PART 2 Materials

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CHAPTER 1 Steel

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1.1 General

1.1.1 The requirements specified in the "Rules and Regulations for the Classification and Construction of Steel Ships", Part 2, are to be complied with, to the extent applicable.

1.2 Asbestos Containing Materials

1.2.1 Any installation of materials that contain asbestos shall be prohibited, for yachts with the notation "COMMERCIAL YACHT".

CHAPTER 2 Aluminium Alloys

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SECTION 1 Material properties

1.1 Scope

1.1.1 This Section provides the requirements to be applied in the manufacture and testing of sheets, plates, sections and structural pipes made of corrosion resistant aluminium alloys intended for use in the construction of ships and other marine structures.

1.1.2 Other alloys, e.g. those conforming to national or proprietary standards, may be approved provided that their characteristics can be considered equivalent to those required by these Rules or where the Society has given special approval for their use.

1.1.3 These Rules are not applicable to aluminium alloy forgings or castings. For these products suitable alloys in accordance with recognised standards may be used.

1.1.4 Where aluminium alloys are intended for cryogenic applications, such as for the manufacture of tanks for transporting liquefied gases at low temperatures, the specifications shall be submitted for approval.

1.2 Manufacture and condition of supply

1.2.1 Aluminium alloys are to be manufactured at works approved by the Society.

1.2.2 The alloys may be cast either in ingot moulds or by an approved continuous casting process. Sheets and plates are to be formed by rolling and may be cold or hot finished. Sections shall be extruded. Structural pipes shall be extruded followed, where necessary, by drawing.

1.2.3 All products shall be supplied in the condition specified for the alloy depicted in Table 2.1.2.

1.3 Freedom from defects and dimensional tolerances

1.3.1 The products must have a smooth surface compatible with the method of manufacture and must be free of defects liable to impair further manufacturing processes or the proposed application of the products, e.g. cracks, appreciable inclusions of extraneous substances and major mechanical damage.

1.3.2 Surface defects may be repaired only by grinding provided that this is accomplished with a gentle transition to the adjacent surface of the product and that the dimensions remain within the tolerance limits. Repair by welding is not permitted.

1.3.3 The dimensional tolerances are to be in accordance with an acceptable national specification.

1.4 Chemical composition

1.4.1 The chemical composition of the alloys must conform to the requirements of Table 2.1.1.

1.5 Heat treatment

1.5.1 Plates, bars and sections are to be supplied in the following circumstances:

5083-0	annealed
5083-F	as fabricated
5083-H321	strain hardened and stabilized

5086-0	annealed
5086-F	as fabricated
5086-H321	strain hardened and stabilized
6061-T6	solution heat treated and artificially aged
6082-T6	solution heat treated and artificially aged

1.6 Mechanical properties

1.6.1 The required values of tensile strength, 0,2% proof stress and elongation specified in Table 2.1.2 must be fulfilled under tensile testing at ambient temperature.

1.7 Weldability

1.7.1 All materials must be capable of being welded by established methods, preferably by gas- shielded welding processes.

1.8 Mechanical tests

1.8.1 Materials of the same product form, i.e. sheets, plates, etc., and thickness, and having the same nominal chemical composition, are to be presented for test in batches of not more than 5 tn. Plates differing in thickness by up to 5 mm may be grouped together. If the material is supplied in the heat treated condition, each batch is to be treated in the same furnace charge or subjected to the same finishing treatment when a continuous furnace is used.

1.8.2 Sheets and plates up to 4 mm thick and sections and structural pipes weighing up to 1 kg per meter may be tested in accordance with the requirements of an acceptable national specification. Manufacturer's test certificates will be acceptable for these materials and are to be provided for each consignment.

1.8.3 For plates over 300 mm in width, tensile test specimens are to be cut with their longitudinal axis perpendicular to the principal direction of rolling. For narrow plates the test specimens are to be cut in the longitudinal direction. For extruded sections and structural pipes the specimens shall be taken with their longitudinal axis parallel to the direction of extrusion. Extruded bars for structural applications shall be treated as sections.

1.8.4 At least one tensile test specimen is to be prepared from each batch of material submitted for acceptance. Tensile test specimens are to be as defined in Chapter 2 of "Rules and Regulations for the Classification and Construction of Steel Ships".

1.9 Test of surface finish and dimensions

1.9.1 All pieces shall be inspected by the manufacturer with regard to their surface finish and dimensions. The pieces shall then be presented to the Surveyor for final inspection.

1.10 Non-destructive tests

1.10.1 Where called for in the purchase order or required by the specification, the manufacturer must subject the products to a suitable non-destructive test. Where necessary, agreements shall be

reached regarding the method of testing and the permitted limits for indications of defects. Furthermore, the Surveyor may require that a test be performed if there are reasons to doubt that the products are free from defects.

