of ship structural steel may be used for the preparation of these test assemblies. The weld metal is to be deposited in single or multi-run layers according to normal practice, and the direction of deposition of each layer is to alternate from each end of the plate, each run of weld metal being not less than 2 mm and not more than 4 mm thick. Between each run, the assembly is to be left in still air until it has cooled to less than 250°C but not below 100°C, the temperature being taken in the centre of the weld, on the surface of the seam. After welding, the test assemblies are not to be subjected to any heat treatment.

4.2.2 At the discretion of LHR, the chemical analysis of the deposited weld metal in each test assembly is to be supplied by the manufacturer and is to include the content of all significant alloying element.

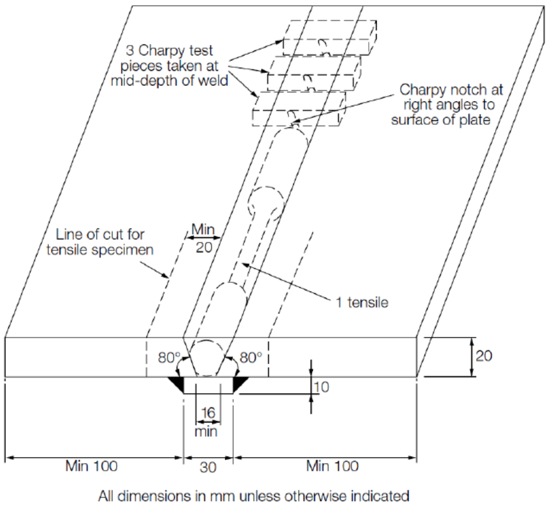
4.2.3 One tensile and three impact test specimens are to be taken from each test assembly as shown in Figure 10.4.1. Care is to be taken that the axis of the tensile test specimen coincides with the centre of the weld and the mid-thickness of the plates. Tests are to be performed according to SECTION 3 of this Chapter.

4.2.4 The results of all tests are to comply with the requirements of Table 10.4.1 as appropriate.

Table 10.4.1: Requirements for deposited metal tests (covered manual electrodes)

Grade	Yield stress N/mm^2 minimum	Tensile strength N/mm^2	Elongation on 50 mm gauge length (L_0=5 d) % minimum	Charpy V-notch impact tests	
				Test Temperature °C	Average Energy J minimum
1 2 3	305	400-560	22	20 0 -20	47 47 47
2Y 3Y 4Y	375	490-660	22	0 -20 -40	47 47 47
2Y40 3Y40 4Y40 5Y40	400	510-690	22	0 -20 -40 -60	47 47 47

Figure 10.4.1: Deposited metal test assembly



4.3 Butt weld tests

4.3.1 Butt weld assemblies as shown in Figure 10.4.2 are to be prepared for each welding position (downhand, horizontal-vertical, vertical-upward, vertical-downward and overhead) for which the electrode is recommended by the manufacturer, except that electrodes satisfying the requirements for downhand and vertical-upward positions will be considered as also complying with the requirements for the horizontal-vertical position subject to the agreement of LHR.

4.3.2 Where the electrode is to be approved only in the downhand position, an additional test assembly is to be prepared in that position.

4.3.3 The steel grades and the individual electrode grades used for the preparation of the test assemblies are to be as follows:

(1) Grade 1 electrodes LHR-A

(2)	Grade 2 electrodes	LHR-A, LHR-B, LHR-D
(3)	Grade 3 electrodes	LHR-A, LHR-B, LHR-D, LHR-E
(4)	Grade 2Y electrodes	AH-32, AH-36, DH-32, DH-36
(5)	Grade 3Y electrodes	AH-32, AH-36, DH-32, DH-36, EH-32, EH-36.
(6)	Grade 4Y electrodes	AH-32, AH-36, DH-32, DH-36, EH-32, EH-36, FH-32, FH-36
(7)	Grade 2Y40 electrodes	A-40, D-40
(8)	Grade 3Y40 electrodes	A-40, D-40, E-40
(9)	Grade 4Y40 electrodes	A-40, D-40, E-40, F-40
(10)	Grade 5Y40 electrodes	A-40, D-50, E-40, F-40

Where higher strength steel with minimum yield strength 315 N/mm² is used for Grade 2Y, 3Y and 4Y electrodes, the actual tensile strength of the steel is to be not less than 490 N/mm². The chemical composition including the content of grain refining elements is to be reported.

4.3.4 The test assemblies are to be made by welding in accordance with Figure 10.4.2. The following welding procedure is to be adopted in making the test assemblies:

1. Downhand (a). The first run with 4 mm diameter electrode. Remaining runs (except the last two layers) with 5 mm diameter electrodes or above according to the normal welding practice with the electrodes. The runs of the last two layers with the largest diameter of electrode manufactured.

2. Downhand (b). (Where a second downhand test is required). First run with 4 mm diameter electrode. Next run with an electrode of intermediate diameter of 5 mm or 6 mm, and the remaining runs with the largest diameter of electrode manufactured.

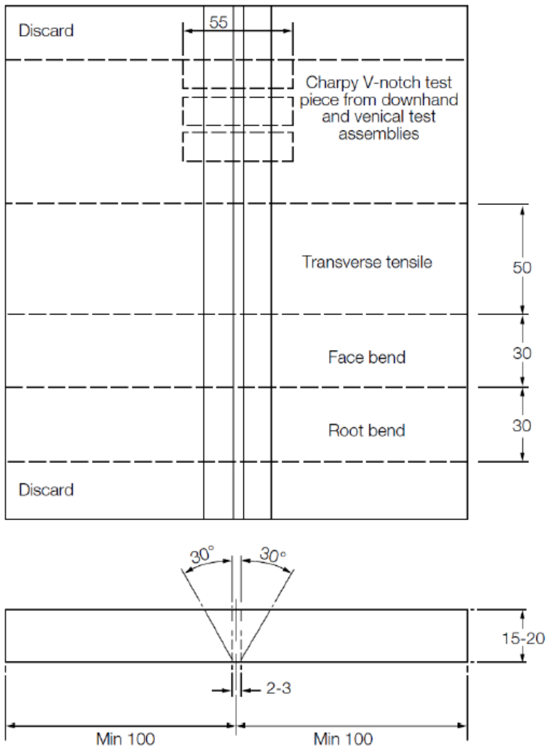
3. Horizontal-vertical. First run with 4 mm or 5 mm diameter electrode. Subsequent runs with 5 mm diameter electrodes.

4. Vertical-upward and overhead. First run with 3,25 mm diameter electrode. Remaining runs with 4 mm diameter electrodes or possibly with 5 mm, if this is recommended by the manufacturer for the positions concerned.

5. Vertical-downward. If the electrode tested is intended for vertical welding in the downward direction, this technique is to be adopted for the preparation of the test assembly using electrode diameters as recommended by the manufacturer.

For all assemblies the back sealing runs are to be made with 4 mm diameter electrodes in the welding position appropriate to each test sample, after cutting out the root run to clean metal. For electrodes suitable for downhand welding only, the test assemblies may be turned over to carry out the back sealing run. Normal welding practice is to be used, and between each run the assembly is to be left in still air until it has cooled to less than 250°C but not below 100°C, the temperature being taken in the centre of the weld, on the surface of the seam. After welding, the test assemblies are not to be subjected to any heat treatment.

Figure 10.4.2: Butt weld test assembly



All dimensions in mm unless otherwise indicated

4.3.5 It is recommended that the welded assemblies be subjected to a radiographic examination to ascertain if there are any defects in the weld prior to the preparation of test specimens.

4.3.6 The test specimens as shown in Figure 10.4.2 are to be prepared from each test assembly. Tests are to be performed according to SECTION 3 of this Chapter.

4.3.7 The results of all tensile and impact tests are to comply with the requirements of Table 10.4.2 as appropriate. The position of fracture in the transverse tensile test is to be reported. The bend test specimens can be considered as complying with the requirements if, after bending, no crack or defect having any dimensions exceeding 3 mm can be seen on the outer surface of the test specimen.

Table 10.4.2: Requirements for butt weld test (covered manual electrodes)

Grade	Tensile strength (transverse test) N/mm²	Charpy V-notch impact tests		
		Test Temperature °C	Average energy - J minimum	
			Downhand, horizontal-vertical, overhead	Vertical (upward and downward)
1	400	20	47	34
2		0	47	34
3		-20	47	34
2Y	490	0	47	34
3Y		-20	47	34
4Y		-40	47	34

2Y 40 3Y 40 4Y 40 5Y 40	510	0 -20 -40 -60	47 47 47 47	39 39 39 39

4.4 Hot cracking test

4.4.1 Hot cracking test may be required at the discretion of LHR.

4.5 Hydrogen test

4.5.1 At the request of the manufacturer, electrodes may be submitted to a hydrogen test. A suffix H15, H10 or H5 will be added to the grade number to indicate compliance with the requirements of this test.

4.5.2 The mercury method or thermal conductivity detector method according to Standard ISO 3690-1977:2018 as amended is to be used. Four weld assemblies are to be prepared. The temperature of the specimens and minimum holding time are to be complied with following, according to the measuring method respectively:

Measuring Method		Test Temperature (°C)	Minimum Holding Time (h)
Thermal Conductivity Detector Method (1)	Gas Chromatography	45	72
		150	6

Note:
(1): The use of hot carrier gas extraction method may be considered subject to verification of the testing procedure to confirm that collection and measurement of the hydrogen occurs continuously until all of the diffusible hydrogen is quantified.

The use of the glycerin method may be admitted at the discretion of LHR. This method is described hereafter:

Four test specimens are to be prepared, measuring 12 mm by 25 mm in cross section by about 125 mm in length. The parent metal may be any grade of ship structural steel and before welding, the specimens are to be weighed to the nearest 0,1 gram. On the 25 mm surface of each test specimen, a single bead of welding is to be deposited, about 100 mm in length, by a 4 mm electrode, fusing 150 mm of the electrode. The welding is to be carried out with an arc as short as possible and with a current of about 150 A.

The electrodes, prior to welding, can be submitted to the normal drying process recommended by the manufacturer. Within 30 seconds of the completion of the welding of each specimen the slag is to be removed and the specimen quenched in water at approximately 20°C.

After 30 seconds in the water, the specimen is to be cleaned and dried, and then placed in an apparatus suitable for the collection of hydrogen by displacement of glycerine. The glycerine is to be kept at a temperature of 45°C during the test. All four specimens are to be welded and placed in individual hydrogen collecting apparatus within a period of time which will limit any variation in hydrogen content due to variation in exposure to moisture absorption following any driving treatment. This should not exceed 30 minutes.

The specimens are to be kept immersed in the glycerin for a period of 48 hours and, after removal, are to be cleaned in water and spirit dried and weighed to the nearest 0,1 gram to determine the amount of weld deposit. The amount of gas involved is to be measured to the nearest 0,05 cm^3 and corrected for temperature and pressure to 0°C and 760 mm Hg.

4.5.3 The individual and average diffusible hydrogen contents of the four specimens are to be reported, and the average value in cm^3 per 100 grams is not to exceed the following:

Mark	Diffusible Hydrogen Contents	Measuring Method
H 15	15(1)	Mercury Method Thermal Conductivity Detector Method Glycerine Method
H 10	10(2)	
H 5	5	Mercury Method Thermal Conductivity Detector Method
(1): 10 cm^3 per 100 grams where the glycerine method is used. (2): 5 cm^3 per 100 grams where the glycerine method is used.		

Note: The glycerine method is not to be used for the welding consumables with H5 mark.

4.6 Covered electrodes for manual fillet welding

4.6.1 Where an electrode is submitted only to approval for fillet welding and to which the butt weld test provided in 4.3 is not considered applicable, the first approval tests are to consist of the fillet weld tests given in 4.6.2 and deposited metal tests similar to those indicated in 4.2. Where an electrode is submitted to approval for both butt and fillet welding, the first approval tests may, at the discretion of LHR, include one fillet weld test as detailed hereunder and welded in the horizontal-vertical position.

4.6.2 When the electrode is proposed only for fillet welding, fillet weld assemblies as shown in Figure 10.4.3 are to be prepared for each welding position (horizontal-vertical, vertical upwards, vertical downwards or overhead) for which the electrode is recommended by the manufacturer. The length of the test assemblies L is to be sufficient to allow at least the deposition of the entire length of the electrode being tested. The grade of steel used for the test assemblies is to be as detailed in 4.3.1. The first side is to be welded using the maximum size of electrode manufactured and the second side is to be welded using the minimum size of electrode manufactured and recommended for fillet welding. The fillet size will in general be determined by the electrode size and the welding current employed during testing.

4.6.3 Each test assembly is to be sectioned to form three macro-sections each about 25 mm thick. They are to be examined for root penetration, satisfactory profile, freedom from cracking and reasonable freedom from porosities, undercuts and slag inclusions.

4.6.4 At the discretion of LHR, the hardness of the weld, of the heat affected zone (HAZ) and of parent metal may be determined, and reported for information (see Figure 10.4.4).

4.6.5 One of the remaining sections of the fillet weld is to have the weld on the first side gouged or machined to facilitate breaking the fillet weld, on the second side by closing the two plates together, submitting the root of the weld to tension. On the other remaining section, the weld on the second side is to be gouged or machined and the section fractured using the same procedure. The fractured surfaces are to be examined and there should be no evidence of incomplete penetration, or internal cracking and they should be reasonably free from porosity.

Figure 10.4.3 Fillet weld test assembly

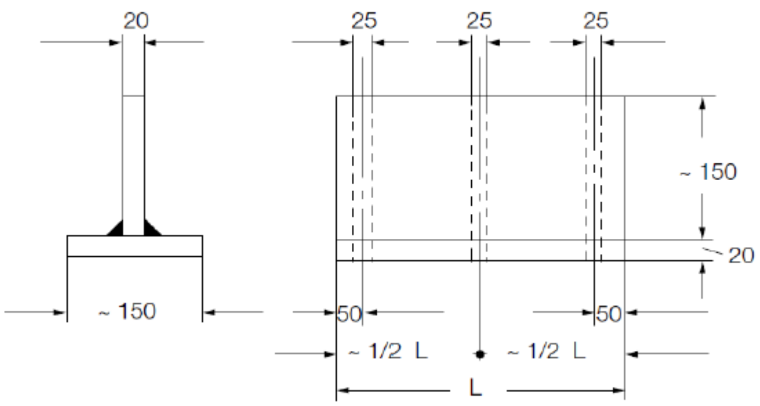
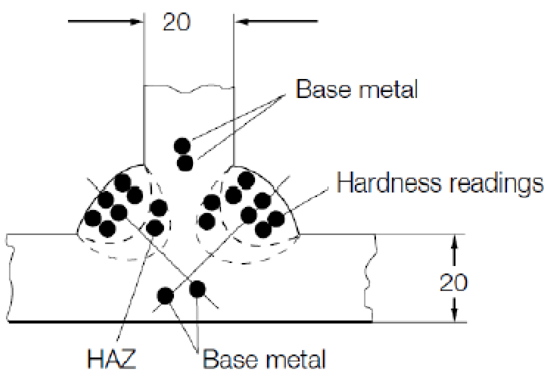


Figure 10.4.4: Hardness readings



4.7 Covered electrodes for gravity or contact welding

4.7.1 Where an electrode is submitted solely to approval for use in contact welding using automatic gravity or similar welding devices, deposited metal tests, fillet weld tests (see 4.6) and, where appropriate, butt weld tests similar to those for normal manual electrodes are to be carried out using the process for which the electrode is recommended by the manufacturer.

4.7.2 Where a covered electrode is submitted to approval for use in contact welding using automatic gravity or similar welding devices in addition to normal manual welding, fillet weld and, where appropriate, butt weld tests, using the gravity of other contact device as recommended by the manufacturer, are to be carried out in addition to the normal approval tests.

4.7.3 In the case of approval of a fillet welding electrode using automatic gravity or similar contact welding devices, the fillet welding should be carried out using the welding process recommended by the manufacturer, with the longest size of the electrode manufactured. The manufacturer's recommended current range is to be reported for each electrode size.

4.7.4 Where approval is requested for the welding of both normal strength and higher strength steel, the assemblies are to be prepared using higher strength steel.

4.8 Annual tests and upgrading

4.8.1 All establishments where approved electrodes are manufactured shall be subject to annual inspection.

4.8.2 The annual tests are to consist of at least the following:

a) Covered electrode for normal manual arc welding.

   Two deposited metal test assemblies are to be prepared in accordance with 4.2. The mechanical properties (one tensile test, three Charpy-V impact tests on each assembly) are to be in accordance with Table 10.4.1. This also applies to electrodes which are approved only for fillet welding.

   At the discretion of LHR a butt weld test to be welded in down-hand or in vertical position, can be required in lieu of the deposited metal test 4 mm electrodes. Three Charpy V-notch impact test specimens are to be taken from the butt weld assembly. For Mark H10 and Mark H5 covered electrodes, a hydrogen test following 4.5 can also be required for each annual test at the discretion of LHR.

b) Covered electrodes for gravity or contact welding.

   Where an electrode is approved solely for gravity or contact welding, the annual test is to consist of one deposited metal test assembly using the gravity or other contact device as recommended by the manufacturer. If this electrode is approved also for normal manual arc welding the annual test is to be performed according to 4.8.2(a).

4.8.3 Upgrading and uprating of electrodes will be considered only at the manufacturer's request, preferably at the time of annual testing. Generally, for this purpose, tests on butt-weld assemblies will be required in addition to the normal re-approval tests.

4.8.4 Upgrading of electrodes refers to notch toughness and consequently, only Charpy-V impact tests are required from the respective butt-weld assemblies as required by 4.3 (downhand, horizontal vertical, vertical up or/and down, overhead, as applicable), and have to be performed at the upgraded temperature. These butt-weld tests are to be made in addition to the normal requirements for annual deposited metal tests (which have, of course, to take into consideration the upgraded temperature for Charpy-V specimens).

4.8.5 Uprating of electrodes refers to the extension of approval in order to cover the welding of higher strength steels; of course, welding of normal strength steels continue to be covered by the extended approval, as stated in 1.2.1. For this purpose all butt-weld tests are to be made again, as required in 4.3 and using higher strength steel, as parent metal.