1.11 Marking

1.11.1 The manufacturer is to adopt a system of identification which will ensure that all finished material in a batch presented for test is of the same nominal chemical composition.

Table 2.1.1: Chemical composition limits of aluminium alloys

Material designation	Chemical composition (%)											
	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	OTHERS		Al
										Each	Total	
5083	0,40 max	0,40 max	0,10 max	0,40-0,10	4,0-4,9	0,05-0,25	-	0,25 max	0,15 max	0,05 max	0,15 max	remainder
5086	0,40 max	0,50 max	0,10 max	0,20-0,70	3,5-4,5	0,05-0,25	-	0,25 max	0,15 max	0,05 max	0,15 max	remainder
6061	0,40-0,80	0,70 max	0,15-0,40	0,15 max	0,8-1,2	0,04-0,35	-	0,25 max	0,15 max	0,05 max	0,15 max	remainder
6082	0,70-1,30	0,50 max	0,10 max	0,40-1,0	0,6-1,2	0,25 max	-	0,20 max	0,10 max	0,05 max	0,15 max	remainder

Table 2.1.2: Mechanical properties of selected aluminium alloys

Alloy and temper	**Tensile strength (N/mm^2)**	**0,2% proof stress (N/mm^2)**	**Elongation on 5,65 $\sqrt{S_o}$ (%)**
	minimum	**minimum**	**minimum**
5083-0 and F	260	125	14
5083-H321	300	215	12
5086-0 and F	240	95	14
5086-H112	240	110	8
5086-H321	270	195	12
6061-T6	290	240	10
6082-T6	290	240	8

1.11.2 Products are to be clearly marked by the manufacturer. The following particulars are to be shown on all materials which have been accepted:

(a) Manufacturer's name or trade mark.

(b) Short designation of alloy.

(c) Identification mark which will enable the full history of the item to be traced.

(d) Personal stamp of the Surveyor responsible for the final inspection.

(e) LHR mark.

1.12 Certification

1.12.1 Each test certificate or shipping statement is to include the following particulars:

(a) Purchaser and order number.

(b) Construction project number, where known.

(c) Number, description, dimensions and weight of the products.

(d) Specification or grade of alloy.

(e) Method of manufacture.

(f) Identification mark which will enable the full history of the item to be traced.

(g) Chemical composition.

(h) Mechanical test results (not required on shipping statement).

(i) Details of heat treatment where applicable.

1.12.2 Where the alloy is not produced at the works at which it is wrought, a certificate is to be supplied by the manufacturer of the alloy stating the cast number and chemical composition. The works at which the alloy was produced must be approved by the Society.

SECTION 2 Aluminium weldings and welding procedures

2.1 Application

2.1.1 The requirements of this Section are applicable to mono-hull and multi-hull craft of aluminium construction.

2.1.2 In this Section are included 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.

2.2 General design principles

2.2.1 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.

2.2.2 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.

2.2.3 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.

2.2.4 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.

2.2.5 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.

2.2.6 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.

2.2.7 Welded joints are to be designed to ensure that the proposed weld type and quality can be satisfactorily achieved under the given fabricating conditions.

2.2.8 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).

2.3 Welding consumables

2.3.1 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 see SECTION 1.

2.3.2 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.

2.3.3 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.

2.3.4 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.

2.4 Welder qualifications

2.4.1 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.

2.5 Documentation to be submitted

2.5.1 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.

2.5.2 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

2.6 Butt welding

2.6.1 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).

2.6.2 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.

2.6.3 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 beveled and the web slit and expanded or pressed together to equalise the depths of the members. The length of the transition should be at least equal twice the difference in depth.

2.6.4 To provide smooth stress flow, the transition between differing plate thickness is to be gradual. Where the difference in thickness exceeds 3mm, the thicker plate to be welded is to be tapered with a maximum slope $^1/_3$. Differences in thickness of 3mm 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.

2.6.5 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.

2.6.6 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 25mm 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.

2.6.7 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.

2.6.8 In Table 2.2.1 and Table 2.2.2 a number of typical joint preparations for TIG and MIG welding is shown respectively.

Table 2.2.1: Typical joint preparations for TIG welding of aluminium alloys

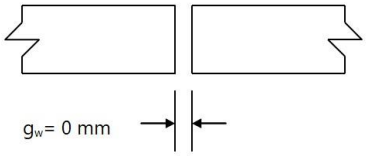
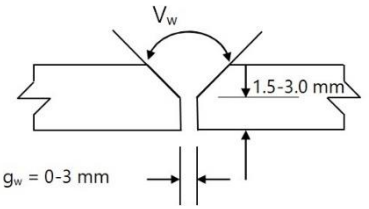
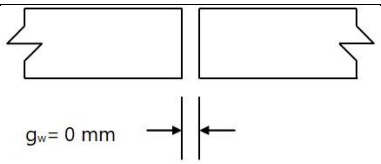
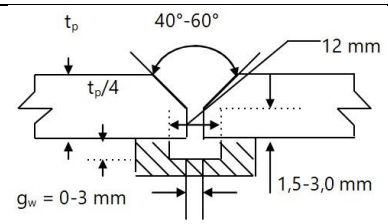
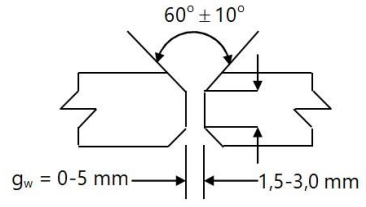
Thickness (mm)	Joint design	Welding position/comments
2,5 – 3,0		Flat Horizontal Vertical Overhead
3,0 – 10,0		Flat and Vertical V = 60° Horizontal and Overhead V = 90° - 110°
Symbols and definitions:		
g_w = weld gap, mm V_w = weld preparation angle, degrees		

Table 2.2.2: Typical joint preparations for semi-automatic MIG welding

Thickness (mm)	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
Symbols and definitions:		
g_w = weld gap, mm t_p = plate thickness, mm		

2.7 Fillet welds

2.7.1 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 2.2.1. 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 beveled.

2.7.2 The throat thickness a of fillet welds is to be determined from:

$$a = t_p \times \beta \times \left(\frac{d}{s}\right) mm$$

Where:

s = the length of correctly proportioned weld fillet, clear of end craters, in 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, in mm, on which weld fillet size is based

β = weld factor

Weld factors are contained in Table 2.2.3

Note: For double continuous fillet welding, $\left(\frac{d}{s}\right)$ is to be taken as 1 (see 2.10.1)

2.7.3 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 2.2.2).

2.7.4 Where an approved automatic deep penetration procedure is used, the weld factors given in Table 2.2.3 may be reduced by 15%.

2.7.5 The leg length of the weld is to be not less than $\sqrt{2}$ times the specified throat thickness.

2.7.6 The plate thickness t_p to be used in 2.7.2 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.

2.8 Throat thickness limits

2.8.1 The throat thickness limits given in Table 2.2.4 are to be complied with.

2.9 Single sided welding

2.9.1 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.

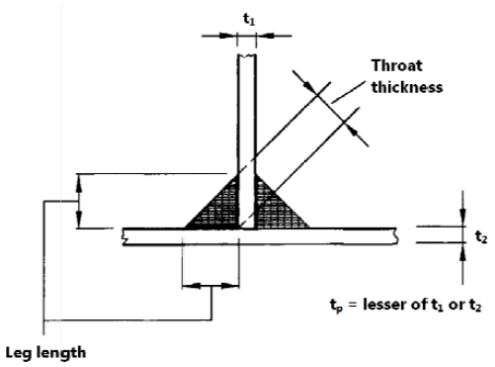
2.9.2 Where internal access for welding is impracticable, backing bars are to be fitted in way of butt and fillet welds, or alternative means of obtaining full penetration welds are to be agreed. Backing bars are to be permanent or temporary.

2.9.3 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.

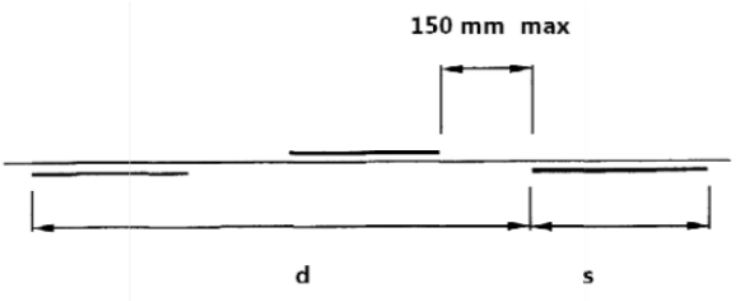
2.9.4 Backing bars are to be continuous for the full length of the weld and joints in the backing bar are to be by full penetration welds, ground smooth.