SECTION 5 Wire-flux combinations for submerged arc welding

5.1 General

5.1.1 Wire-flux combinations for single electrode submerged arc automatic welding are divided into the following two categories:

- For use with the multi-run technique.
- For use with the two-run technique.

Where particular wire-flux combinations are intended for welding with both techniques, tests are to be carried out for each technique.

5.1.2 Depending on the results of impact tests, wire-flux combinations are divided into the following grades:

- For normal strength steel: Grades 1, 2 or 3.
- For higher strength steels with minimum yield strength up to 355 N/mm²: Grades 1Y, 2Y, 3Y or 4Y.
- For higher strength steels with minimum yield strength up to 390 N/mm²: Grades 2Y40, 3Y40, 4Y40 or 5Y40.

The suffixes T, M or TM will be added after the grade mark to indicate approval for the two-run technique, multi-run technique or both techniques, respectively.

5.1.3 Wire-flux combinations for multiple electrode submerged arc welding will be subject to separate approval tests. They are to be carried out generally in accordance with the requirements of this section.

5.1.4 Mechanical tests on assemblies with submerged arc welding for wire-flux approval are given in Table 10.5.1.

Table 10.5.1: General table giving the mechanical tests on assemblies with submerged arc welding for wire/flux approval

<table>
<tr><th colspan="2">M
(multi-run technique)</th><th colspan="2">T
(two-run technique)</th><th colspan="4">TM
(two-run and multi-run technique)</th></tr>
<tr><th rowspan="3">Deposited metal assembly</th><th rowspan="3">Butt weld assembly</th><th rowspan="3">Butt weld assembly (minimum thickness)</th><th rowspan="3">Butt weld assembly (maximum thickness)</th><th rowspan="3">Deposited metal assembly</th><th colspan="3">Butt Weld Assembly</th></tr>
<tr><th rowspan="2">Multi-run technique</th><th colspan="2">Two-run technique</th></tr>
<tr><th>(Minimum thickness)</th><th>(Maximum thickness)</th></tr>
<tr><td>3 CV
2 LT</td><td>2 TT
4 TB
3 CV</td><td>2 TT
2 TB
3 CV</td><td>2 TT
2 TB
3 CV
1 LT</td><td>3 CV
1 LT</td><td>2 TT
4 TB
3 CV</td><td>2 TT
2 TB
3 CV</td><td>2 TT
2 TB
3 CV
1 LT</td></tr>
</table>

Symbol definition:

TT: Transverse Tensile Test on the butt weld assembly

TB: Transverse Bend Test on the butt weld assembly

CV: Charpy-V Impact Test in the axis of the weld

LT: Longitudinal Tensile Test in the weld

5.2 Approval tests for multi-run technique

5.2.1 Where approval for use with the multi-run technique is requested, deposited metal and butt weld tests are to be carried out. For deposited metal test assembly any grade of ship structural steel may be used. For butt weld test assembly one of the grades of steel as listed below for the individual grades of wire-flux combinations shall be used:

(1) Grade 1 wire-flux combinations: LHR-A

(2) Grade 2 wire-flux combinations: LHR-A, LHR-B, LHR-D

(3) Grade 3 wire-flux combinations: LHR-A, LHR-B, LHR-D, LHR-E

(4) Grade 1Y wire-flux combinations: AH-32, AH-36

(5) Grade 2Y wire-flux combinations: AH-32, AH-36, DH-32, DH-36

(6) Grade 3Y wire-flux combinations: AH-32, AH-36, DH-32, DH-36, EH-32, EH-36

(7) Grade 4Y wire-flux combinations: AH-32, AH-36, DH-32, DH-36, EH-32, EH-36, FH-32, FH-36

(8) Grade 2Y40 wire-flux combinations: A-40, D-40

(9) Grade 3Y40 wire-flux combinations: A-40, D-40, E-40

(10) Grade 4Y40 wire-flux combinations: A-40, D-40, E-40, F-40

5.3 Deposited metal test assemblies (multi-run technique)

5.3.1 One deposited metal test assembly is to be prepared as shown in Figure 10.5.1.

5.3.2 Welding is to be carried out in the downhand position, and the direction of deposition of each run is to alternate from each end of the plate. After completion of each run, the flux and welding slag is to be removed. Between each run the assembly is to be left in still air until it has cooled to less than 250°C, but not below 100°C, the temperature being taken in the centre of the weld, on the surface of the seam. The thickness of the layer is to be neither less than the diameter of the wire nor less than 4 mm.

5.3.3 The welding conditions, including amperage, voltage and rate of travel are to be in accordance with the recommendations of the manufacturer and are to conform with normal good welding practice for multi-run welding.

5.3.4 At the discretion of LHR, the chemical analysis of the deposited weld metal in this test assembly is to be supplied by the manufacturer and is to include the content of all significant alloying elements.

5.3.5 In accordance with Table 10.5.1, the test specimens as shown in Figure 10.5.1 are to be prepared from each test assembly. Tests are to be performed according to requirements of SECTION 3 of this Chapter.

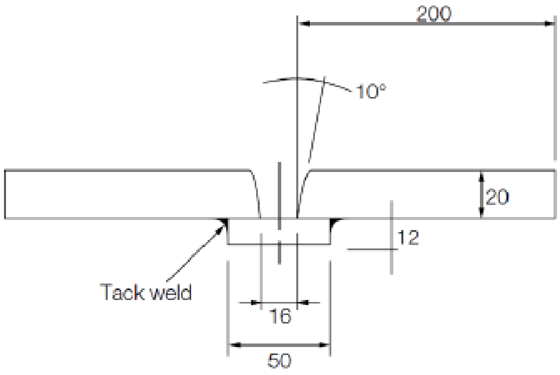
5.3.6 The results of all tests are to comply with the requirements of Table 10.5.2 as appropriate.

Table 10.5.2: Requirements for deposited metal tests (wire-flux combinations)

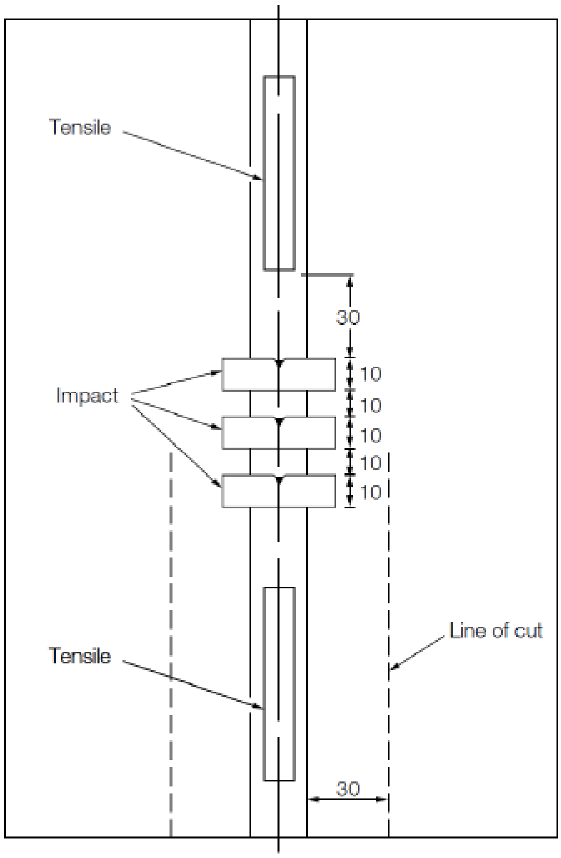
Grade	Yield stress N/mm² minimum	Tensile strength N/mm²	Elongation on 50 mm gauge length (L_o = 5 d) % minimum	Charpy V-notch impact tests	
				Test Temperature °C	Average Energy J minimum
1 2 3	305	400-560	22	20 0 -20	34 34 34
1Y 2Y 3Y 4Y	375	490-660	22	20 0 -20 -40	34 34 34 34
2Y40 3Y40	400	510-690	22	0 -20	39 39

4Y40 5Y40				-40 -60	39 39

Figure 10.5.1



All dimensions in mm unless otherwise indicated



All dimensions in mm unless otherwise indicated

5.4 Butt weld test assembly (multi-run technique)

5.4.1 One butt weld test assembly is to be prepared as shown in Figure 10.5.2 in the downhand position by welding together two plates (20 to 25 mm thick), each not less than 150 mm in width and of sufficient length to allow the cutting out of test specimens of the prescribed number and size.

5.4.2 The plate edges are to be prepared to form a single vee joint, the included angle between the fusion faces being 60° and the root face being 4 mm.

5.4.3 The welding is to be carried out by the multi-run technique and the welding conditions are to be the same as those adapted for the deposited metal test assembly. The back sealing run is to be applied in the downhand position after cutting out the root run to clean metal. After welding the test assembly is not to be subject to any heat treatment.

5.4.4 It is recommended that the welded assembly be subject to a radiographic examination to ascertain if there are any defects in the weld prior to the preparation of test specimens.

5.4.5 The test specimens to be prepared from the welded assembly are given in Table 10.5.1 and shown in Figure 10.5.2. The tests are to be performed according to the requirements of SECTION 3 of this Chapter.

5.4.6 The results of all tensile and impact tests are to comply with the requirements of Table 10.5.3 as appropriate. The position of the fracture in the transverse tensile test is to be reported.

5.4.7 The bend test specimens can be considered as complying with the requirements if, after bending, no crack or defect, having any dimension exceeding 3 mm can be seen on the outer surface of the test specimen.

Table 10.5.3: Requirements for butt weld tests (wire-flux combinations)

Grade	Tensile strength (transverse test) (N/mm²)	Charpy V-notch impact test	
		Test temperature (°C)	Average energy (J) minimum
1 2 3	400	20 0 -20	34 34 34
1Y 2Y 3Y 4Y	490	20 0 -20 -40	34 34 34 34
2Y40 3Y40 4Y40 5Y40	510	0 -20 -40 -60	39 39 39 39

5.5 Approval tests for two-run techniques

5.5.1 Where approval for use with the two-run technique is requested, two butt weld test assemblies are to be prepared using the following thicknesses:

(1) For Grades 1 and 1Y — 12 to 15 mm and 20 to 25 mm

(2) For Grades 2, 2Y, 3, 3Y and 4Y — 20 to 25 mm and 30 to 35 mm.

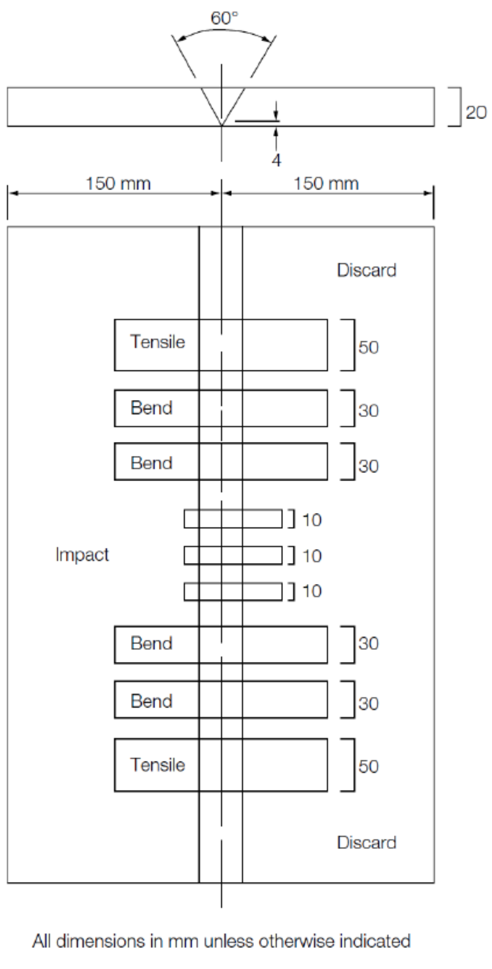
(3) For Grades 2Y40, 3Y40, 4Y40 and 5Y40 — 20 to 25 mm and 30 to 35 mm.

A limitation of the approval to the medium range (up to the maximum welded plate thickness) may be agreed to by LHR. Test assemblies shall then be welded using plates of 12 to 15 mm and 20 to 25 mm irrespective of the grade for which the approval is requested.

When a wire-flux combination is offered to approval for use with the two-run technique only, it is reminded that no deposited metal test assemblies have to be done. In this case approval tests are limited to the butt welds on two-run assemblies described in 5.6.

5.5.2 Where approval is requested for welding of both normal strength and higher tensile steel two assemblies are to be prepared using higher tensile steel. Two assemblies prepared using normal strength steel may also be required at the discretion of LHR.

Figure 10.5.2: Multi-run butt weld test assembly (submerged arc welding)



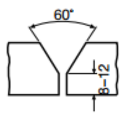
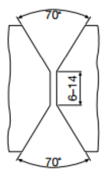
5.6 Butt weld test assemblies (two-run technique)

5.6.1 The maximum diameter of wire, grades of steel plate and edge preparation to be used are to be in accordance with Table 10.5.4. Small deviations in the edge preparation may be allowed if requested by the manufacturer. The root gap should not exceed 1 mm.

5.6.2 Each butt weld is to be welded in two runs, one from each side, using amperages, voltages and travel speeds in accordance with the recommendations of manufacturer and normal good welding practice. After completion of the first run, the flux and welding slag are to be removed and the assembly is to be left in still air until it has cooled to 100°C, the temperature being taken in the centre of the weld, on the surface of the seam. After welding, the test assemblies are not to be subjected to any heat treatment.

5.6.3 It is recommended that the welded assemblies be subjected to radiographic examination to ascertain if there are any defects in the weld prior to the preparation of test specimens.

Table 10.5.4: Butt weld test assemblies (two-run technique)

Plate thickness [mm]	Recommended preparation [mm]	Maximum diameter of wire [mm]	Grade wire-flux combination	Grade of normal strength steel	Grade of higher strength steel
about 12-15		5	1 1Y	LHR-A -	AH-32, AH-36
about 20-25		6	1 1Y 2 2Y 2Y40 3 3Y 3Y40 4Y 4Y40 5Y40	LHR-A - LHR-A, -B or -D - - LHR -A, -B, -D or -E - - - - -	- AH-32, AH-36 - AH-32, AH-36, DH-32, DH-36 A-40, D-40 - AH-32, AH-36, DH-32, DH-36, EH-32, EH-36 A-40, D-40, E-40 AH-32, AH-36, DH-32. DH-36, EH-32, EH-36, FH-32, FH-36 A-40, D-40, E-40, F-40 A-40, D-40, E-40, F-40
about 30-35		7	2 2Y 2Y40 3 3Y 3Y40 4Y 4Y40 5Y40	LHR-A, -B or -D - - LHR-A, -B, -D, or -E - - - - -	- AH-32, AH-36, DH-32, DH-36 A-40, D-40 - AH-32, AH-36, DH-32, DH-36, EH-32, EH-36 A-40, D-40, E-40 AH-32, AH-36, DH-32, DH-36 EH-32, EH-36, FH-32, FH-36 A-40, D-40, E-40. F-40 A-40, D-40, E-40, F-40

5.6.4 The test specimens indicated in Table 10.5.1 and shown in Figure 10.5.3 are to be prepared from each test assembly. Tests are to be performed according to the requirements of SECTION 3 of this Chapter. The Charpy V-notch impact test pieces are to be machined from each welded assembly from the positions and with the orientations shown in Figure 10.5.4.

5.6.5 The results of all tensile and impact tests are to comply with the requirements of Table 10.5.2 and Table 10.5.3, as appropriate. The position of fracture in the transverse tensile test is to be reported. The bend test specimens can be considered as complying with the requirements if, after bending, no crack or defect having any dimensions exceeding 3 mm can be seen on the outer surface of the test specimen.

5.6.6 The chemical analysis of the weld metal is to be supplied by the manufacturer, and is to include the content of all significant alloying elements.

5.7 Annual tests and upgrading

5.7.1 All establishments where approved wire/flux combinations are manufactured shall be subject to annual inspection.

5.7.2 Annual tests are to consist of at least the following:

1. Multi-run technique: one deposited metal assembly and tests: one tensile and three impact tests.
2. Two-run technique: one butt weld assembly with 20 mm minimum thickness plate and tests: one transverse tensile, two transverse bends and three impact tests. One longitudinal tensile test specimen is also to be prepared where the wire-flux combination is approved solely for the two-run technique.

5.7.3 The assemblies are to be prepared and tested in accordance with the requirements for first approval.

5.7.4 Where a wire-flux combination is approved for welding both normal strength and higher tensile steel, the latter steel is to be used for the preparation of the butt weld assembly required by 5.7.2(2).

5.7.5 Upgrading of wire-flux combinations in connection with the impact properties will be considered as detailed in 4.8.4, and for wire-flux combinations approved for two runs welding, a butt-weld in the maximum thickness approved is to be made and sampled for Charpy-V testing in accordance with 5.6.4.

5.7.6 Uprating of wire-flux combinations in connection with the tensile properties will be considered as detailed in 4.8.5.

Figure 10.5.3:

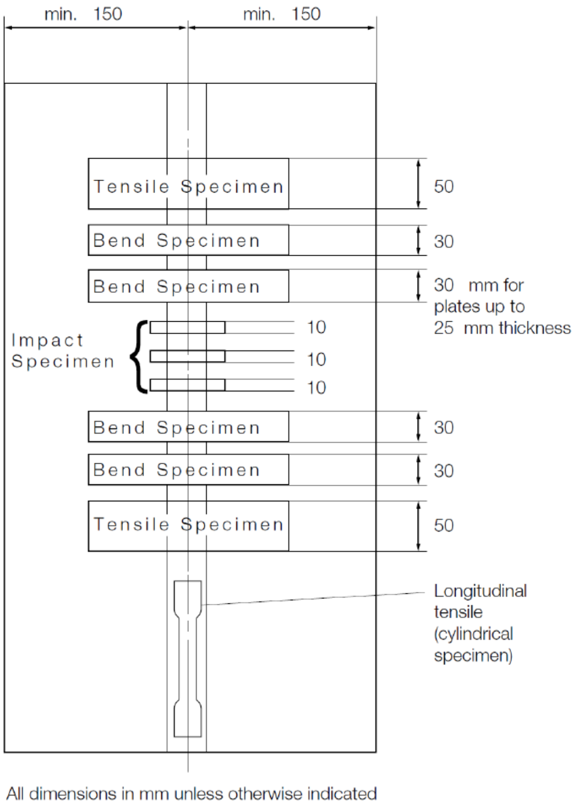
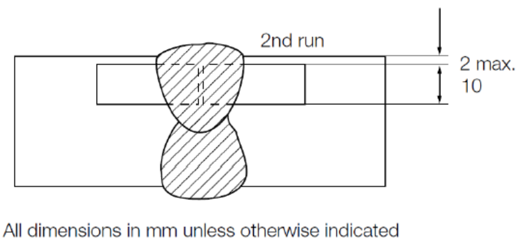


Figure 10.5.4



SECTION 6 Wires and wire-gas combinations for metal arc welding

6.1 General

6.1.1 Wire-gas combinations and flux-cored or flux-coated wires (for use with or without a shielding gas) are divided into the following categories for the purposes of approval testing:

(1) For use in semi-automatic multi-run welding.

(2) For use in single electrode automatic multi-run welding.

(3) For use in single electrode automatic two-run welding.

6.1.2 The term semi-automatic is used to describe processes in which the weld is made manually by a welder holding a gun through which the electrode wire is continuously fed.

6.1.3 Depending on the results of impact tests, wires and wire-gas combinations are divided into the following grades:

- For normal strength steel: Grades 1, 2 and 3.
- For higher strength steels with minimum yield strength up to 355 N/mm^2: Grades 1Y, 2Y, 3Y and 4Y.
- For higher strength steels with minimum yield strength up to 390 N/mm^2: Grades 2Y40, 3Y40, 4Y40 and 5Y40.

6.1.4 A suffix "S" will be added after the grade mark to indicate approval for semi-automatic multi-run welding.

6.1.5 For wires intended for automatic welding, the suffixes "T", "M" or "TM" will be added after the grade mark to indicate approval for two-run, multi-run, or both welding techniques, respectively.

6.1.6 For wires intended for both semi-automatic and automatic welding, the suffixes will be added in combination.

6.1.7 Where applicable, the composition of the shielding gas is to be reported. Unless otherwise agreed by LHR, additional approval tests are required when a shielding gas is used other than that used for the original approval tests.

6.1.8 The approval of a wire in combination with any particular gas can be applied or transferred to any combination of the same wire and any gas in the same numbered group as defined in Table 10.6.1 subject to the agreement of LHR.

6.1.9 Flux-cored or flux-coated wires which have satisfied the requirements for Grades 2, 2Y, 2Y40, 3, 3Y40, 4Y, 4Y40 and 5Y40 may, at manufacturer's option, be submitted to the hydrogen test as detailed in 4.5, using the manufacturer's recommended welding conditions and adjusting the deposition rate to give a weight of weld deposit per sample similar to that deposited when using manual electrodes. A suffix H15, H10 or H5 will be added to the grade mark, in the same conditions as for manual arc welding electrodes (see 4.5.3 above) to indicate compliance with the requirements of the test.

Table 10.6.1: Compositional limits of designated groups of gas types and mixtures

Group		Gas composition (Vol. %)			
		CO_2	O_2	H_2	A_r
M1	1	0 < ... ≤ 5	-	0 < ... ≤ 5	Rest (1) (2)
	2	0 < ... ≤ 5	-	-	Rest (1) (2)
	3	-	0 < ... ≤ 3	-	Rest (1) (2)
	4	0 < ... ≤ 5	0 < ... ≤ 3	-	Rest (1) (2)
M2	1	5 < ... ≤ 25	-	-	Rest (1) (2)
	2	-	3 < ... ≤ 10	-	Rest (1) (2)
	3	5 < ... ≤ 25	0 < ... ≤ 8	-	Rest (1) (2)
M3	1	25 < ... ≤ 50	-	-	Rest (1) (2)
	2	-	10 < ... ≤ 15	-	Rest (1) (2)
	3	5 < ... ≤ 50	8 < ... ≤ 15	-	Rest (1) (2)

C	1	100	-	-	-
	2	Rest	0 < ... ≤ 30	-	-

(1): Argon may be substituted by Helium up to 95% of the Argon content.
(2): Approval covers gas mixtures with equal or higher Helium contents only.

6.2 Approval for semi-automatic multi-run welding

6.2.1 Approval tests for semi-automatic multi-run welding are to be carried out generally in accordance with SECTION 4, except as required by 6.2, using the semi-automatic multi-run technique for the preparation of all test assemblies.

6.2.2 Two deposited metal test assemblies are to be prepared in the downhand position, as shown in Figure 10.4.1, one using the smallest diameter, and the other using the largest diameter of wire intended for the welding of ship structures. Where only one diameter is manufactured, only one deposited metal assembly is to be prepared.

6.2.3 The weld metal is to be deposited according to the practice recommended by the manufacturer, and the thickness of each layer of weld metal is to be between 2 and 6 mm.

6.2.4 The chemical analysis of the deposited weld metal in each test assembly is to be supplied by the manufacturer, and is to include the content of all significant alloying elements.

6.2.5 On each assembly, tests are to be made in accordance with 4.2.3, and the results are to comply with the requirements of 4.2.4, appropriate to the required grade.

6.2.6 Butt weld assemblies as shown in Figure 10.4.2 are to be prepared for each welding position (downhand, horizontal-vertical, vertical upwards, vertical downwards and overhead) for which the wire or wire-gas combination is recommended by the manufacturer.

6.2.7 The downhand assembly is to be welded using, for the first run, wire of the smallest diameter to be approved and, for the remaining runs, wire of the largest diameter to be approved.

6.2.8 Where approval is requested only in the downhand position, an additional butt weld assembly is to be prepared in that position using wires of different diameter from those required by 6.2.7. Where only one diameter is manufactured, only one downhand butt weld assembly is to be prepared.

6.2.9 The butt weld assemblies in positions other than downhand, are to be welded using, for the first run, wire of the smallest diameter to be approved, and, for the remaining runs, the largest diameter of wire recommended by the manufacturer for the position concerned.

6.2.10 It is recommended that the welded assemblies are subjected to radiographic examination to ascertain if there are any defects in the welds prior to the preparation of test specimens.

6.2.11 On each assembly, tests are to be made in accordance with 4.3.6, and the results are to comply with the requirements of 4.3.7.

6.2.12 Fillet weld test assemblies are required to be made and tested in accordance with 4.6.

6.3 Approval for automatic multi-run welding

6.3.1 Approval tests for automatic multi-run welding are to be carried out generally in accordance with the requirements of SECTION 5, except as required by 5.2 using the automatic multi-run technique for the preparation of all test assemblies.

6.3.2 One deposited metal assembly is to be prepared as shown in Figure 10.5.1. Welding is to be as detailed in 5.3.1 to 5.3.3, except that the thickness of each layer is to be not less than 3 mm.

6.3.3 The chemical analysis of the deposited weld metal in this test assembly is to be supplied by the manufacturer, and is to include the content of all significant alloying elements.

6.3.4 Tests on this assembly are to be made in accordance with 5.3.5 and the results are to comply with the requirements of 5.3.6.

6.3.5 One butt weld assembly is to be prepared in each welding position which is to be approved. Generally, this will be the downhand position only, in which case only one assembly is required. Preparation of the assembly is to be in accordance with 5.4.1 to 5.4.3.

6.3.6 It is recommended that each assembly be subjected to a radiographic examination to ascertain any defect in the weld prior to testing.

6.3.7 Tests are to be made on each assembly in accordance with 5.4.5 and the results are to comply with the requirements of Table 10.5.3. Where more than one assembly is prepared and tested, the number of transverse tensile and bend test specimens from each assembly may be halved.

6.3.8 At the discretion of LHR, wires or wire-gas combinations approved for semi-automatic multi-run welding may also be approved, without additional tests, for automatic multi-run welding approval. This is generally the case when automatic multi-run welding is performed in the same conditions of welding current and energy as semi-automatic welding with the concerned wire-gas combination. The only difference between the two welding processes in this case is that the welding gun is held by an automatic device instead of the welder's hand.

6.4 Approval for automatic two-run welding

6.4.1 Approval tests for automatic two-run welding are to be carried out generally in accordance with the requirements of 5.5 and 5.6, except as required by this Subsection, using the automatic two-run welding technique for the preparation of all test assemblies.

6.4.2 Two butt weld test assemblies are to be prepared, generally as detailed in 5.5 and 5.6, using plates 12-15 mm and 20-25 mm in thickness. If approval is requested for welding plate thicker than 25 mm, one assembly is to be prepared using plates approximately 20 mm in thickness and the other using plates of the maximum thickness for which approval is requested.

6.4.3 The plate preparation of the test assemblies is to be as shown in Figure 10.6.1. Small deviations in the edge preparation may be allowed, if requested by the manufacturer. For assemblies using plates over 25 mm in thickness, the edge preparation is to be reported for information. Deviations or variations will be expected to form part of the manufacturer's standard recommended procedure for this technique and thickness range.

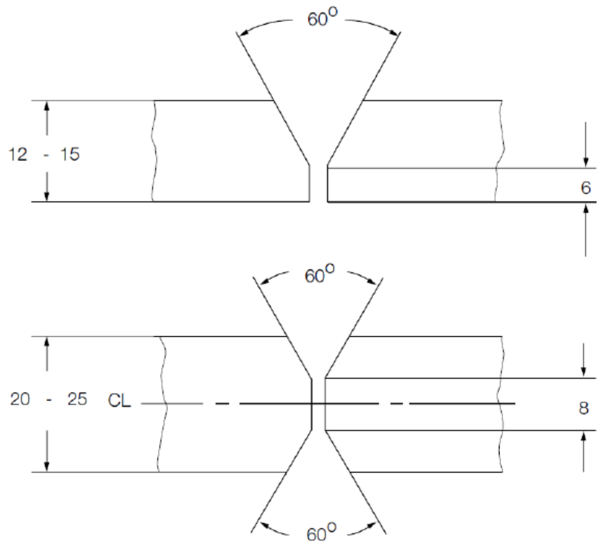
6.4.4 The diameters of wires used are to be in accordance with the recommendations of the manufacturer and are to be reported.

6.4.5 It is recommended that the welded assemblies be subjected to radiographic examination to ascertain any defect in the weld prior to testing, and to confirm full penetration continuously along the major part of the welded length of each assembly.

6.4.6 Tests are to be made on each assembly in accordance with 5.6.4 to 5.6.6 and the results are to comply with the requirements of 5.3.6 and Table 10.5.3.

6.4.7 The chemical analysis of the deposited weld metal on the second side welded is to be reported for each assembly.

Figure 10.6.1: Recommended edge preparation for two-run butt weld test assemblies



All dimensions in mm unless otherwise indicated

6.5 Annual tests and upgrading

6.5.1 Annual tests are to consist of at least:

(1) Wires approved for semi-automatic or for both semi-automatic and automatic multi-run welding: one deposited metal test assembly prepared in accordance with 6.2.2 and 6.2.3 using a wire of diameter within the range approved for the semi-automatic multi-run welding of ship structures.

(2) Wires approved for automatic multi-run welding: one deposited metal test assembly prepared in accordance with 6.3.2 using a wire of diameter within the range approved for automatic multi-run welding of ship structures.

(3) Wires approved for automatic two-run welding: one butt weld test assembly prepared in accordance with 6.4.2 to 6.4.4 using plates of 20-25 mm in thickness. The wire diameter used is to be reported.

6.5.2 The test specimens are to be prepared and tested in accordance with the requirements of this SECTION, except that only the following tests are required:

(1) For deposited metal assemblies (semi-automatic and automatic multi-run): one tensile and three impact tests.

(2) For butt weld assemblies (automatic two-run): one transverse tensile, two bend and three impact tests. One longitudinal tensile test is also required where the wire is approved solely of automatic two-run welding.

6.5.3 At the discretion of LHR, hydrogen test can be carried out following 4.5.

6.5.4 Upgrading of flux cored wires and wire-gas combinations in connection with the impact properties will be considered as detailed in 4.8.4.

6.5.5 Uprating of flux cored wires and wire-gas combinations with the tensile properties will be considered as detailed in 4.8.5.

SECTION 7 Consumables for use in electroslag and electrogas vertical welding

7.1 General

7.1.1 The requirements for the two-run technique as detailed in SECTION 5 of this Chapter, are applicable for the approval of special consumables used in electroslag and electrogas vertical welding with or without consumable nozzles except as otherwise required by the following requirements especially as regards the number and kind of the test-pieces used for the mechanical tests and taken from the butt welded assemblies.

7.1.2 For Grades 1Y, 2Y, 3Y, 4Y, 2Y40, 3Y40, 4Y40 and 5Y40 approval of the consumables may be restricted for use only with specific types of higher tensile steel. This is in respect of the content of grain refining elements, and if general approval is required, a niobium treated steel is to be used for the approval tests.

7.1.3 For these special welding consumables, the prescription 1.2.1 may be not entirely applicable for technical reasons. Where approval is requested for welding of both normal strength and higher tensile steel two assemblies are to be prepared using higher tensile steel. Two assemblies prepared using normal strength steel may also be required at the discretion of LHR.

7.2 Butt weld tests

7.2.1 Two butt weld test assemblies are to be prepared, one of them with plates 20/25 mm thick, the other with plates 35/40 mm thick or more. The grade of the steel to be used for each one of these assemblies must be selected according to the requirements given in Table 10.5.4 for two-run submerged arc welding.

7.2.2 The chemical composition of the plate, including the content of grain refining elements is to be reported.

7.2.3 The welding conditions and the edges preparation are to be those recommended by the welding consumable manufacturer and are to be reported.

7.2.4 It is recommended that the welded assemblies be subjected to a radiographic examination to ascertain if there are any defects in the weld prior to the preparation of test specimens.

7.2.5 Each assembly shall be cut to give test specimens according to Figure 10.7.1.

7.2.6 The length of the assembly should be sufficient to allow the selection of all the test specimens:

- Two longitudinal tensile test specimens with their axis at the centre of the weld.
- Two transverse tensile test specimens.
- Two side bend test specimens.
- Two sets of three Charpy-V notch impact test specimens in accordance with Figure 10.7.1.
    - One set with the notch in the axis of the weld.
    - One set with the notch at 2 mm from the fusion line in the deposited metal.
- Two macro-sections to the weld (towards the middle of the weld and towards one end).

7.2.7 The results of the tensile, bend and impact tests are to comply with the requirements of 5.5 (two-run welding) for the class of filler product in question.

7.3 Annual tests and upgrading

7.3.1 All factories which manufacture approved consumables for use in electroslag and electrogas welding must be subject to an annual inspection and tests in accordance with 2.4.

7.3.2 One test assembly must be prepared from plates 20/25 mm thick, and tested as indicated in 7.2.

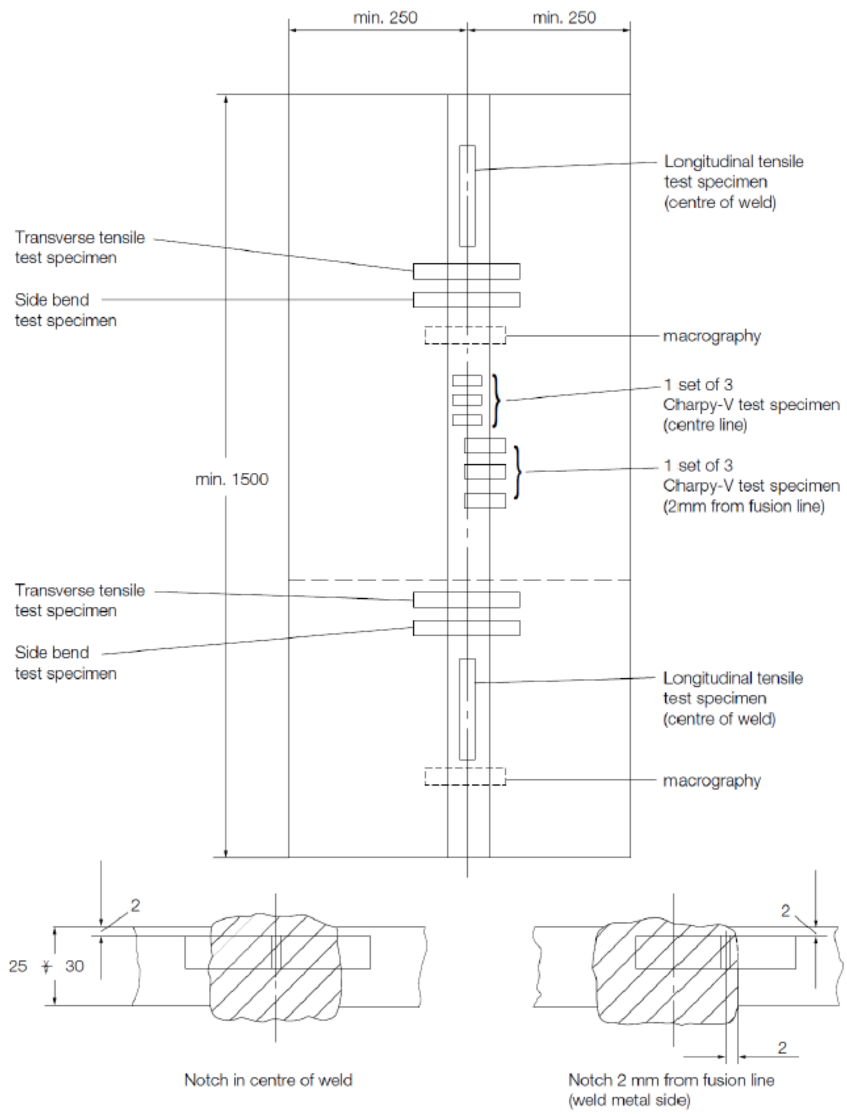
7.3.3 The following specimens are to be selected:

- One longitudinal tensile specimen from the axis of the weld.
- One transverse tensile specimen.
- Two side bend specimens.
- Three Charpy-V specimens notched at the centre of the weld (position 1 Figure 10.7.1).
- Three Charpy-V specimens cut out transverse to the weld with their notches at 2 mm from the fusion line, in the weld.
- macro-section.

7.3.4 The results to be obtained should meet the requirements given in 5.5 (two-run welding) for the class of the consumables in question.

7.3.5 Upgrading and uprating will be considered only at the manufacturers request, preferably at the time of annual testing. Generally, for this purpose, full tests from butt weld assemblies as indicated in 7.2 will be required, irrespective of the other tests requested if the concerned consumable is also approved (and possibly upgraded or uprated) according to SECTION 5, or SECTION 6 of this Chapter.