Figure 2.2.1: Weld types

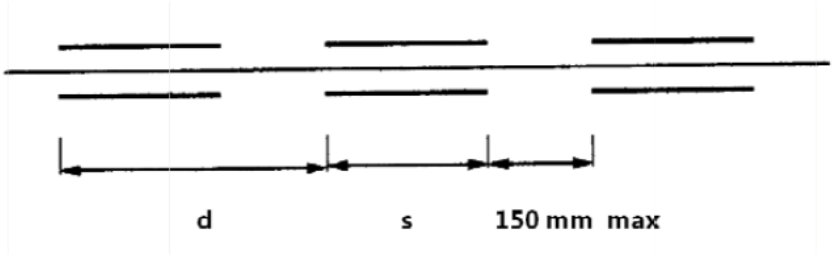
(a) Weld fillet dimensions



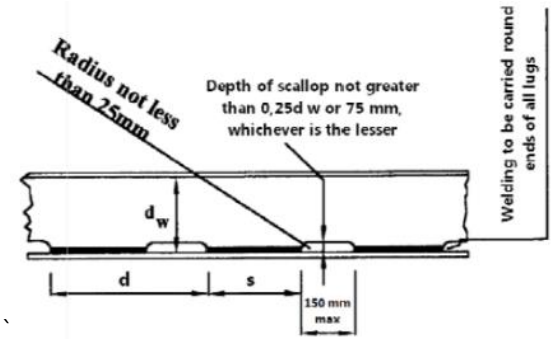
(b) Staggered intermittent



(c) Chain intermittent



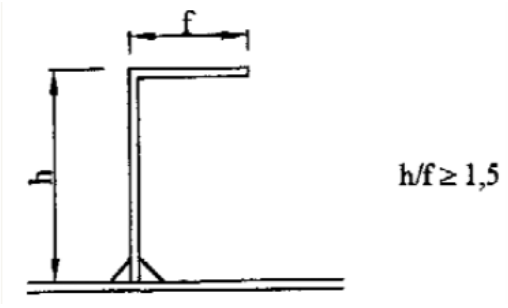
(d) Scalloped construction



2.9.5 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.

2.9.6 Temporary backing bars are to be suitable grooved in way of the weld to ensure gull penetration.

Figure 2.2.2: Web height/flange breadth ratio



2.10 Double continuous welding

2.10.1 Where double continuous fillet welding is proposed, the throat thickness is to be in accordance with 2.7.2 taking $\left(\frac{d}{s}\right)$ equal to 1

2.10.2 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 2.2.3: Weld factors (to be continued)

Item	Weld Factor β	Remarks
(1) General application:		except as required below
a) Shell envelope boundary, including sea chests and hull penetrations	Full penetration	For hull penetrations, fitted with a flange or other support, equivalent arrangements may be considered
b) Watertight plate boundaries	0,34	
c) Non-tight plate boundaries	0,13	
d) 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
e) Panel stiffeners	0,10	
f) Overlap welds generally	0,27	
g) Longitudinals of the flat-bar type to plating		see 2.10.2
(2) Bottom construction:		
a) Non-tight centre girder:		
- to keel	0,27	no scallops
- to inner bottom	0,21	
b) Non-tight boundaries of:		
- floors, girders and	0,21	in way of 0,2 x span at ends
- brackets	0,27	in way of brackets at lower end of main frame
Watertight bottom girders	0,34	
Connection of girder to inner bottom in way of longitudinal bulkheads supported on inner bottom	0,44	
c) Inner bottom longitudinals, or face flat to floors reverse frames	0,13	
d) 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:		
a) Webs of web frames and stringers:		
- to shell	0,16	
- to face plate	0,13	
(4) Decks and supporting structure:		
a) Weather deck plating to shell	0,44	
Other decks to shell and bulkheads (except where forming tank boundaries)	0,21	generally continuous
b) Webs of cantilevers to deck and to shell in way of root bracket	0,44	
c) Webs of cantilevers to face plate	0,21	
d) Girder webs to deck clear of end brackets	0,10	
e) Girder webs to deck in way of end brackets	0,21	
f) Web of girder to face plate	0,10	
g) Pillars:		
- fabricated	0,10	
- end connections	0,34	
- end connections (tubular)	full penetration	
h) Girder web connections and brackets in way of pillar heads and heels	0,21	Continuous
(5) Bulkheads and tank construction:		
a) 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