Figure 10.7.1: Electroslag and electrogas butt weld test assembly



SECTION 8 Approval of Welding Consumables for High Strength Steels for Welded Structures (IACS UR W23 Corr.1 (2019))

8.1 General

8.1.1 Scope

(a) These requirements supplement the previous SECTIONS 1 to 7 and give the conditions of approval and inspection of welding consumables used for high strength quenched and tempered or TMCP steels for welded structures according to Part 2, Chapter 3, Section 9 with yield strength levels from 420 N/mm² up to 960 N/mm² and impact grades LHR-A, LHR-D, LHR-E and LHR-F, except that impact grade LHR-F is not applicable for 890 N/mm² and 960 N/mm² yeild strength levels.

Where no special requirements are given, those of SECTION 1 to SECTION 7 apply in analogous manner.

(b) The welding consumables preferably to be used for the steels concerned are divided into several categories as follows:

- covered electrodes for manual welding,
- wire-flux combinations for multirun [(1)] submerged arc welding,
- solid wire-gas combinations for arc welding (including rods for gas tungsten arc welding),
- flux cored wire with or without gas for arc welding.

NOTES:

1. Wire-flux combinations for single or two-run technique are subject to special consideration of LHR.

8.1.2 Grading, Designation

(a) Based on the yield strength of the weld metal, the welding consumables concerned are divided into eight (yield) strength groups:

- Y 42 - for welding steels with minimum yield strength 420 N/mm²
- Y 46 - for welding steels with minimum yield strength 460 N/mm²
- Y 50 - for welding steels with minimum yield strength 500 N/mm²
- Y 55 - for welding steels with minimum yield strength 550 N/mm²
- Y 62 - for welding steels with minimum yield strength 620 N/mm²
- Y 69 - for welding steels with minimum yield strength 690 N/mm²
- Y 89 - for welding steels with minimum yield strength 890 N/mm²
- Y 96 - for welding steels with minimum yield strength 960 N/mm²

(b) Each of the eight (yield) strength groups is further divided into three main grades in respect of Charpy V-notch impact test requirements (test temperatures):

- Grade 3, test temperature -20°C
- Grade 4, test temperature -40°C
- Grade 5, test temperature -60°C

(c) Analogously to the designation scheme used in previous SECTION 1 to 7, of this Chapter, the welding consumables for high strength steels are subject to classification designation and approval as follows:

- According to 8.1.2(b) with the quality Grades 3, 4 or 5
- With the added symbol Y and an appended code number designating the minimum yield strength of the weld metal corresponding 8.1.2(a): Y 42, Y 46, Y 50, Y 55, Y 62, Y 69, Y 89 and Y 96
- With the added symbol H10 or H5 for controlled hydrogen content of the weld metal
- With the added symbol S (= semi-automatic) for semi-mechanized welding
- With the added symbol M designating multi-run technique [(1)] (and is applicable only to welding consumables for fully mechanized welding)

(d) Each higher quality grade includes the one (or those) below Grade LHR-A... and LHR-D... steels according to Part 2, Chapter 3, SECTION 9 are to be welded using welding consumables of at least quality grade 3, grade LHR-E... steels using at least quality grade 4 and grade LHR-F... steels using at least quality grade 5., see the following table:

Consumable Grade	Steel Grades covered
3Y..	LHR-D.. and LHR-A..
4Y..	LHR-E.., LHR-D.. and LHR-A..
5Y..	LHR-F.., LHR-E.., LHR-D.. and LHR-A..

[(1)]: Wire-flux combinations for single or two-run technique are subject to special consideration of LHR.

Welding consumables approved with grades ..Y 42, ..Y 46 and ..Y 50 are also considered suitable for welding steels in the two strength levels below that for which they have been approved. Welding consumables approved with grades ..Y 55, ..Y 62 and ..Y 69 are also considered suitable for welding steels in the one strength level below that for which they have been approved.

Welding consumables with grade Y 89 are considered suitable for welding steels in the same strength level only. Welding consumables with grade Y 96 are also considered suitable for welding steels in the one strength level below that for which they have been approved.

For grade Y 89 and Y 96, where the design requirements permit undermatching weld joint, then welding consumables within the scope of this SECTION can be considered subject to LHR discretion and manufacturer's recommendations.

The LHR may, in individual cases, restrict the range of application in (up to) such a way, that approval for any one strength level does not justify approval for any other strength level.

8.1.3 Manufacture, testing and approval procedure

(i) Manufacturer's plant, production methods and quality control measures shall be such as to ensure reasonable uniformity in manufacture, see also SECTION 1 to SECTION 7.

(ii) Testing and approval procedure shall be in accordance with SECTION 2 and SECTION 3 and as required in this Chapter for the individual categories (types) of welding consumables mentioned in 8.1.1(b) above.

8.2 Testing of the weld metal

8.2.1 For testing the deposited weld metal, test pieces analogous to those called for in 4.2, 5.2, 6.2, or 6.3 of this Chapter shall be prepared, depending on the type of the welding consumables (and according to the welding process). The base metal used shall be a fine-grained structural steel compatible with the properties of the weld metal, or the side walls of the weld shall be buttered with a weld metal of the same composition.

8.2.2 The chemical composition of the deposited weld metal shall be determined and certified in a manner analogous to that prescribed in 4.2.2 of this Chapter. The results of the analysis shall not exceed the limit values specified in the standards or by the manufacturer, the narrower tolerances being applicable in each case.

8.2.3 Depending on the type of the welding consumables (and according to the welding process), the test specimens prescribed in 3.1 and 4.2, 5.2, 6.2, or 6.3 of this Chapter shall be taken from the weld metal test pieces in a similar manner.

8.2.4 The mechanical properties must meet the requirements stated in Table 10.8.1 and Table 10.8.2. The provisions of SECTION 1 to SECTION 7 apply in analogous manner to the performance of the tests, including in particular the maintenance of the test temperature in the notched bar impact test and the carrying out of results.

Table 10.8.1: Required toughness properties of the weld metal

Quality grade	Test temperature [°C]	Minimum notch impact energy [J] (1)
3	-20	Y 42 ≥ 47
4	-40	Y 46 ≥ 47
		Y 50 ≥ 50
5	-60	Y 55 ≥ 55
		Y 62 ≥ 62
		Y 69 ≥ 69
		Y 89 ≥ 69 (2)
		Y 96 ≥ 69 (2)

Notes:
1. Charpy V-notch impact test specimen, mean value of three specimens; for requirements regarding minimum individual values and retests, see Part 2, Chapter 10, SECTION 3, 3.3.3.
2. Quality grade 5 is not applicable for Y89 and Y96 grade consumables.

Table 10.8.2: Required strength properties of the weld metal

Symbols added to quality grade	Minimum yield strength or 0.2% proof stress [N/mm^2]	Tensile Strength [N/mm^2]	Minimum elongation [%]

Y 42	420	520-680	20
Y 46	460	540-720	20
Y 50	500	590-770	18
Y 55	550	640-820	18
Y 62	620	700-890	18
Y 69	690	770-940	17
Y 89	890	940-1100	14
Y 96	960	980-1150	13

8.3 Testing on welded joints

8.3.1 Depending on the type of the welding consumables (and according to the welding process), the testing on the welded joints shall be performed on butt-weld test pieces in analogous manner to 4.3, 5.2, 6.2, 6.3, or 6.4 of this Chapter.

8.3.2 Depending on the type of the welding consumables (and according to the welding process), the butt-weld test pieces called for in 8.3.1 shall be welded in a manner analogous to that prescribed in SECTION 1 to SECTION 7. The base metal used shall be a high-strength fine-grained structural steel with an appropriate minimum yield strength and tensile strength and compatible with the added symbol for which application is made.

8.3.3 Depending on the type of the welding consumables (and according to the welding process), the test specimens described in SECTION 1 to SECTION 7 shall be taken from the butt-weld test pieces.

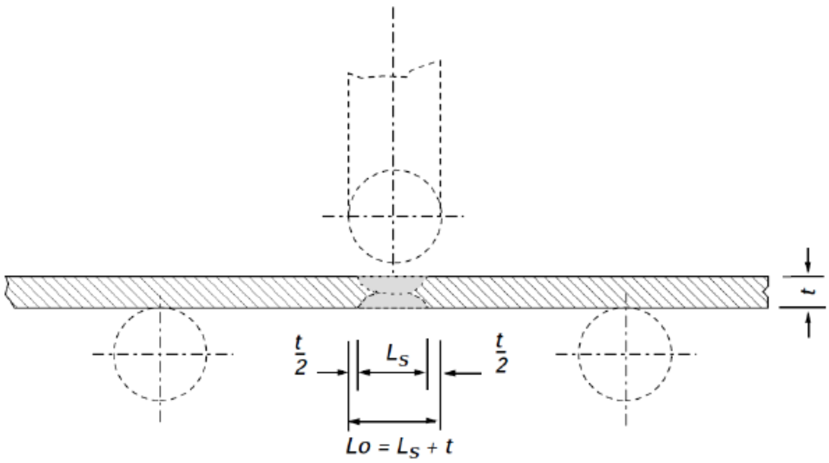
8.3.4 The mechanical properties must meet the requirements stated in Table 10.8.3. The provisions of SECTION 1 to SECTION 7 apply in analogous manner to the performance of the tests, including in particular the maintenance of the test temperatures in the notched bar impact test and the requirements regarding the retest specimens.

Table 10.8.3: Required properties of welded joints

Quality grade	Added symbol	Minimum tensile strength [N/mm^2]	Minimum notch impact energy, test temperature	Minimum bending angle (1)	Bend ratio D/t^2 (2)
3 to 5 accordance with Table 10.8.1	Y 42	520	Depending on the quality grade & yield strength in accordance Table 10.8.1	120°	4
	Y 46	540			4
	Y 50	590			4
	Y 55	640			5
	Y 62	700			5
	Y 69	770			5
	Y 89	940			6
	Y 96	980			7

Notes:
1. Bending angle attained before the first incipient crack, minor pore exposures up to a maximum length of 3mm allowed.
2. D = Mandrel diameter, t = specimen thickness

8.3.5 Where the bending angle required in Table 10.8.3 is not achieved, the specimen may be considered as fulfilling the requirements, if the bending elongation on a gauge length Lo fulfills the minimum elongation requirements stated in Table 10.8.2. The gauge length Lo = Ls + t (Ls = width of weld, t = specimen thickness), see sketch below.



8.4 Hydrogen test

8.4.1 The welding consumables, other than solid wire-gas combinations, shall be subjected to a hydrogen test in accordance with the mercury method to ISO 3690 as amended, or any other method such as the gas chromatographic method which correlates with that method, in respect of cooling rate and delay times during preparation of the weld samples, and the hydrogen volume determinations.

8.4.2 The diffusible hydrogen content of the weld metal determined in accordance with the provisions of SECTION 1 to SECTION 7 shall not exceed the limits given in Table 10.8.4.

Table 10.8.4: Allowable diffusible hydrogen content

Yield Strength group	Hydrogen symbol	Maximum hydrogen content cm^3/100g deposited weld metal
Y 42 Y 46 Y 50	H10	10
Y 55 Y 62 Y 69	H5	5
Y 89	H5	5

Y 96		

8.5 Annual repeat test

8.5.1 The annual repeat tests specified in SECTIONS 1 to 7 of this Chapter shall entail the preparation and testing of weld metal test pieces as prescribed under 8.2. For grades Y 69 to Y 96 annual hydrogen test is required. In special cases, LHR may require more extensive repeat tests.

SECTION 9 Requirements for welding consumables for aluminium alloys (IACS UR W26 Rev.2 (2021))

9.1 Scope

9.1.1 These requirements give the conditions of approval and inspection of welding consumables to be used for hull construction and marine structure aluminium alloys according to Part 2, Chapter 7, SECTION 4. Where no special requirements are given herein, e.g. for the approval procedure or for the welding of test assemblies and testing, those of SECTION 1 to SECTION 7 apply in analogous manner.

9.1.2 The welding consumables preferably to be used for the aluminium alloys concerned are divided into two categories as follows:

- W = wire electrode - and wire - gas combinations for metal-arc inert gas welding (MIG, 131 according to ISO 4063:2009 as amended), tungsten inert gas arc welding (TIG, 141), or plasma arc welding (15).
- R = rod - gas combinations for tungsten inert gas arc welding (TIG, 141), or plasma arc welding (15).

9.2 Grading, Designation

9.2.1 The consumables concerned are graded as mentioned in Table 10.9.1, in accordance with the alloy type and strength level of the base materials used for the approval tests.

Table 10.9.1: Consumable grades and base materials for the approval test

Consumable quality grade (Symbol)	Base material for the tests	
	Alloy Designation	
	Numerical	Chem. symbol
RA/WA	5754	AlMg3
RB/WB	5086	AlMg4
	5083	AlMg4, 5Mn0,7

RC/WC	5383	AlMg4, 5Mn0,9
	5456	AlMg5
	5059	-
RD/WD	6005A	AlSiMg(A)
	6061	AlMg1SiCu
	6082	AlSi1MgMn

Note: Approval on higher strength AlMg base materials covers also the lower strength AlMg grades and their combination with AlSi grades.

9.2.2 Approval of a wire or a rod will be granted in conjunction with a specific shielding gas according to Table 10.9.2, or defined in terms of composition and purity of "special" gas to be designated with group sign "S". The composition of the shielding gas is to be reported. The approval of a wire or rod with any particular gas can be applied or transferred to any combination of the same wire or rod and any gas in the same numbered group as defined in Table 10.9.2, subject to the agreement of LHR.

Table 10.9.2: Compositional limits of shielding gases and mixtures to be used

Group	Gas composition (Vol. %) (1)	
	Argon	Helium
I-1	100	---
I-2	---	100
I-3	Rest	0 < ... ≤ 33
I-4	Rest	33 < ... ≤ 66
I-5	Rest	66 < ... ≤ 95
S	Special gas, composition to be specified, see 9.2.2	
NOTE: 1. Gases of other chemical composition (mixed gases) may be considered as, ‘’special gases" and covered by a separate test.		

9.3 Manufacture, testing and approval procedure

9.3.1 Manufacturer's plant, production methods and quality control measures shall be such as to ensure reasonable uniformity in manufacture, see also SECTIONS 1 to 7 of this Chapter.

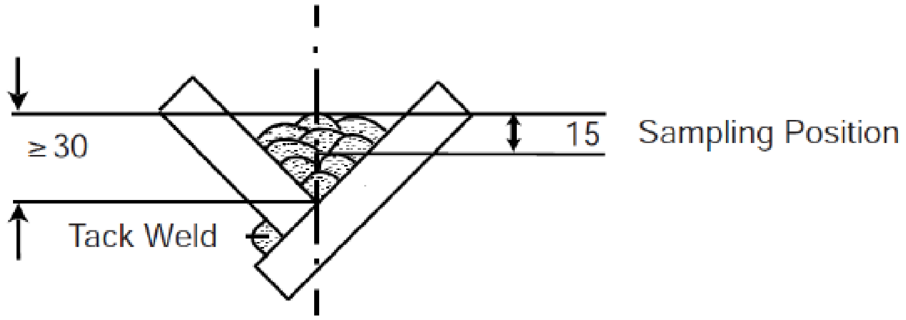
9.3.2 Testing and approval procedure shall be in accordance SECTIONS 2 and 3 of this Chapter and as required in this Chapter for the individual categories (types) of welding consumables, shielding gases and their mixtures mentioned in 9.1.2 above.

9.4 Testing, required properties

9.4.1 Testing of the deposited weld metal

For the testing of the chemical composition of the deposited weld metal, a test piece according to Figure 10.9.1 shall be prepared. The size depends on the type of the welding consumable (and on the welding process) and shall give a sufficient amount of pure weld metal for chemical analysis. The base metal used shall be compatible with the weld metal in respect of chemical composition.

Figure 10.9.1: Deposited weld metal test assembly



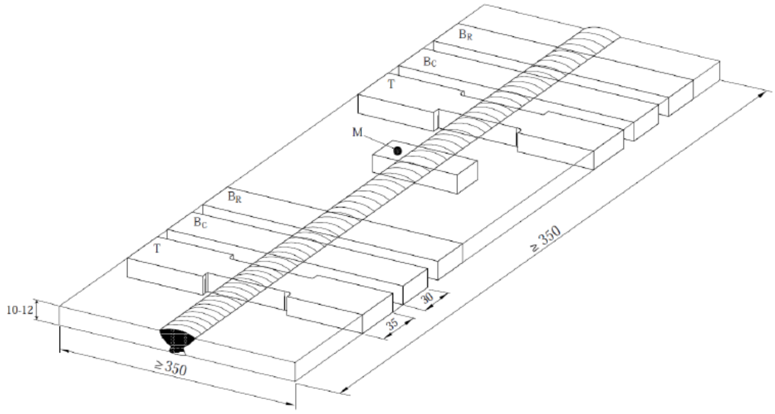
The chemical composition of the deposited weld metal shall be determined and certified in a manner analogous to that prescribed in SECTION 6, 6.2.4 of this Chapter. The results of the analysis shall not exceed the limit values specified by the manufacturer.

9.4.2 Testing of butt weld assemblies

(a) The testing of the welded joints shall be performed on butt-weld test assemblies according to Figure 10.9.2 and Figure 10.9.3, made from materials as given in Table 10.9.1, in an analogous manner to 4.3, 6.2.6 to 6.2.9, 6.3.5 or 6.4.2 to 6.4.4 of this Chapter respectively.

(b) Butt weld test assemblies according to Figure 10.9.2, with a thickness of 10 to 12 mm are to be prepared for each welding position (downhand, horizontal-vertical, vertical-upward and overhead) for which the consumable is recommended by the manufacturer; except that consumables satisfying the requirements for downhand and vertical-upward positions will be considered as also complying with the requirements for the horizontal-vertical position subject to the agreement of LHR.(c) Additionally one test assembly according to Figure 10.9.3, with a thickness of 20 to 25 mm is to be welded in the downhand position only.

Figure 10.9.2: Butt weld test assembly for positional welding

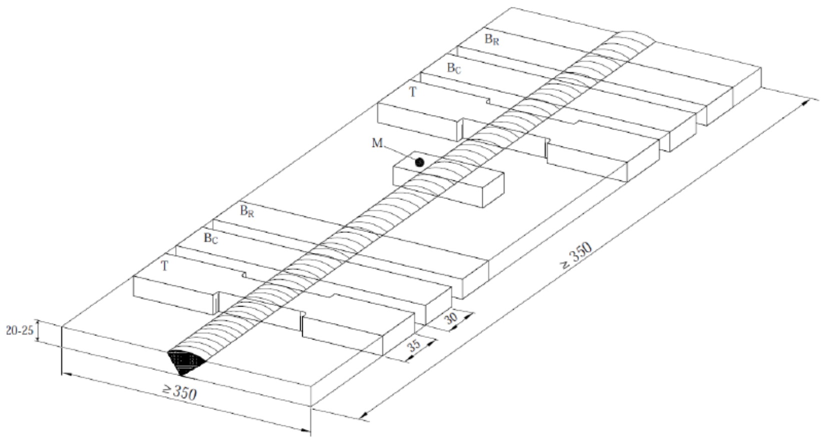


T= Flat tensile test specimen
B_C = Face bend test specimen
B_R = Root bend test specimen
M = Macrographic section

Notes for Figure 10.9.2:

1. Edge preparation is to be single V or double V with 70° angle.
2. Back sealing runs are allowed in single V weld assemblies.
3. In case of double V assembly both sides shall be welded in the same welding position.

Figure 10.9.3: Additional butt weld test assembly in downhand position



T = Flat tensile test specimen
B_C = Face bend test specimen
B_R = Root bend test specimen
M = Macrographic section

NOTES for Figure 10.9.3:

1. Edge preparation is to be a single V with 70° angle.
2. Back sealing runs are allowed.

(d) On completion of welding, assemblies must be allowed to cool naturally to ambient temperature. Welded test assemblies and test specimens must not be subjected to any heat treatment.
Grade LHR-D assemblies should be allowed to naturally ageing for a minimum period of 72 hours from the completion of welding before testing is carried out.

(e) The test specimens shown in Figure 10.9.2 and Figure 10.9.3 and described in this Chapter shall be taken from the butt weld test assemblies.

(f) The mechanical properties must meet the requirements stated in Table 10.9.3. The provisions of this Chapter apply in analogous manner to the performance of the tests, including the requirements regarding the annual repeat tests and retesting. The position of the fractures is to be stated in the report. The macrographic specimen shall be examined for imperfections such as lack of fusion, cavities, inclusions, pores or cracks.

Table 10.9.3: Requirements for the transverse tensile and bend tests

Grade	Base material used for the test	Tensile strength R_m [N/mm^2] min.	Former diameter	Bending angle(1) [°] min.
RA/WA	5754	190	3t	180
RB/WB	5086	240	6t	
RC/WC	5083	275	6t	
	5383 or 5456	290	6t	
	5059	330	6t	
RD/WD	6061, 6005A or 6082	170	6t	

Note:
During testing, the test specimen shall not reveal any one single flaw greater than 3 mm in any direction. Flaws appearing at the corners of a test specimen shall be ignored in the evaluation, unless there is evidence that they result from lack of fusion.

9.5 Annual repeat tests

9.5.1 The annual repeat tests shall entail the preparation and testing of the deposited weld metal test assembly as prescribed under 9.4.1 (Figure 10.9.1) and of the downhand butt weld test assembly according to 9.4.2 (Figure 10.9.2).

CHAPTER 11 Hull Construction Welding

CONTENTS

SECTION 1 Scope

1.1 General

1.1.1 These rules are intended to apply in new constructions, repairs or conversions carried out on the ship's structure and on all equipment components forming part of the ship's structure, including hatch covers, where these components are subject to the Hellenic Register of Shipping Rules for the Classification and Construction of Steel Vessels.

1.1.2 These welding rules may, by agreement, also be applied to other welding operations whose supervision and inspection is the concern of LHR, e.g. as in the case of industrial acceptance tests.

1.2 Plans and specifications

1.2.1 The plans and specifications submitted for approval before the start of the welding work should contain:

(1) Grades and thicknesses of parent materials.

(2) Welding consumables and auxiliary materials.

(3) Forms of groove, the shape and dimensions of welds (relating to fillet welds: whether weld sizes given are throat thicknesses or leg lengths).

(4) Heat treatment before, during and after welding.

(5) Subsequent machining of the welds, e.g. grinding to remove notches.

(6) The nature and extension of inspections including the requirements applicable to welds.

1.2.2 Where necessary, LHR may call for the submission of welding sequence plans or other additional information such as welding processes and positions, weld preparation, assembly of prefabricated panels, weld build-up and heat input during welding.

SECTION 2 Production welding

2.1 Weather protection

2.1.1 All welding is to be carried out under conditions where the welding site is sheltered from moisture, wind and cold. Where gas shielded arc welding is performed, special precautions are to be taken to protect the whole process against draughts. When working in the open under unfavorable weather conditions it would be better to dry welding edges by heating.

2.1.2 When working at subzero temperatures, not less than -10°C, suitable measures are to be taken to ensure the satisfactory quality of the welds. Such measures include the shielding of components and suitable preheating.

2.2 Preheating

2.2.1 The use of preheating and interpass temperature control are to be considered when welding higher tensile strength steels, thick materials or materials subject to high restraint. Preheating is also necessary where welding is performed under high humidity conditions or where the temperature of steel is below +5°C. Where the workpiece temperature is above this level, preheating shall be applied to wall thicknesses of 30 mm and over. The preheating temperature is to be between approximately 150°C - 200°C depending on factors such as the thickness of the components, the chemical composition and the hardening properties of the base material, the internal shrinking stresses likely to be set up in the components, the ambient and the workpiece temperature. When welding, the interpass temperature should not exceed 250°C. However, the preheat and interpass temperature are to be in accordance with the accepted welding procedure and to the satisfaction of the Surveyor. Generally, preheat and interpass temperature control are to be sufficient to maintain dry surfaces and minimize the possibility of the formation of fractures like cold cracking.

2.2.2 Preheating is to be applied uniformly throughout the thickness of the plate or component and to a distance of four times the plate thickness, though not more than 100 mm, on both sides of the weld. Local overheating is to be avoided. Preheating with gas burners should be performed with a gentle, though not sooty, flame. The preheating temperature shall be kept constant throughout the duration of the welding work.

2.3 Welding sequence

2.3.1 Welding to be performed symmetrically so that shrinkage on both sides of the structure will be equalized. The welding sequence is to be chosen to allow shrinkage to take place as freely as possible by welding first the more relatively free to draw together.

2.3.2 As a general rule, welds are not to be carried out across an unwelded joint. As a consequence, when butt welds are intersected, it is recommended to leave one unattached to a distance of approximately 250 mm beyond the intersection, and to finish it up after the latter is welded. Butt welds are to be carried out prior to the fastening of internal members. Where finished panels (plating with the internals) are to be welded together, the ends of internals should be left unattached to the plating up to a distance of 250 mm beyond the plate edge intended to be connected with the other panel's edge.

2.3.3 LHR may ask for welding sequence plans to be submitted in order to examine the assembly procedure.

2.3.4 Where welded and riveted joints meet, the welds shall be made first, followed by the riveting adjoining the weld.

2.4 Alignment of components and tack welds

2.4.1 Components to be welded are to be aligned as accurately as possible for maintaining them in the correct position. Generally, any strong back or other appliance used for this purpose is to be so arranged as to allow for expansion and contraction during production welding. Strong back and erection clips should be removed with minimum skewing of plates. They may not be welded to components (e.g. hatchway corners) subject to particularly high stresses, nor shall they be welded to the edges of flange plates, or, especially, to the upper edge of sheer strakes and continuous hatchway side coamings.

2.4.2 Attention shall be paid to the alignment of abutting girders, etc. which are interrupted by transverse members. If necessary, such alignment shall be facilitated by drilling check holes in the transverse member which are later seal-welded.

2.4.3 The permissible edge alignment error depends on the importance and loading of the component concerned. It is to be specified in the workshop documents, where necessary. Edge alignment errors are to be in accordance with recommended manufacturing standards. In spite of that, LHR will consider in each case the proposed values.

2.4.4 Tack welding is to be carried out as sparingly as possible, made with the same grade of filler metal as intended for production welding and being of consistent good quality as demanded in production welding. Tack welds are to be deposited in such a manner as not to interfere with the completion of the final weld. Where tack welds are found upon examination to be thoroughly clean and free from cracks and other defects, meeting the requirements of the subsequent welded joint, they need not be removed before the permanent weld is made.

2.4.5 Preheat may be necessary prior to tack welding, when the materials to be joined are highly restrained.

2.5 Cleanliness

2.5.1 Components must be clean and dry in the area of welding operations. Any scale, rust, cutting slag, grease, paint or dirt is to be carefully removed before welding. Scale and slag are to be removed not only from the edges to be welded but also from each pass or layer before the deposition of subsequent passes or layers.

2.5.2 Primer coatings may be used provided that it is demonstrated that their use has no adverse effect in the production of satisfactory welds.

2.6 Weld shapes and edge preparation

2.6.1 Weld shapes and root openings are to be in accordance with the approved joint detail. The edge preparation is to be as accurate and uniform as possible. Plate edges are to be prepared by methods providing smooth surfaces, such as by oxygen cutting. The possible resulting irregularities along the cut edge may require smoothing off by grinding or chipping. Weld joints prepared by arc-air gouging may also require additional preparation by grinding or chipping and wire brushing prior to welding to minimize the possibility of excessive carbon on the scarfed surfaces.

2.6.2 The root opening is not to exceed twice the specified gap. When the root opening is over the specified maximum, correction may be made by build-up of one or both plate edges, permanent or temporary backing strip, liner treatment or plate renewal. Any proposed method is to be submitted for special consideration. Where the gap is considered too large for building up the plate edges by welding, an insert plate may be used, with the LHR's agreement. The width of that insert plate is defined in SECTION 3. Particular attention should be given to the welding sequence so that distortion and cracking during welding will be avoided.

2.6.3 Care should be taken so that the rolling direction of the insert plate should be the same as that of the original plating.

2.6.4 The efficiency of the proposed method for reducing the root opening may be required by LHR to be proved through a welding procedure qualification test.

2.7 Back gouging

2.7.1 Chipping, grinding, arc-air gouging or other suitable methods are to be employed at the root or underside of the weld to obtain sound metal before applying subsequent beads for all full-penetration welds. When arc-air gouging is employed, a selected technique is to be used so that carbon build up and burning of the weld or base metal is minimized.

2.8 Peening

2.8.1 Peening is used in order to correct distortion or to reduce residual stresses, immediately after depositing and cleaning each weld pass, but is not recommended for single-pass welds and the root or cover passes on multipass welds.

2.9 Execution of welds

2.9.1 Butt welded joints are to display full fusion over the entire cross-section. Consequently, where it is not practicable to perform double sided welding, the root is to be grooved and sealed. For welds made from both sides, the root of the first side welded is to be removed to sound metal by an approved method before applying subsequent weld passes on the reverse side. Where welding is to be deposited from one side only, appropriate backing (either permanent or temporary) is to be provided, subject to approval by LHR. Following, a successful welding procedure test confirmed by LHR, single-side welds, e.g. using ceramic backing, may be regarded as equivalent to butt welds executed from both sides.

2.9.2 Single and double-bevel T-joints are to be made either with grooved roots as full penetration welded joints or with a permitted incomplete penetration at the root or defined root face. The particular weld shapes are to be specified in the drawings in each case and are subject to approval by LHR.

2.9.3 Particular attention is to be given to a good root penetration in fillet welds. The penetration is to extend at least to the immediate vicinity of the theoretical root point. Fillet welds appearance is that of an equal-sided flat-faced weld with smooth transitions to the parent material.

2.9.4 The surfaces of welds are to be visually inspected and are to be regular and uniform with a minimum amount of reinforcement and reasonably free from undercut and overlap. Welds and adjacent parent metal are to be free from injurious arc strikes.

2.9.5 Cracked locations of tack welds are not to be welded over but they are to be machined out. In multipass welding, the slag of the previous run shall be completely removed before the next pass. Pores, visible slag inclusions and other welding defects and cracks are not to be welded over, but are to be machined out and repaired.

2.9.6 Major defects in the materials or indications of faulty workmanship are to be repaired with the Surveyor's consent. Minor surface defects shall be removed by shallow grinding. Defects which penetrate more deeply into the material (e.g. cracks or tears left by the removal of auxiliary erection welds) shall be machined clean, ground and repair-welded with on adequate heat input.

SECTION 3 Weld joint design and dimensioning

3.1 General design principles

3.1.1 Any abrupt change in the general contour of the structure increase the stress level of the adjacent area well above the average stress level. For that reason, it is important to eliminate, as far as it is practicable, details such as groove welds, small insert plates and drain holes in the vicinity of significant structural discontinuities. Measures are to be taken to provide as smooth a stress flow in the structural contour as it is possible by using, for instance, connecting brackets.

3.1.2 Where a rigid member terminates abruptly in the middle of a plate panel which is inherently flexible, a point of stress concentration is produced. Such points are to be avoided.

3.1.3 Welds are to be located in a way so as to avoid the creation of high restraints against weld shrinkage, e.g. the welding of small thick insert plates. Therefore, the use of small inserts for reinforcement of openings should be avoided (see 3.3 and 3.4).

3.1.4 When designing weld joints, factors concerned with material special characteristics are to be taken into account, such as the reduced strength values of rolled plates in the through thickness direction. Material properties and the specific location of weld joints should be specially considered in order to avoid dangerous phenomena such as lamellar tearing.

3.1.5 The design of welded joints and the sequence of welding should enable residual welding stresses to be kept to a minimum. Welded joints are not to be over-dimensioned. SECTION 2 provides with general principles for producing successful welding sequences.

3.1.6 Weld joints, and especially heavily loaded weld joints, are to be so designed that the most suitable method of testing for defects can be used (radiography, ultrasonic, surface crack inspection) in order that a reliable examination may be carried out.

3.1.7 Welded joints are to be designed to ensure that the proposed weld type and quality can be satisfactorily achieved under the given fabricating conditions.

3.1.8 Where different types of materials are welded and operate in sea water or any other electrolytic medium, i.e. weld joints made between unalloyed and stainless steels in the wear linings of jet rudders and the build-up welds on rudderstocks, attention is to be paid to the increased tendency towards corrosion, especially at the weld, due to the differences in electrochemical potential. Where necessary, the welded joints should be located at points where there is less danger of corrosion (e.g. outside tanks) or special corrosion protection should be provided (e.g. coating or catholic protection).

3.2 Butt welding

3.2.1 Butt welding is to be used for plates and section butts. It is mandatory for heavily stressed butts such as those of the bottom, keel, side shell, sheerstrakes and strength deck plating, joints and butts of bulkheads (especially those bulkheads located in areas where vibrations occur).

3.2.2 Wherever possible, joints in girders and sections are not to be located in areas of high bending stress. Joints at the buckling points of the flanges are to be avoided.

3.2.3 The transition between differing component dimensions are to be smooth and gradual. Where the depth of web of girders or sections differs, the flanges or bulbs are to be bevelled and the web slit and expanded or pressed together to equalize the depths of the members. The length of the transition should be at least equal twice the difference in depth.

3.2.4 To provide smooth stress flow, the transition between differing plate thickness is to be gradual. Where the difference in thickness exceeds 3 mm, the thicker plate to be welded is to be tapered with a maximum slope 1/3. Differences in thickness of 3 mm or less may be accommodated within the weld. In the assembly of two plates of different thickness, the weld must be followed by a backweld.

3.2.5 For the welding on plates or other relatively thin-walled elements, steel castings and forgings must be appropriately tapered or provided with integrally cast or forged welding flanges.

3.2.6 Where stiffening members are going to be attached in plating by continuous fillet welds and to cross completely finished butt welds, the weld reinforcement of butt welds are to be removed and the welds are to be made flush with the adjacent surface. Where butt welding of stiffeners is made prior to continuous fillet welding on plating, the weld reinforcement is also to be removed. Care is to be taken so that the ends of the flush portion not to have notches liable to impair the soundness of the continuous fillet welding. Where these conditions cannot be complied with, a scallop is to be arranged in the web of a stiffening member. A scallop is also used where a butt weld of a stiffener or girder is made after the members have been assembled in place. Scallops shall have a minimum radius of 25 mm or twice the plate thickness whichever is the greater. Because an improperly cut scallop is potentially dangerous scallops should be shaped to provide a gentle transition to the adjoining surface.

3.3 Reinforcements

3.3.1 To reinforce plating (including girder plates and tubewalls) to face successfully local increased stresses, thicker plates should be used whenever possible in preference to plate doublers. Bearing bushes, hubs, etc. invariably take the form of thicker sections welded into the plating.

3.3.2 Reinforcing plates, welding flanges, mountings and similar components socket-welded into plating should be of the following minimum size:

$$D_{min} = 170 + 3 \cdot (t - 10) \geq 170 \text{ mm}$$

where:

D is the diameter of round or length of side of angular weldments, mm.

t is the plating thickness, mm.

The corner radii of angular socket weldments should be at least 50 mm.

3.3.3 Where doublers cannot be avoided, the thickness of the doubling plates should not exceed twice the plating thickness. Doubling plates whose width is greater than approximately 30 times their thickness are to be plug welded to the underlying platting at intervals not exceeding 30 times the thickness of the doubling plate.

3.3.4 The welding of doubling plates should be performed in accordance with a recognized standard.

3.4 Segregation of welds

3.4.1 Short distances between the welds are to be avoided. Adjacent butt welds should be separated from each other by a distance of at least 50 mm plus four plate thickness.

3.4.2 Fillet welds should be separated from each other and from butt welds by a distance of at least 30 mm plus two plate thickness.

3.4.3 The width of insert plates should be at least 300 mm or ten times the plate thickness, whichever is the greater.

3.5 Fillet welding

3.5.1 The symbols used are defined as follows, referring to Figure 11.3.1:

a : throat thickness of the fillet weld, mm,

t_{pl} : the lesser plate thickness of the parts to be welded, mm,

w : fillet weld leg length, mm,

p : for intermittent welds, the distance between start positions, the pitch, mm,

l : for intermittent welds, the length of weld, clear of end craters, mm,

e : for intermittent welds, the interval between the welds, mm.