Item	Weld Factor β	Remarks
b) Secondary members where acting as pillars	0,13	
c) Non-watertight pillar bulkhead boundaries	0,13	
d) Perforated flats and wash bulkhead boundaries	0,10	
e) Deep tank horizontal boundaries at vertical corrugations	full penetration	
(6) Structure in machinery space:		
a) Centre girder to keel and inner bottom	0,27	no scallops to inner bottom
b) Floors to centre girder in way of engine thrust bearers	0,27	
c) Floors and girders to shell and inner bottom	0,21	
d) Main engine foundation girders:		
- to top plate	deep penetration to depend on design	edge to be prepared with maximum root
- to hull structure		$0,33t_p$ generally deep penetration
e) Floors to main engine foundation girders	0,27	
f) Brackets, etc., to main engine foundation girders	0,21	
g) Transverse and longitudinal framing to shell	0,13	
(7) Superstructures and deckhouses:		
a) Connection of external bulkheads to deck	0,34	1st and 2nd tier erections
	0,21	elsewhere
b) Internal bulkheads	0,13	
(8) Steering control systems:		
a) Rudder:		
- fabricated mainpiece and	0,44	
- mainpiece to side plates and webs		
b) Slot welds inside plates	0,44	
c) Remaining construction	0,21	
d) Fixed and steering nozzles:		
- Main structure	0,44	
- Elsewhere	0,21	
e) Fabricated housing and structure of thruster units, stabilisers, etc.:		
- Main structure	0,44	
- Elsewhere	0,21	
(9) Miscellaneous fittings and equipment:		
a) Rings for manhole type covers, to deck or bulkhead	0,34	
b) Frames of shell and weathertight bulkhead doors	0,34	
c) Stiffening of doors	0,21	
d) Ventilator, air pipes, etc., coamings to deck	0,34	Load Line Position 1 and 2
	0,21	elsewhere
e) Ventilator, etc., fittings	0,21	
f) Scuppers and discharges, to deck	0,44	
g) Masts, crane pedestals, etc. to deck	0,44	full penetration welding may be required
h) Deck machinery seats to deck	0,21	generally
i) Mooring equipment seats	0,21	generally , but increased or full penetration may be required
j) Bulwark stays to deck	0,21	
k) Bulwark attachment to deck	0,34	
l) Guard rails, stanchions, etc., to deck	0,34	
m) Bilge keel ground bars to shell	0,34	continuous fillet weld , minimum throat thickness 4 mm
n) Bilge keels to ground bars	0,21	Light continuous or staggered intermittent fillet weld, minimum throat thickness 3 mm
o) Fabricated anchors	full penetration	

2.11 Full penetration welding

2.11.1 Where full penetration welding is required in accordance with 2.6 and 2.7, 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.

2.11.2 Where access to the second side for welding is impracticable, backing bars are to be used in accordance with 2.9.

Table 2.2.4: 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 $t_p \leq 7,5$mm		
Hand or automatic welding	3,0	
Automatic deep penetration welding	3,0	
(ii) Plate thickness $t_p \leq 7,5$ 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. Where t_p exceeds 25 mm, the limiting values may be calculated using a notional thickness equal to 0,4 (t_p + 25) mm.
3. 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'ssatisfaction.

2.12 Intermittent welding (chain)

2.12.1 Chain intermittent welding may be used, outside of the impact area in the bottom shell or crossdeck structure of high speed craft.

2.13 Intermittent welding (staggered)

2.13.1 Where intermittent welding is used, the welding is to be made continuous round the ends of brackets, lugs, scallops, etc.

2.13.2 Staggered intermittent welding is not to be used in the bottom shell or crossdeck structure of high speed craft.

2.14 Stud welding

2.14.1 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.

2.15 Slot welding

2.15.1 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.

2.16 Lap connections

2.16.1 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, in general, to neither 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.

2.17 Connections of primary structure

2.17.1 Connections of primary structure need a full penetration welding.

2.17.2 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:

$$\frac{\text{stiffener plating} \times 0{,}85}{\text{length of web plating between notches}}$$

2.17.3 Where direct calculation procedures have been adopted, the weld factors for the 0,1 x overall length at the ends of the members will be considered in relation to the calculated loads.

2.18 Primary and secondary member end connection welds

2.18.1 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.

2.18.2 The welding of secondary member end connections is to be not less than as required by Table 2.2.5. Where two requirements are given the greater is to be complied with.

2.18.3 The area of weld, A_w, is to be applied to each arm of the bracket or lapped connection.

2.18.4 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 2.2.5: Primary and secondary member end connection welds

Connection	Weld area , A_w , in 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 SM	0,27
(b) in tank	1,4 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 x span at ends, or in way of the end bracket if that be greater		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, x throat thickness, in cm SM = the section modulus, in cm^3, of the stiffener on which the scantlings of the end bracket are based		
NOTE: For maximum and minimum weld fillet sizes, see Table 2.2.4		

2.19 Weld connection of strength deck plating to sheerstrake

2.19.1 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.

2.20 Notches and scallops

2.20.1 Notches and scallops are to be kept clear of the toes of brackets, etc. Openings are to be well rounded with smooth edges.

2.20.2 The size and position of the scallops are such that a satisfactory weld can be made around the ends of openings.

2.21 Watertight collars

2.21.1 Watertight collars are to be fitted, where stiffeners are continuous through watertight or oiltight boundaries.

2.22 Lug connections

2.22.1 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. Some typical lug connections are shown in Figure 2.2.3 and Figure 2.2.