β_1 , β_2 : weld factors.

3.5.2 The throat thickness of fillet welds is to be not less than 3 mm or the value determined by the following formula, whichever is greater:

$$a = \beta_1 \cdot t_{pl} \cdot (p/l) + \beta_2$$

Weld factors are given in Table 11.3.1. For the double continuous fillet welding, the throat thickness is to be determined taking p/l=1. In any case the throat thickness should not exceed 0,45 t_{pl}.

3.5.3 The plate thickness, t_{pl}, is generally the thickness of the thinner plate to be welded. Where the difference in thickness is considerable, the size of fillet will be considered.

3.5.4 The fillet weld leg length is not to be less than $\sqrt{2}$ times the specified throat thickness.

3.5.5 Where an automatic welding procedure giving a deep penetration is used, the rule throat thickness may be reduced according to the properties of the electrodes and filler metals. However, this reduction is not to be exceeding 15% of the weld factor given in Table 11.3.1.

3.5.6 In all intermittent fillet welds, chain, staggered or scalloped, the pitch should not exceed neither four times the length of weld nor 25 times the t_{pl} plus the weld length (i.e. neither $p < 4l$ nor $p \leq 25 t_{pl}+l$). The interval between the welds should not exceed neither three times the length of weld nor 25 times the t_{pl} (i.e. neither $e < 3l$ nor $e \leq 25 t_{pl}$). The throat thickness of the intermittent welds is to be derived from the formula given in 3.5.2 by using a particular value for p/l.

3.5.7 In scalloped fillet welds, the radius of scallop is to be not less than 25 mm and the depth of scallop is to have a size neither greater than 0,25 times the depth of the web nor greater than 25 mm, whichever is the lesser.

3.5.8 Where intermittent welding is used, the welding is to be made continuous in way of brackets, lugs and scallops and at the orthogonal connections with other members.

3.5.9 Continuous welding is to be adopted in the following locations, and may be used elsewhere if desired:

~ Boundaries of weathertight decks and erections including hatch coamings, companionways and other openings.

~ Boundaries of tanks and watertight compartments.

~ All structure in the after peak and the after peak bulkhead stiffeners.

~ All welding inside tanks intended for chemicals or edible liquid cargoes.

~ All lap welds in tanks.

~ Primary and secondary members to bottom shell in the 0,3 L forward.

~ Primary and secondary members to plating in way of end connections and end brackets to plating in the case of lap connections

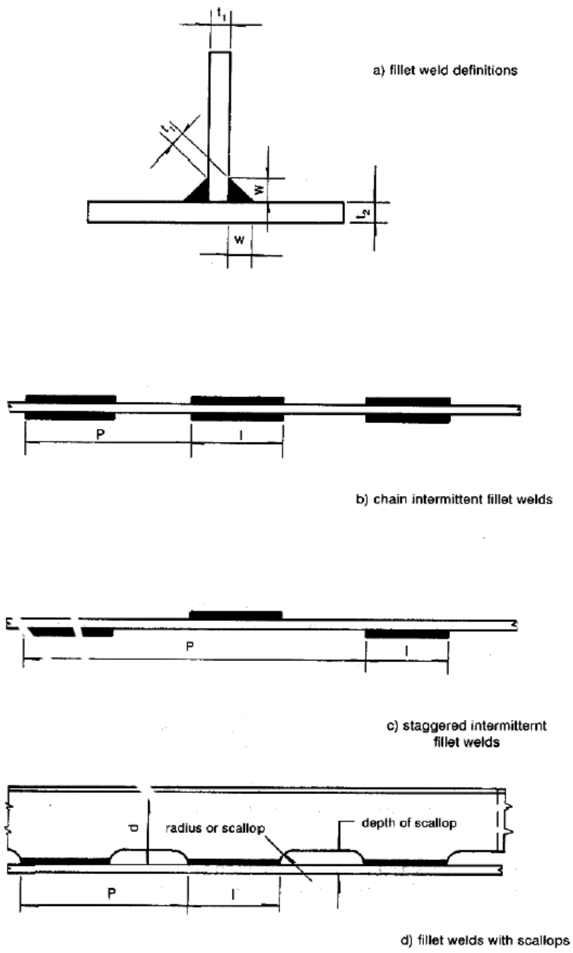
~ Other connections or attachments where considered necessary and in particular the attachment of minor fittings to higher tensile steel plating.

~ Fillet welds where higher tensile steel is used.

3.6 Slot welding

3.6.1 Slot welding may be used with the consent of LHR, for the attachment of plating to the face plates of internal webs and wherever access for welding is not practicable. The slots shall take the form of elongated holes lying in the direction of the main stress. Slots are to have a minimum width of twice the plate thickness and a minimum length of 90 mm. Slots are to have smooth, clean and square edges and should by spaced not more than 230 mm apart center to center. The fillet throat thickness may be established in accordance with 3.3.2. Apart from the necessary fillet welding which is to be carried out, the remaining void is packed with a suitable filler. Slots are not to be filled with welding.

Figure 11.3.1: Fillet welds



3.7 Lapped joints

3.7.1 Lapped joints are generally not to be used where the plates intended for connection are subjected to high stresses. Alternative arrangements are to be considered in order to avoid lapped joints. Where, however, lapped joints are adopted, the width of the overlap is to be approximately 4 times the thickness of the thinner plate but not to exceed 50 mm. Both edges of the lapped joint are to have continuous fillet welds with a throat thickness equal to 0,5 times the lesser plate thickness.

Table 11.3.1: Fillet weld connections

Structural items to be connected	Weld factor β_1	Weld factor β_2	Intermittent welds permissible
Rudder			
~ Rudder plating to rudder webs	0,186	1,760	✓
~ Slot welds in side plates	0,440		
Bottom structure-Bottom floors			
~ Floors to shell or inner bottom plating in afterpeak	0,125	2,126	
~ Floors to shell in way of bottom strengthening forward	0,266	0,399	
~ Floors to inner bottom plating in machinery space	0,180	1,690	✓
~ Floors to shell or inner bottom plating (elsewhere)	0,166	1,400	✓
~ Floors to face plates (single bottom)	0,115	2,170	✓
~ Floors to face plates in machinery space (single bottom)	0,120	2,160	
~ Floors to side girders for transverse framing (except from joints in way of transverse bulkheads)	0,115	2,170	✓
~ Floors to stiffeners (double bottom)	0,135	2,030	✓
~ Floors to stiffeners in the aft peak (double bottom)	0,140	2,020	✓
~ Floor to margin or bilge plate	0,300	0,990	
Bottom structure - Bottom girder			
~ Centre girder to bar keel	0,200	1,750	
~ Centre girder to face plates	0,135	2,030	✓
~ Centre girder to inner bottom clear of engine	0,190	1,570	✓

~ Centre girder to inner bottom in way of engine	0,323	0,744	✓
~ Side girders to shell or inner bottom plating (double bottom)	0,140	1,920	
~ Side girders to shell or inner bottom plating ~ in way of engine seating	0,185	1,580	
~ Side girders and face plates	0,140	1,820	✓
Bottom Structure general			
Inner bottom to shell or margin plate	0,370	0,409	

Structural items to be connected	Weld factor β_1	Weld factor β_2	Intermittent welds permissible
Main engine's foundation girders and top plates	0,400	0,199	
Brackets and stiffeners in way of engine seating	0,170	1,960	
Inner bottom longitudinals	0,067	2,496	✓
Longitudinals and shell (strengthening of bottom forward)	0,087	2,386	
Longitudinal girders and shell (strengthening of bottom forward)	0,160	1,880	
Bilge keel to shell	0,230	1,340	✓
Frames			
Transverse frames to shell within 0,125 forward	0,100	2,300	✓
Transverse frames to shell in the after peak	0,125	2,200	✓
Transverse frame to shell	0,112	2,206	✓
Web frames or side stringers to shell	0,105	2,290	✓
Web frames or side stringers to face plates	0,053	2,634	✓
Deck			
Deck stringer and shear strake (strength deck)	0,409	0	
Decks to shell (apart from strength deck)	0,135	2,030	
Beams and decks	0,123	2,024	✓
Deck longitudinals and decks	0,113	2,144	✓
Deck transverses and decks (deck frames longitudinally)	0,100	2,200	
Deck transverses and face plates	0,130	1,940	✓
End connections of pillars	0,310	0,780	
Cantilevers to face plates	0,200	1,450	
External bulkheads to freeboard deck	0,332	0,195	
Stiffeners to Deckhouse and superstructure	0,127	2,006	✓

Bulkheads			
Watertight bulkhead plating to inner bottom	0,370	0,560	
Stiffeners and watertight bulkheads	0,130	2,140	✓
Webs and watertight bulkheads in way of tanks	0,140	2,020	
Webs of watertight bulkheads in way of tanks and face plates	0,110	2,180	✓
Wash plates and adjacent plating	0,100	2,300	✓
Hatch covers			
Hatch coamings to decks	0,308	0,854	
Hatch coaming to decks at corners	0,430	0,039	
Hatch coamings to vertical stiffeners	0,039	2,720	✓
Stiffeners of hatch covers to plating and to face plates	0,105	2,290	✓
Hatch covers watertight fillet welds	0,370	0,260	

SECTION 4 Testing of welded joints

4.1 General

4.1.1 All finished welds are to be sound and free from cracks. They should also be substantially free from lack of fusion, solid inclusions and porosity. The surfaces of the welds are to be free from undercuts, shrinkage grooves, excessive deposition of weld metal, excessive convexity or underfill in fillet welds. Incompletely filled grooves, overlaps and root concavities are to be avoided. Attention should be paid so that the specified dimensions of fillet welds have been achieved. Reference to particular imperfections may be made to ISO 6520-1982 "Classification of imperfections in metallic fusion welds with explanations". Quality levels, necessary for the evaluation of defects, are contained and explained in EN 2817 "Arc-welded joints in steel - Fusion welding - Guidance on quality levels for imperfections" or ISO 5817:1991.

4.1.2 Every welding workshop is to have a department, consisting of trained personnel, entrusted with the inspection of welding operations. LHR's Surveyors cannot be expected to act as a substitute to workshop inspections for the work to be undertaken. After welding operations have been accomplished and subjected to workshop inspection, the work shall be presented to the Surveyor for checking at suitable stages of fabrication. To accommodate any extent of inspection, at any time, welds shall be readily accessible and shall normally be uncoated. Nevertheless, the Surveyor has the right to carry out inspections wherever he wants.

4.1.3 Where the workshop inspections have been proved inadequate, the Surveyor may reject components and require to be presented again after satisfactory workshop inspection and any necessary repair work to be performed.

4.2 Weld inspection

4.2.1 The weld inspection includes visual inspection and non destructive testing. A visual inspection is to be carried out, to check the surface of the line of welding, its uniformity and thickness.

4.2.2 Welded joints are to be subjected to non-destructive examination such as radiographic, ultrasonic, magnetic particle or dye penetrant inspection or other approved method as appropriate. The method of inspection to be applied in each instance shall be selected with due consideration for the test conditions (shape and size of the weld, nature and location of possible defects, accessibility) so that any defects may be reliably detected. The method of inspection shall be agreed to by LHR. LHR may also require that two or more inspection techniques be used in conjunction.

4.2.3 Radiographic or ultrasonic inspection, or both is to be used when the overall soundness of the weld cross section is to be evaluated. Magnetic particle or dye penetrant inspection or other approved methods are to be used when investigating the outer surface of welds or may be used as a check of intermediate weld passes, such as root passes, and also to check back-gouged joints prior to depositing subsequent passes.

4.2.4 Radiographic examination is generally to be used on butt welds. Where it is proposed to substitute ultrasonic examination for radiography, details of these arrangements are to be submitted for approval. For wall and plate thicknesses of approximately 30 mm and over, ultrasonic testing is to be preferred to radiography as a method of inspection. Particular attention is to be paid to highly stressed items. Magnetic particle inspection is to be used at ends of fillet welds, T-joints and other joints where welds join or cross in main structural members. Surface crack inspections shall generally be carried out following the welding of large sections, particularly those of steel castings and forgings as well as in the case of welds made under stress or at low temperatures.

4.2.5 The testing appliances and equipment used shall conform to the state of technique and the relevant standards. The tests are to be performed by properly qualified and experienced testers.

4.2.6 Random non-destructive inspections may also be carried out at the discretion of the Surveyor. The positions of those random examinations are to be recorded. Where radiographic inspections are performed randomly, they are to be carried out mainly at the intersections of longitudinal seams and transverse joints, at sectional joints and at joints presenting difficulty or requiring to be welded in a fixed position. Joints in girders and stiffeners are to be categorized similarly to those in plating and are to be included in the inspection.

4.2.7 The location and number of welds to be examined by non-destructive examination is to be agreed between the welding workshop and the Surveyor. Recommended locations and number of non-destructive examination are shown in Table 11.4.1.

4.2.8 A plan of the proposed areas to be examined and the methods to be employed is to be submitted for approval. Radiographic and other test records of non-destructive examination are to be made available to the Surveyor for assessment. The evaluation of weld defects identified to their nature, location, size and distribution shall take due account of the location of the joint and loading conditions. The test results shall be evaluated by the testing department of the welding workshop. The final evaluation, together with the right of decision as to the acceptance or repair of defects in the material or the weld, shall rest with the Surveyor.

These are in addition to locations selected at intersection of butts and seams of fabrication and erection welds.

Additional locations are to be selected in the forward region.

Selected NDE locations are to be evenly distributed.

Where radiographic examination is carried out at weld intersections, the length of the film is to be in the direction of the butt.

Where defects are observed at or near the ends of radiographs, additional radiography is to be carried out to determine the full extent.

Table 11.4.1: Inspection of welds

Material class (Note 1)	Recommended locations and number of non-destructive examination to be applied	
	Intersections of butts and seams of fabrication and erection welds	Butt and seams additional to the intersections (Note 2)
V & IV	Minimum - one in two	Minimum - one for each 10 m of weld length
III	Minimum - one in three	Minimum - one for each 20 m of weld length
II	Minimum - one in four	Minimum - one for each 30 m of weld length
I	At selected locations (Note 3)	At selected locations (Note 3)
	Butt welds of hull envelope longitudinals are to be examined as follows: within 0,4 L amidships - one in ten: outside 0,4 L amidships - one in twenty	

NOTES:

1. Material class definition is contained in Part 3, Chapter 1, Section 5.

4.3 Repair and re-inspection

4.3.1 Externally detectable defects affecting the loading capacity and/or the integrity of a welded seam shall be repaired in accordance with the Surveyor's directions. Undercuts in need of repair are to be ground out with smooth transitions to the surrounding material or, if they are too deep for this, they shall, with the Surveyor's consent, be ground out and repair welded. Removal by grinding of minor surface imperfections such as scars, tack welds and arc strikes may be permitted at the discretion of the attending Surveyor.

4.3.2 Defects assessed as needing repair are to be carefully grooved over a sufficient length (especially in the case of intersecting welds) and rewelded. Where a number of defects needing repair are located close together in a single section of weld, the entire section shall be worked out and rewelded.

4.3.3 Repair welds shall be re-inspected. Non destructive testing shall be performed not only on the joint but also on the adjacent parts.

4.3.4 Special precautions, such as the use of preheat, interpass temperature control, and low-hydrogen electrodes are to be considered when repairing welds in all higher strength steel, ordinary strength steel of thick cross section, or steel subject to high restraint.

SECTION 5 Welding procedure qualification tests for hull construction welding

5.1 General requirements

5.1.1 Welding procedure qualification tests are required for all welding processes and materials with the exception of manual arc welding with covered electrodes and semiautomatic gas shielded metal arc welding with solid wire electrodes performed on normal strength steels LHR-A to LHR-D, comparable grades of steel forgings and castings and aluminium alloys conforming to LHR's Rules for materials. An exception to this is welding in the vertical down position, in every case a welding procedure test is required.

5.1.2 All requirements mentioned in Chapter 9, Section 2 are also applicable in hull construction welding.

5.1.3 For hull structure steels, the parent materials shall be chosen in accordance with Table 11.5.1 so as to give approval for a particular range of materials.

Table 11.5.1: Approved range of application of the welding process

Parent metal	Range of approval
Grades LHR-R or LHR-B	Grades LHR-A and LHR-B
Grades LHR-A and LHR-D	Grades LHR-A, LHR-B, LHR-D
Grades LHR-A and LHR-E	Grades LHR-A, LHR-B, LHR-D, LHR-E
Grades LHR-AH36 and LHR-DH36	Grades LHR-AH32, LHR-DH32, LHR-AH36, LHR-DH36
Grades LHR-AH36 and LHR-DH36	Grades LHR-AH32, LHR-BH32, LHR-DH32, LHR-AH36, LHR-BH36, LHR-DH36

5.2 Requirements for hull structural steels

5.2.1 In welding procedure qualification tests, butt weld test specimens must meet the minimum requirements indicated in Table 11.5.2.

Table 11.5.2: Requirements applicable to hull structural steels

Grade	Tensile strength (N/mm^2)	Impact energy (J)		Bending angle (D=37)
LHR-A	400	47	+20	120
LHR-B/D			± 0	
LHR-E			-20	
LHR-AH-32/DH-32	440	47	± 0	
LHR-EH-32			-20	
AH-36/DH-36	490	47	± 0	
LHR-EH-36			-20	

5.2.2 Impact energy values relating to welding positions other than those specified and to transition and heat affected zones shall be assessed with due regard for the parent metals and the features of the welding process used. Two thirds of the values indicated in Table 11.5.2 may be used as a guide when allowing for these two factors.

5.2.3 In special cases (e.g. where the working temperature of the component is below -10°C) the test temperatures and impact energy values laid down in the material specifications for the testing of the steels concerned may also be stipulated for welding procedure tests in place of the test temperatures and impact energy values indicated in Table 11.5.2. Unless otherwise agreed, these values shall then apply to all welding positions and notch positions.

5.2.4 Where the plate thickness is less than 10 mm, notched bar impact test specimens with a width corresponding to the plate thickness, and wherever possible 7,5 mm or 5 mm, may be used. In such cases the impact energy values specified in Table 11.5.2 shall be reduced as given below:

Specimen section (mm x mm)	**Specified impact energy value to be multiplied by**
10 x 7,5	5/6
10 x 5,0	2/3

The notched bar impact test is normally dispensed with for plates less than 5 mm thick. However, other tests of resistance to brittle fracture may be demanded.

CHAPTER 12 Welding of Boilers and Pressure Vessels Pipelines and Machinery Components

CONTENTS

SECTION 1 General requirements

1.1 General

1.1.1 This section provides the general requirements to be applied in the fabrication by welding of boilers and pressure vessels, pipelines and machinery components.

1.1.2 SECTION 2, SECTION 3 and SECTION 4 provide the more specific requirements governing the welding of boilers and pressure vessels, pipelines, and machinery components, respectively. SECTION 5 gives the requirements for the non-destructive evaluation of these weldments.

1.1.3 Where these rules make no provisions regarding certain requirements, recognized standards or welding regulations are to be applied.

1.2 Plans and specifications

1.2.1 Prior to the start of manufacture the welding workshop must submit to LHR for scrutiny and approval, plans of the components to be fabricated together with the full details required for their assessment. Details of welding and assembly sequences, welding specifications, test schedules or other specifications are to be submitted where necessary.

1.3 Design details

1.3.1 Major changes in the contour of the structure are to be avoided when designing components, especially in the case of highly stressed positions. Where major differences in thickness at butt welds cannot be avoided, the thicker wall is to be chamfered down to the lesser wall thickness.

1.3.2 Welds are not to be spaced closely to avoid high restraints against weld shrinkage.

1.3.3 Discontinuous fillet welds are not to be applied to components exposed to corrosive media, e.g. sea water.

1.3.4 Owing to the danger of the presence of segregations and the associated internal stresses, welds should not be located in the concave fillets of sections.

1.4 Preparation of welded joints

1.4.1 Weld shapes are to conform to recognized standards or to the details shown on the approval plans.

1.4.2 Edges produced by thermal cutting or shears may only be welded without subsequent machining if the area affected by the cutting operation is completely fused in the process.

1.5 Preheating and post-weld heat treatment

1.5.1 Preheating is to be applied under the same conditions as in hull construction (see Part 2, Chapter 11, SECTION 2, 2.2).

1.5.2 Post-weld heat treatment is to be applied using heat treatment furnaces or equipment fitted with means of controlling and monitoring the temperature. Guide values for heat treatment are contained in the standards relating to materials or in the specific rules for particular components.

SECTION 2 Welding of boilers and pressure vessels

2.1 General

2.1.1 The rules contained in this Section apply to the construction and testing of welded steam boilers and welded pressure vessels which are mentioned in Part 5, Chapter 7.

2.1.2 Welds are evaluated according to a weld joint efficiency, "E" of 1,0 or 0,85. Where the components meet the requirements contained in these rules and where the welds are subjected to tests according to 2.8 and 2.9, the welds are considered of an efficiency E = 1. An evaluation of E = 0,85 is applicable where non-destructive tests are to be performed only at random. This is only allowed where weldable carbon and carbon manganese steels with nominal yield strengths of ≤ 355 N/mm² or austenitic stainless steels are used for the fabrication of the component in question and where the wall thickness of the shell is ≤ 30 mm.

2.2 Materials

2.2.1 The selection of steels is to be carried out by reference to Part 2, Chapter 3.

2.2.2 Rimming steels are not allowed for the pressurized parts of steam boilers and pressure vessels of Classes I and II (see Part 5, Chapter 7).

2.3 Welding consumables

2.3.1 Welding consumables are to be selected in such a way that the requirements specified for the parent metal can be met by the weld metal and the joint. This shall be proved by a welding procedure qualification test in accordance with 2.5.

2.3.2 All consumables (including wire-flux and wire-gas combinations) must have been approval tested either by LHR or by a testing authority recognized by LHR, in accordance with the requirements of Part 2, Chapter 10.

2.4 Drawings and documents

2.4.1 The drawings, which are to be submitted to LHR, for approval are to contain at least the following details:

Materials and their wall thicknesses.

Weld preparation, including throat thicknesses of fillet welds.

Welding method.

Welding consumables.

Weld joint efficiency (E=1,0 or E=0,85).

Heat treatment.

Tests.

2.4.2 Where special requirements are necessary, e.g. with respect to welding sequence, heat input, heat treatment or testing, welding specifications, details of the welding sequence and test schedules are also to be submitted.

2.5 Welding procedure qualification tests

2.5.1 Welding procedure qualification tests are to be carried out following the basic principles, the type of test pieces and test specimens and the testing as prescribed in Part 2, Chapter 9, SECTION 2.

2.5.2 The test piece for the performance of welding procedure tests on plates is that described for plates in Part 2, Chapter 9, SECTION 2. In the case of high temperature alloy steels of types 1Cr0.5Mo and 2.25Cr1Mo, one fillet weld test piece is to be welded in accordance with standard workshop practice.

2.5.3 Test pieces shall be subjected to the specified non-destructive and destructive tests mentioned in Part 2, Chapter 9, SECTION 2, Table 9.2.1 and the test results are to be in accordance with Table 12.2.1. For fillet weld test piece on plates, hardness values are to be those of Table 12.2.1.

Table 12.2.1: The required mechanical properties of welded joints

Type of test	Minimum requirement
Tensile test	Minimum tensile strength of parent material
Bend test	Bending angle 120° for ferritic steels D = 4·a for austenitic stainless steels D = 2·a
Notched bar impact test (IS0 V-notch specimens) notch located at centre of	ferritic steels: the minimum impact energy of the parent metal austenitic stainless steels: at least 41 Joules

weld metal (Note 1)	
Notched bar impact test (ISO V-notch specimens) notch located at centre of weld metal (Note 1)	for ferritic steels: 70% of the specified impact energy of the parent metal but not less than 27 J for austenitic stainless steels: at least 41 J
Metallographic inspection	Satisfactory weld buildup, complete fusion with no bonding defects
Hardness test (ferritic steels)	The hardness (HV 10) in the heat affected zone may not exceed 350 HV

2.5.4 Where a welding procedure qualification test is performed on a particular grade of steel, the test may simultaneously encompass the steel grades of groups shown in Table 12.2.2. Besides this, the ranges of approval for wall thickness, welding positions, etc. are to be taken from Part 2, Chapter 9, SECTION 2.

Table 12.2.2: Validity of the welding procedure test

Steel Group	Steel types according to Part 2, Chapter 3, SECTION 4	A test carried out on one grade of steel is also valid for:
1	Semi killed steels	all semi killed steels
2	Killed unalloyed steels with yield strength ≤ 355 N/mm^2	All types of steel within this group
3	Fine grained structural steels	All fine grained structural steels with lower yield stresses and all steels in groups 1 and 2
4	High temperature alloy steels of types: 0.3 Mo, 1Cr 0.5Mo, 2,25Cr 1Mo	The next lower steel type
5	Austenitic stainless steels	All steels in this group
6	Other special steels, e.g. to manufacturer's material specification	The steel grade tested

2.6 Weld design

2.6.1 Welded seams in pressurized component walls are not to be interrupted by holes or cut-outs. Weld intersections are to be avoided. Where the vessel is made up of a number of rings, the longitudinal seams are to be staggered by at least 4t, where t is the wall thickness, and in any case by not less than 100 mm at the joints between the shell rings.

2.6.2 Permanent backing rings or strips must be made of material of the same composition as the base metal.

2.7 Welding technique

2.7.1 All butt welds must be full penetration welds unless otherwise specified. The butt welds in shells and bottoms must be welded on both sides.

2.7.2 The fillet welds of sockets and fittings which may induce stresses in the walls of the vessel are to be laid down in more than one pass.

2.7.3 All the welded fittings, such as doubling plates, flanges, mountings and lifting lugs must be attached to the contour of the vessel, prior to any heat treatment and before pressure testing.

2.8 Workmanship tests

2.8.1 Where the component is intended to be evaluated with a weld joint efficiency E=1,0, a number of tests is to be carried out on every boiler drum and pressure vessel which is being constructed. The longitudinal seam of every boiler drum and pressure vessel is to be extended so as to provide at least one test piece for the workmanship test. In the case of a vessel which is made up of more than 5 shell rings, at least 2 test pieces are to be welded. The test pieces are to be large enough to provide the specimens prescribed in Table 12.2.3. The length of the weld must in every case be at least 300 mm.

2.8.2 The test pieces are to be heat-treated in conjunction with the corresponding component.

2.8.3 For steels which are not mentioned in Table 12.2.3, the number of test pieces, the nature and the number of test specimens is subject to special agreement.

2.8.4 Where the method of welding used for circumferential welds differs from that employed for the longitudinal seams, test pieces of circumferential welds shall be prepared at random and subjected to test.

2.8.5 At the discretion of LHR, a workmanship test may be called for, where the weld joint efficiency is E=0,85 and where special proof of the weld quality is considered necessary.

2.8.6 The test results must meet the requirements stated in Table 12.2.1. If they fail to do so, the relevant section of the weld must be machined out and rewelded and its mechanical characteristics must be proved by inspection of a new test piece.

2.9 Non-destructive tests

2.9.1 To evaluate a weld with a weld joint efficiency, E = 1,0, the extent of NDT is to be as follows:

All longitudinal welds are to be subjected to 100% radiographic inspection.

All circumferential welds are to be subjected to 25% radiographic inspection.

Sockets and fillet welds are to undergo at least 10% testing for surface cracks.

With wall thicknesses of ≤ 30 mm, 10% inspection of the circumferential welds may, with the Surveyor's consent, be sufficient, provided that inspection of the longitudinal seams has not revealed any defects. Notwithstanding the foregoing provisions, circumferential, socket and fillet welds are to be subjected to 100% inspection in the case of normalized fine grained structural steels with minimum yield strengths of ≥ 460 N/mm².

2.9.2 Where the weld joint efficiency is E=0,85, random non-component-specific inspection shall be applied to longitudinal seams. Such inspection is to encompass points where the longitudinal welds intercept the circumferential seams. Random inspection shall cover 2% of welds where the wall thickness is ≤ 15 mm and 10% of the welds where the wall thickness exceeds this value.

2.9.3 At the discretion of LHR, radiographic inspection may be partly or wholly replaced by ultrasonic examination. Inspection for surface cracks may be performed by the magnetic particle or dye penetrant method.

2.9.4 The requirements for NDT set out in SECTION 5 are to be applied.

Table 12.2.3: Nature and number of specimens required for workmanship tests

Steel type	Heat treatment (Note 1)	Wall-thickness (mm)	Bend test t ≤ 15 mm	Notched bar impact test t > 15 mm weld metal	Notched bar impact test t > 15 mm fusion zone	Tensile test	High-temperature tensile test (Note 2)	Other specimens
Carbon and carbon manganese steels with minimum yield strengths of ≤ 355 N/mm² and within the following analytical limits (Note 3) :	U	≤ 30	2	3	-	-	-	1 macrographic specimen
		> 30	-	3	3	1	1	
C ≤ 0,22 S ≤ 0,55 Mn ≤ 1,60 Cr ≤ 0,30 Mo ≤ 1,15 Ni ≤ 0,40 Cu ≤ 0,30	HT	≤ 30	2	3	-	-	-	1 macrographic specimen
		> 30	-	3	-	1	1	
Normalised fine-grained structural steels with miniimum yield strengths of > 355 N/mm²	U	≤ 15	2	-	-	1	-	1 macrographic specimen
		> 15 ≤ 30	-	3	3	1	1	
	HT	≤ 30	2	3	3	1	1	
		> 30	-	3	3	1	1	
Mo alloy steels 0,3Mo (0,5Mo)	U	≤ 30	2	3	-	1	1	1 macrographic specimen
	HT	≤ 30	2	3	-	1	1	
		> 30	-	3	-	1	1	
CrMo alloy steels 1Cr 0,5Mo 2,25 Cr 1Mo	HT	≤ 30	2	3	-	1	1	1 macrographic specimen
		> 30	-	3	3	1	1	
Austenitic stainless steels	U	≤ 50	2	3	-	1	1	1 macrographic specimen 1 specimen for testing resistance to inter-crystalline corrosion (Note 4)

NOTES:

1. U: Untreated HT: heat-treated.

2. High-temperature tensile test or analysis of weld metal for operating temperatures over 350°C; in the case of fine-grained structural steels, high-temperature tensile test for operating temperatures over 200°C.

3. Where the analytical limits are exceeded, the nature and number of the specimens is subject to separate specification.

4. Only in the case of joints for which resistance to intercrystalline corrosion cannot be guaranteed in the as-welded condition.

SECTION 3 Welding of pipelines

3.1 General

3.1.1 These rules apply to the fabrication of welded joints belonging to Class I or II piping systems as prescribed in Part 5, Chapter 8. The application of these Rules to Class III piping systems or to pipelines made of non-ferrous materials is subject to special agreement.

3.1.2 These rules are related to piping systems made of unalloyed, low-alloy or austenitic steels which are intended for use at ambient temperature down to about -10°C, as well as at elevated temperatures. The materials are selected in accordance with Chapter 6 by reference to allowable stresses and must meet the requirements specified therein. The pipes may be seamless or welded through approved methods.

3.2 Welding consumables

3.2.1 The principle for the selection of welding consumables is that both the weld metal and the joint must have the specified mechanical properties of the parent metal.

3.2.2 Welding consumables must have been approval tested by LHR or by a testing body recognized by LHR.

3.3 Drawings and specifications

3.3.1 Before the start of manufacture, drawings and/or specifications are to be submitted to LHR, containing at least the following details:

Grades and dimensions of pipes.

Operating temperatures and pressures.

Edge preparation of the welded joints.

Welding processes and positions.

Welding consumables.

Heat treatment.

Proposed tests and their extension.

3.4 Edge preparation of welded joints

3.4.1 Edge preparation is to be in accordance with recognized standards and/or approved drawings. It should be carried out preferably by mechanical means. When flame cutting is used, care should be taken to remove the oxide scales and any notch due to irregular cutting by machining, grinding or chipping back to sound metal.

3.5 Alignment and assembling

3.5.1 Sections to be welded must be axially aligned. Unless otherwise agreed by LHR, the tolerances on the alignment of the pipes to be welded are to be as follows:

Pipes of all diameters and thicknesses welded with permanent backing rings: 0,5 mm max.

Pipes welded without fitted backing ring having:

Inside diameter less than 150 mm, thicknesses up to 6 mm included: 1 mm or t/4, whichever is lower.

Inside diameter greater or equal to 150 mm but less than 300 mm, thicknesses up to 9,5 mm: 1,5 mm or t/4, whichever is lower.

Inside diameter less than 300 mm included, any thickness: 2 mm or t/4, whichever is lower.

Any inside diameter, thickness larger than 9,5 mm: 2 mm or t/4, whichever is lower.

3.5.2 Weld reinforcements shall lie within the following tolerances:

~ excess weld metal : $H \leq 1 + 0{,}15 \cdot B$ (mm)

~ excessive penetration : $h \leq 1 + 0{,}6 \cdot b$ (mm)

where B and b is the width of the face and root of the weld, respectively.

3.5.3 Tack welds should be made with an electrode suitable for the parent metal. Where tack welds are intended to form part of the finished weld, they must be of the same quality as the root welds. Where welding materials require preheating, the same preheating should be applied during tack welding.

3.6 Welding processes

3.6.1 Manual or semi-automatic electric arc welding processes are to be used for butt joints in pipes, for branch pieces and for the attachment of flanges. Oxy-acetylene welding may also be used, but in general, is suitable only for butt joints in pipes not exceeding 100 mm diameter or 9,5 mm thickness.

3.6.2 All butt welds must be full penetration joints.

3.7 Preheating

3.7.1 Preheating of the different types of steels will be dependent upon their thickness and chemical composition as indicated in Table 12.3.1. Preheating is not normally required for austenitic pipes. However, dryness is to be ensured during preheating. The values given in Table 12.3.1 are based on the use of low hydrogen processes. Where low hydrogen processes are not used consideration should be given to the use of higher temperatures.

Table 12.3.1: Guide values for preheating in pipeline welding

Steel type		Thickness of thicker part (mm)	Minimum preheating temperature (°C)
C and C/Mn steels	$C + \frac{Mn}{6} \leq 0{,}40$	≥ 20 (Note 2)	50
	$C + \frac{Mn}{6} \leq 0{,}40$	≥ 20 (Note 2)	100
0,3Mo		> 13 (Note 2)	100
1Cr 0,5Mo		< 13 ≥ 13	100 150
2,25 Cr 1 Mo (Note 1)		< 13 ≥ 13	150 200

NOTES:

1. For these materials, preheating may be omitted for thicknesses up to 6 mm if the results of hardness tests carried out on welding procedure specification are considered acceptable by LHR.

2. For welding in ambient temperature below 0°, the minimum preheating temperature is required independent of the thickness unless specifically approved by LHR.

3.8 Heat treatment after forming and welding

3.8.1 The heat treatments after forming and welding are not to impair the specified properties of the materials. Where necessary, verification to prove that may be required. The heat treatments are preferably to be carried out in suitable furnaces provided with temperature recording equipment. However, localized heat treatments on a sufficient portion of length in way of the welded joint, carried out with approved procedures, may be accepted.

3.8.2 The hot forming of ferritic steels is to be generally carried out in the temperature range from 1000°C to 850°C for all grades. However, the temperature may decrease to 750°C during the forming process. Austenitic steels must be hot formed in the temperature range from 1150° to 750°C.

3.8.3 When hot forming is carried out within the above-mentioned temperature range, the following are generally applied:

(1) For C, C-Mn and 0.3Mo steels, no subsequent heat treatment is required.

(2) For Cr-Mo and Cr-Mo-V steels, a subsequent heat treatment in accordance with Table 12.3.2 is required.

Table 12.3.2:Gide values for the heat treatment of welded pipes

Steel type	Type of heat treatment	Temperature range (°C)
Carbon and carbon manganese steels	normalizing	880 to 940
0,3Mo	normalizing	910 to 940
1Cr 0,5Mo	normalizing tempering	900 to 960 640 to 720
2,25Cr - 1Mo	normalizing tempering	900 to 960 650 to 780
0,5Cr - 0,5Mo - 0,3V	normalizing tempering	930 to 980 670 to 720
Austenitic stainless steels	Solution treating and quenching Note 1, 2	1000 to 1100

Notes:

1. Stabilising heat treatment at 960°C and 900°C respectively (according to the material) is also appropriate for austenitic stainless steels with carbon contents of 0,03% and for stabilised steels containing no molybdenum.