Figure 2.2.3: Typical lug connections

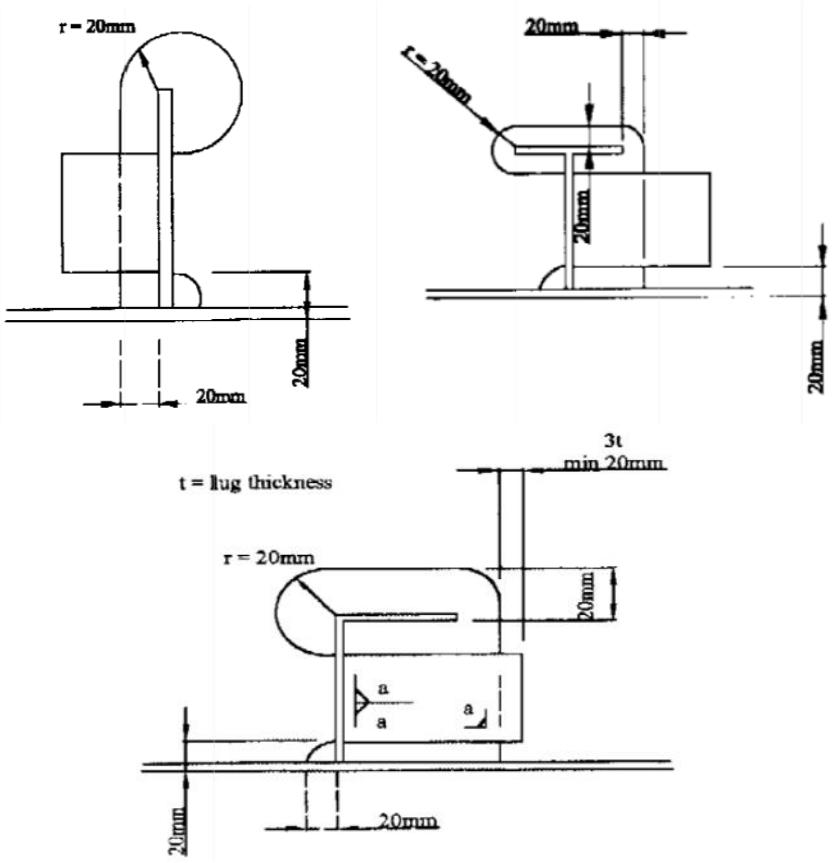
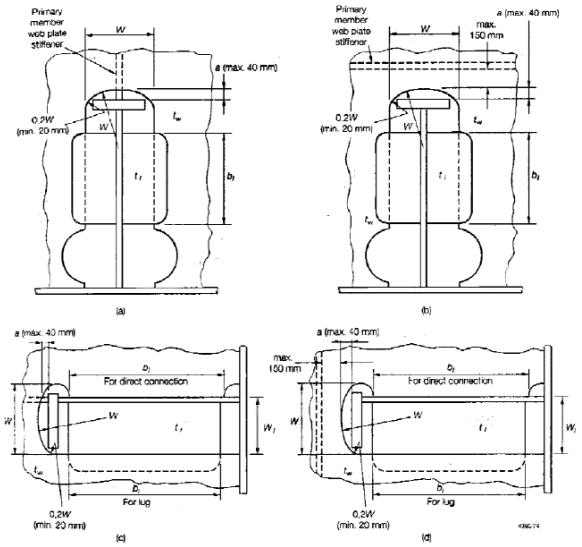


Figure 2.2.4: Cut-outs and connections



2.22.2 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.

2.22.3 Lugs or tripping brackets are also to be fitted where continuous secondary stiffeners are greater than half the depth of the primary stiffeners.

2.23 Insert plates

2.23.1 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.

2.23.2 The corners of insert plates are to be suitably radiused.

2.24 Doubler plates

2.24.1 It is usually preferable doubler plates to be avoided in areas, which are easily affected by corrosion and present difficulty in inspection and maintenance.

2.24.2 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.

2.25 Joint preparation

2.25.1 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.

2.25.2 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.

2.25.3 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.

2.25.4 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.

2.25.5 In Table 2.2.1 and Table 2.2.2 are shown typical butt joints.

2.26 Triaxial stresses

2.26.1 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.

2.27 Aluminium / Wood connection

2.27.1 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.

2.27.2 Timbers such as western red cedar, oak and chestnut are not, unless well-seasoned, to be directly in contact with aluminium.

2.27.3 The following types of timber preservatives should be avoided: copper napthanate, copper-chrome-arsenate, borax-boric acid.

2.28 Aluminium / Steel connection

2.28.1 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.

2.28.2 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.

2.28.3 The aluminium material is to comply with the requirements of SECTION 1 and the steel is to be of an appropriate grade complying with the relevant LHR requirements.

2.28.4 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.

2.28.5 Bimetallic joints where exposed to seawater or used internally within wet spaces are to be suitably protected to prevent galvanic corrosion.

CHAPTER 3 FRP and Sandwich materials

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SECTION 4	Manufacturing

SECTION 1 General

1.1 General requirements

1.1.1 The requirements of this Chapter are applicable to craft generally constructed of fibre-reinforced plastic, using hand lay-up, mechanical deposition (i.e. spray moulding), contact moulding or vacuum assisted and resin injection techniques. Construction may be either of the single-skin or sandwich type, or a combination of both.

1.1.2 Other materials (i.e. non-FRP materials) are to be of good quality and suitable for the purpose intended. Details of these materials are to be stated on the relevant construction plans. When these materials are attached to, or encapsulated within, the plastic construction, the material is not to affect adversely the cure of the plastic materials.

1.1.3 Where moulding techniques and methods of construction differing from those given in SECTION 4 are proposed, details are to be submitted for consideration by LHR.

1.1.4 Reinforcement, matrix, fillers and core materials for major hull structural elements are normally to be delivered with a Type Approval Certificate issued by LHR or other recognized Classification Society. Where the ship is built under special survey, the main raw materials are to be homologated by the Society.

1.1.5 The outer reinforcement ply of the outer hull skin laminate is to be at least 300 g/m^2 of chopped strand fibers containing as little water-soluble bonding components as possible. Normally, spray roving or powder bound mat should be used. Other material systems giving an equivalent surface protection may also be accepted. Areas inside the hull, expected to be continuously exposed to water submersion (i.e. bilge wells, etc.) shall have a surface lining as required for tanks in 1.1.6.

1.1.6 The insides of tanks shall have a surface lining consisting of at least 600 g/m^2 reinforcement material as specified in 1.1.5 above, impregnated with Grade-A polyester. If Grade-A polyester is used throughout the tank construction, the reinforcement may be as described in 1.1.5. The surface lining is, as far as practicable, to be laid continuously in the sides and bottom of the tanks.

1.1.7 The construction specifications to be submitted for examination by the Head Office shall in general contain the following data:

(a) Designation, type and manufacturer of resins, both for laminating resin and gel coat, and of the single reinforcements of laminates as well as of the core material of structures of sandwich construction.

(b) Brief description of manufacturing procedure of laminates and of the manufacturing environmental conditions.

1.2 Terminology

1.2.1 Basic terminology is as follows:

(a) For the purposes of these Rules, a '**plastic**' is regarded as an organic substance, which may be thermosetting or thermoplastic and which, in its finished state, may contain reinforcements or additives.

(b) **Reinforced plastics**: heterogeneous material consisting of a matrix of resin with relevant additives and of fiber reinforcements, produced in the form of laminate formed on a mould.

(c) **Resins**: unsaturated polyester, vinylester, epoxy or phenolic resins.

(d) **Reinforcement of reinforced plastics**: fibres in the form of mat, woven roving, cloth or tape. The

reinforcement is called:

~ of a homogeneous type, when the fibres are of a single material (e.g. glass) in the whole laminate;

~ of a mixed type, when the fibres of some layers are of a material other than that of the others;

~ of a hybrid type, when the fibres of one or more layers are of two or more different materials.

(e) **Single-skin laminate**: reinforced plastic material, in general in the form of a flat or curved plate or of sections.

(f) **Sandwich laminate**: material composed by two single-skin laminates structurally connected to each other by the interposition of a core of light material.

SECTION 2 Raw Materials

2.1 General

2.1.1 Provision is made in this Chapter for the manufacture and testing of plastic materials used in the construction of ships and other marine structures and associated machinery items, which are classed or are intended for classification by LHR.

2.1.2 These materials and products are to be manufactured and surveyed in accordance with the general requirements of SECTION 2, SECTION 3 and SECTION 4.

2.1.3 Raw materials must be type approved by the LHR or other recognized Classification Society. Minimum requirements for approval of raw materials are given in SECTION 3.

2.1.4 Materials making up the laminates shall have characteristics suitable for the purpose of hull building, at the judgment of the manufacturer. On the basis of the relevant information provided to LHR, this latter may require, at its own judgment, the carrying out of special checks on the laminates.

2.1.5 Details of all the approved and accepted plastic materials are to be submitted by the boat manufacturer with the initial submission of plans. The types and quantities of curing systems reported, are to be those recommended by the resin manufacturer for the approved resin systems. When specifying materials, the manufacturer's exact type designation, identification and reference numbers are to be quoted. All sandwich core materials are to be of a type acceptable by LHR and are to be clearly identified, together with any core-bonding adhesive to be used. Fibre contents by weight for each type of reinforcement are to be reported. To the manufacturers of hulls built with type-approved materials, LHR will issue, upon request, a relevant Statement; on the Certificate of the ship or boat a specific symbol or notation will be entered.