2. The material is quenched in water or air to effect a rapid drop from the heat treatment temperature.

3.8.4 For austenitic steels, where the initial forming temperatures are within the range of 1000-1150°C and the final forming temperatures are above 750°C or above 900°C in the case of destabilized steels with a carbon content of > 0,03% and where accelerated cooling is carried out, then no subsequent heat treatment is required. Where these conditions do not apply, the heat treatment mentioned in Table 12.3.2 is applicable.

3.8.5 After cold forming, when $R \leq 4 \cdot D$ (where R is the mean bending radius and D is the outside diameter of the pipe) consideration is to be given to a complete heat treatment in accordance with Table 12.3.2. In any case, a stress relieving heat treatment in accordance with Table 12.3.3 is required for all grades other than C and C-Mn steels with R_m 320, 360 and 410 N/mm².

Table 12.3.3

Steel type	Thickness of thicker part (mm)	Stress relief heat treatment temperature (°C)
C and C-Mn	≥ 15 (Note 1, 3)	550 to 620
0,3Mo	≥ 15 (Note 1)	580 to 640
1Cr 0,5Mo	> 8	620 to 680
2,25 Cr 1Mo and 0,5Cr 0,5Mo 0,25V	any (Note 2)	650 to 720

NOTES:

1. When steels with specified Charpy V notch impact properties at low temperature are used, the thickness above which postweld heat treatment shall be applied may be increased by special agreement with LHR.

2. Heat treatment may be omitted for pipes having thickness ≤ 8 mm, diameter ≤ 100 mm and minimum service temperature 450°C.

3. For C and C-Mn steels, stress relieving heat treatment can be omitted up to 30 mm thickness by special agreement with LHR.

3.8.6 Austenitic steel pipes need not be subjected to subsequent heat treatment where local cold forming operations do not entail more than 15% cold forming. This is to be applied, only where the material has been in the proper heat-treated condition (solution treated and quenched) before forming and shall, after forming, retain a residual elongation of at least 15% together with resistance to intercrystalline corrosion. If this is not the case, or if the local degree of cold forming is greater than 15%, subsequent heat treatment must be applied.

3.8.7 Austenitic steel pipes do not normally require heat treatment after welding.

3.8.8 Stress relieving heat treatment after welding for other than oxy-acetylene welding process is required as indicated in Table 12.3.3 depending on the types of steel and thickness. The temperature ranges given in this table are in accordance with common practice. The stress relieving heat treatment is to consist of heating the piping slowly and uniformly to a temperature range specified in Table 12.3.3, soaking at this temperature for a suitable period, generally one hour per 25 mm of thickness with minimum half an hour, cooling slowly and uniformly in the furnace to a temperature not exceeding 400°C and subsequently cooling in a still atmosphere. In no case, the heat treatment temperature is to be higher than T_f - 20°C, where T_f is the temperature of the final tempering treatment of the material.

3.8.9 Unless otherwise specified, for oxy-acetylene welding, the heat treatment indicated in Table 12.3.2 depending on the type of steel is required. The temperatures ranges given in the table are in accordance with common practice. Different values for upper and lower temperature limits may be stipulated by LHR, when it is necessary.

3.9 Non-destructive testing and acceptance criteria

3.9.1 Generally, the welded joints are to be visually examined, including the inside where possible. Non-destructive tests will be required depending on the class of pipes and type of joints as hereunder indicated:

(1) For butt-welded joints radiographic examination is to be required as follows:

(a) Pipes of Class I: 100% radiographic examination when the outside diameter is greater than 75 mm.

(b) Pipes of Class II: at least 10% radiographic examination when the outside diameter is greater than 100 mm.

More stringent requirements may be applied at LHR's discretion depending on the kind of material, welding procedure and controls during the fabrication. An approved ultrasonic testing procedure may be accepted, at LHR's discretion in lieu of radiographic testing when the conditions are such that a comparable level of weld quality is assured.

(2) Fillet welds of flange pipe connections are to be examined by the magnetic particle method or by other appropriate non-destructive methods, in the case of Class I pipes. In other cases, magnetic particle examination or equivalent non-destructive testing may be required at the discretion of the Surveyor. Class II fillet welds are to be subjected to random inspection covering at least 10% of the welds.

(3) Ultrasonic examination in addition to the above non-destructive testing may be required in special cases at the discretion of LHR.

3.9.2 Radiographic and ultrasonic examination is to be performed with an appropriate technique by trained operators. At the request of LHR, complete details of the radiographic or ultrasonic technique is to be submitted for approval.

3.9.3 Magnetic particle examination is to be performed with suitable equipment and procedures and with a magnetic flux output sufficient for defect detection. The equipment may be required to be checked against standard samples.

3.9.4 The welds are to meet the acceptable standard level as required by LHR. Unacceptable defects are to be removed and repaired according to the satisfaction of LHR.

3.10 Welding procedure qualification tests

3.10.1 Welding procedure qualification tests for pipes are to be performed in order to prove the satisfactory industrial application of a particular welding process at particular welding position(s), materials, types of joints, thicknesses intended to be carried out. Welding procedure qualification tests are to be carried out in accordance with the requirements of Chapter 9, Section 2.

3.10.2 Test pieces are to be either butt welded or fillet welded (branch connection) depending on the particular kind of weldment carried out in production.

3.10.3 The test pieces are to be made from pipes whose characteristics are attested by a test certificate issued by LHR or by a corresponding certificate recognised by LHR. Where heat treatment is specified for the pipe joints, the test pieces must be heat-treated in the same way. One test piece shall be welded for each welding position for which approval is intended. Where the pipe diameter allows, welding in all positions may be carried out on the same test piece. When small pipe diameters are used, several test pieces may be necessary.

3.10.4 For the purposes of range approval Table 12.3.4 contains the groups of materials. A procedure test performed on one of the steels of a group covers the lower alloyed steels for the intentional added elements but not for fortuitous impurities, or the steels with lower specified yield stress of this group, as long as the welding consumables used for the test can also be used for the other steels of the group. Group 2 covers Group 1. A separate welding procedure test approval shall be obtained for each steel or steel combinations not covered by the grouping system.

Table 12.3.4

Group	Pipe steels in accordance with Chapter 6	Corresp. EN 288-3 Group	Steel grades referred in Part 2, Chapter 6
1	Carbon and carbon manganese steels with a tensile strength Rm of 520 N/mm² or yield stress Re ≤ 355 N/mm²	1	C and C-Mn steels 0,3Mo
2	Normalised or thermo-mechanically treated fine grain steels with specified minimum yield stress Re > 355 N/mm²	2	
3	Steels with Cr max. 0,6%, Mo max 0,5%, Vmax 0,25%	4	0,5Cr 0,5Mo 0,25V
4	Steels Cr max 9% Mo max 1,2%	5	1Cr 0,5Mo 2,25 Cr 1Mo
5	Steels with Ni max 9%	7	3,5Ni 9Ni
6	Austenitic steels	9	Ausentiic stainless steels

3.10.5 Specimens must meet the requirements stated in Table 12.3.5 and Table 12.3.6. If they fail to do so, specimens for re-tests shall be prepared in accordance Chapter 9, Section 2.

Table 12.3.5:Requirements

Test type	Minimum requirements
Transverse tensile test	minimum tensile strength of parent metal
Transverse bend tests	bending angle 120° diameter of the former = 4·t No flows > 3 mm in any directions
Impact testing	as specified for the filler, but at least 27 Joules for ferritic and 41 Joules for austentiic steels
Structural inspection	macrographic: satisfactory weld buildup with complete fusion and no bonding defects micrographic: satisfactory structure free from micro cracks
Hardness test for ferritic steels only	see Table 12.3.6
Test of resistance to inter- crystallire corrosion for austenitic stainless steel pipes	the minimum requirements specified in a recognized standard e.g. DIN 50914 are applicable

Table 12.3.6: Permitted maximum hardness values HV 10

Steel groups	Single-run butt and fillet welds		Multi -run butt and filler welds	
	Non heat-treated	Heat-treated	Non heat-treated	Heat-treated
1,2	380	320	350	320
3,4	special agreement	320	special agreement	320
Ni ≤ 4%	»	300	320	300
Ni ≥ 4%	»	special agreement	400	special agreement

SECTION 4 Welding of machinery components

4.1 General

4.1.1 The rules of this Section apply to the fabrication of welded machinery components such as bedplates, crankcases, frames, housings, etc.

4.1.2 Welders for manual or partly mechanized welding operations must possess adequate manual skill and experience and must have been qualification tested in accordance with a recognized standard. The scope of the test must cover the welding method, parent metal, filler metal and welding position relevant to the work to be undertaken.

4.1.3 Welding ships must have at their disposal adequate and suitable workshop facilities, facilities for storing and drying filler materials, preheating and heat treatment equipment, test equipment, etc.

4.2 Plans and specifications

4.2.1 Before the start of construction, plans including specifications containing details such as the following are to be submitted for consideration:

(1) Parent metals and their dimensions.

(2) Welding methods and positions.

(3) Welding consumables.

(4) Weld preparation.

(5) Heat treatment preheating and post weld heat treatment.

(6) Tests to be applied.

(7) Welding procedure specification.

(8) Welding sequence.

4.3 Welding consumables

4.3.1 Welding consumables are to be selected in such a way that the specified mechanical properties of the parent metal can be met by the weld metal and the joint.

4.3.2 Welding consumables must have been approval tested by LHR or by a testing authority recognized by LHR.

4.4 Materials

4.4.1 All plates, sections, forgings and steel castings required for the manufacture of machinery components must be in accordance with Part 2, Chapters 3, 4 and 5.

4.4.2 The carbon content is not to exceed 0,23%. The nominal yield strength of fine grained structural steels should generally not exceed 355 N/mm^2.

4.4.3 Where steels with higher carbon contents are planned to be used, they may be approved subject to satisfactory results from welding procedure qualification tests.

4.5 Design and construction

4.5.1 Edge preparations are to be accurately machined or flame-cut to shape. Flame cut surfaces are to be cleaned by machining or grinding. If the flame-cut surfaces are smooth, wire brushing may be accepted.

4.5.2 Before welding is commenced the component parts are to be accurately fitted and aligned.

4.5.3 Welds attaching bearing housings to transverse girders are to have a smooth contour and, if necessary, are to be made smooth by grinding.

4.5.4 Components shall be designed so as to avoid seam intersections, wherever possible. Individual components of complicated shape which, if welded, would result in a clustering of welded seams, e.g. bearing brackets, should either be cast in steel or, if welded, should undergo stress relief heat treatment.

4.5.5 Butt welds which are critical to the strength of the component are to be so designed that they can be executed as full-penetration welds. This category includes the butt weld joining the web and flange plates of engine bed plates and the butt welds joining bearing brackets and connecting plates.

4.5.6 The fillet welds of load bearing members, e.g. the neck seams of plate girders for joining flange and web plates, must be capable of being welded without a break. For this purpose adequate welding apertures are to be provided in the bracket plates close to the neck seams.

4.6 Preheating

4.6.1 Carbon and carbon manganese steels with a carbon content of ≤ 0.23% and fine-grained structural steels with yield strengths of ≤ 355 N/mm^2 normally require preheating to about 100-150°C only if the thickness is 30 mm or over. Steels with higher carbon contents and alloy steels shall be preheated irrespective of thickness, and the preheating temperature shall be specially determined by reference to the chemical composition of the material, the weld thickness and the welding method used.

4.7 Post-weld heat treatment

4.7.1 Components conforming to these rules shall normally undergo stress relief heat treatment after welding. If the dimensions make it impracticable to heat treat the component in one piece, the various constituent parts may be heat-treated separately provided that the parts can later be assembled without giving rise to significant stresses.

4.7.2 In the case of components of simple shape which are mainly subjected to static loads and which are made of rolled, weldable carbon or carbon manganese steels, the stress relief heat treatment may, with the consent of LHR, be dispensed with if a low level of residual stress is ensured by the design of the component and the welding method used.

4.8 Welding procedure qualification tests

4.8.1 Welding procedure qualification tests are to be carried out as provided in Chapter 9, Section 2. The requirements stated in Table 12.4.1 shall apply.

Table 12.4.1: Required mechanical properties of welded joints

Type of test	Minimum requirements
Tensile test on flat tensile specimen	The minimum tensile strength of the parent metal. Where two different parent metals are joined, the lower value is applicable
Bend test	Bending angle: 180° The mandrel diameter shall be greater by one specimen thickness t than the parent metal requires, but shall not exceed 5·t
Notched bar impact test with notch at centre of weld metal (Note 1)	The minimum impact energy of the parent metal (Note 2)
Notched bar impact test with notch in the transition zone (Note 1)	70% of the impact energy measured on transverse specimens required for the parent metal
Macrographic examination	Satisfactory weld build up with complete fusion and no bonding defects
Hardness test	For C and C-Mn steels the hardness may not be greater than 350 HV10; for alloy steels the maximum value shall be specially stipulated

NOTES:

1. The test shall be performed at the test temperatures specified for the parent metal.

2. For specimens with the notch in the weld metal it may also be agreed that the guaranteed characteristics of the weld metal shall constitute the requirement

SECTION 5 Requirements for non-destructive tests

5.1 General

5.1.1 The rules of this Section provide with the requirements for the non-destructive testing (NDT) of welds of steam boilers, pressure vessels, pipelines and machinery structures by visual inspection as well as by surface crack, radiographic and ultrasonic inspection techniques.

5.2 Visual inspection

5.2.1 The following defects are not permitted:

(1) Cracks of any kind.

(2) Open end craters.

(3) Visible slag inclusions.

(4) Arc strikes outside the weld area.

(5) Incomplete root fusion (in the case of one-sided butt welds).

(6) Undercuts with a depth of >0,5 mm.

(7) Fused weld spatter alongside the seam, where this can harm the material.

(8) Open pores in single-pass butt welds.

5.3 Dye penetrant inspection

5.3.1 The following dye marks are not permitted:

(1) Linear dye marks of any kind.

(2) Isolated dye marks with a diameter of >0,25 x (wall thickness) or 6 mm, whichever is the lesser (real defect diameter >1 mm).

(3) Repetitive sequences of dye marks with individual marks spaced ≤ 1,6 mm apart.

5.4 Magnetic particle inspection

5.4.1 Linear indications are not permitted. If there is doubt as to the interpretation of an indication, additional tests are to be applied to obtain clarification.

5.5 Radiographic inspection

5.5.1 Films are to be evaluated in accordance with Table 12.5.1.

Table 12.5.1: Criteria for the evaluation of radiographs

Nature of defect	Evaluation of defect		
Cracks	Not permitted		
Lack of fusion at root Lack of fusion at sides	Not permitted		
Lack of fusion between passes	May be permitted (Note 2)		
Poor penetration	Not permitted		
Solid elongated inclusions (slag) (Note 3)	Wall thickness t (mm) (Note 1)	max. length of defect (mm)	max. width of defect (mm)
	≤ 10 10 < ... ≤ 75 > 75	7 2/3·t 50	t/10 maximum 3 mm
Linear inclusions (lines of slag) (Note 3)	Permitted if the sum of their individual lengths over a weld length of 6·t is less than t and if the distance between two consecutive inclusions is greater than the length of the larger inclusion.		
Isolated pores, lines of pores, clusters of pores, (Note 3)	May be permitted. The defect is to be evaluated by reference to recognized rules. (Note 4)		

NOTES:

1. In the case of different wall thicknesses, the smaller of the two.

2. Where defects due to incomplete fusion between passes occur, these shall be assessed according to the loading of the weld by reference to Table 12.5.3 (Limit values for ultrasonic indications).

3. In evaluating solid and gaseous inclusions, account shall also be taken of the loading of the weld. In individual cases, the limit values may be exceeded if a repair is unlikely to produce a substantial improvement in the properties of the weld. This does not, however, apply where systematic defects occur. In these circumstances the welding must be discontinued until the causes of the defect have been eliminated.

4. Recognized rules for this purpose are those contained. in the ASME Boiler and Pressure Vessel Code, Section VIII, of the American Society of Mechanical Engineers.

5.6 Ultrasonic inspection

5.6.1 Unless otherwise agreed, indications exceeding the registration levels stated in Table 12.5.2 shall be registered.

Table 12.5.2: Registration levels for longitudinal and trasverse defects

Wall thickness, t (mm) Note 1	Diameter of disc shaped deflector (mm)
t ≤ 10	0,7
10 < t ≤ 15	1,0
15 < t ≤ 20	1,5
20 < t ≤ 40	2,0
t > 40	3,0

NOTE:

1.In the case of different wall thicknesses, the wall thickness is the smaller of the two ignoring the weld reinforcement

5.6.2 Indications which clearly imply the presence of cracks are not permitted.

5.6.3 Longitudinal indications are to be evaluated according to Table 12.5.3. If the limit values shown in the Table are exceeded, a repair or a confirmatory inspection (radiographic inspection or opening of the seam at randomly selected points) is necessary. A repair is also required when the confirmatory inspection cannot prove exclusively that the indication relates to a minor defect.

5.6.4 Transverse defect indications are not permitted unless the indication can be linked to an already detected longitudinal defect or it is demonstrated, e.g. by a radiographic inspection, that the indication exists because of an inclusion (solid or gaseous), which because of its size and distribution, does not need to be repaired.

Table 12.5.3: Limit values of ultrasonic indications for longitudinal defects

Wall thickness or fillet weld throat (mm) (Note 1)	Nos. per m weld length	Registered indications max. registered length (mm)	Excess echo height above registration level stated in Table 12.5.2 (dB)
≤ 10	3	10	≤ 6
10 < ... ≤ 20	10	10	≤ 6
	and 3	20	≤ 6
	and 1	10	≤ 12
20 < ... ≤ 40	10	10	≤ 6
	and 3	25	≤ 6
	and 1	10	≤ 12
40 < ... ≤ 60 (Note 2)	10	10	≤ 6
	and 3	30	≤ 6
	and 1	10	≤ 12

NOTES:

1. In the case of different wall thicknesses the smaller of the two ignoring the weld reinforcement.

2. Where the wall thickness is greater than 60 mm, it is to be divided into test zones each 60 mm thick and the inspection is to be carried out from both faces of the test piece. The test zones may overlap.