2.2 Resin Systems

2.2.1 Resins used are to be of a type that has been approved by LHR or other recognized Classification Society, for marine construction purposes. Samples of the resin batches being used in the construction may be taken for limited quality control examination, at the discretion of the Surveyor. Resins other than those utilized for gel coats, are to be unsaturated, general purpose or fire retardant polyesters suitable for marine use, vinylesters or epoxies and are to be catalyzed in strict accordance with manufacturers' recommendations. Resins are to resist abrasion and to have a good stability regarding aging in marine environment and industrial atmosphere.

2.2.2 Isophthalic or orthophthalic polyester may be used. The former is often used for gel coat and outer ply lamination; the latter is of lesser quality but, when properly used, is an effective laminating resin. The polyester is to be suitable for lamination by hand lay-up or spraying. It is to have good wetting properties

and is to cure satisfactorily at normal room temperature. Polyester intended for other production methods is to be approved after special consideration.

2.2.3 Epoxy resins cannot form a primary bond with polyester and vinylester resins. Therefore, they can only be used either by themselves or in conjunction with fully cured polyester or vinylester resins.

2.2.4 Phenolic resins, although having superior properties regarding fire resistance, are not generally suitable for structural applications. Where fire retardant additives to the resin system are used, the type and quantity are to be as recommended by the resin manufacturer. The results of independently tested fire retardant and fire-restricting materials are to be submitted. All fire retardant systems are to be used in strict accordance with the resin manufacturer's recommendation.

2.2.5 The curing procedure for the resin system is to be the one recommended by the resin manufacturer for the particular application, so that the resin will cure in the required time, in accordance with the approved cure schedule. In general, the rate of gelation is to be controlled by the amount of catalyst/accelerator added to the resin. The quantity of catalyst/accelerator is to be kept within the limits stipulated by the manufacturer and, generally, is to be not less than one per cent of the base resin, by weight. During curing, the exothermic temperature is to be kept at a suitable level.

2.2.6 Wax additives are only to be added by the resin manufacturer in accordance with the agreed procedure and tested accordingly.

2.2.7 Where a resin contains an ingredient that can settle within the resin system, it is the Builder's responsibility to ensure that the resin manufacturer's recommendations regarding mixing and conditioning are complied with prior to use.

2.2.8 Compliant resins for structural applications are to be of types accepted by LHR and are to be used strictly in accordance with the manufacturer's recommendations. The plans submitted for approval are to identify which compliant resins are used in different applications. Surface preparations and over bonding are also to be identified on the submitted plans.

2.2.9 Proposals for the use of structural filleting applications using compliant resin are to be submitted in detail. Such proposals will be subject to individual consideration.

2.3 Gel coat

2.3.1 Gel coat is to be of a thickness of 0,3 - 0,5 mm. Gel coats based on orthophthalic polyester resin systems are not acceptable. Gel coat and topcoat shall be produced of polyester satisfying the requirements of LHR-A resins. All gel coats are to be used strictly in accordance with the manufacturer's recommendations. The curing system is to be in accordance with 2.2.5. Those parts of the inner side of the laminates that can be exposed to water are to be given a topcoat, which both protects the laminates and provides complete curing of these.

2.3.2 Where pigments are to be added, reference is to be made to 2.4. Where pigments are to be added by the Builder, the gel coat is to be allowed to stand for sufficient time to permit entrapped air to be released. The method of mixing is to be carried out strictly in accordance with the resin and pigment manufacturer's instructions. Color pigments and fillers are to be such that separation will not occur during spraying or application by hand.

2.3.3 Where the temperature of the gel coat resin is below that of the workshop, the gel coat resin is to be conditioned to attain the workshop temperature prior to use.

2.3.4 When the inspection of the mould is an agreed hold point, required by the quality plan, the mould is to be inspected by the attending Surveyor prior to gel coating. The Surveyor may also require witnessing the initial application of the gel coat.

2.3.5 Where a gel coat is not used, details of the proposed water barrier are to be submitted for consideration. Where a painted finish is to be adopted in place of a gel coat, a suitable tie coat may be required, in accordance with the paint manufacturer's recommendations.

2.3.6 Where the hull is of sandwich construction and built on a male plug mould, the water barrier on the outer surface of the hull will be specially considered.

2.4 Pigments, Fillers, Additives

2.4.1 Additives are only to be added by the resin manufacturer, in accordance with the agreed procedure and tested accordingly.

2.4.2 Fillers added by a Builder are to be of the dispersed type. The amount of filler that may be added to a resin is to be recommended by the resin manufacturer and is not to alter significantly the viscosity of the resin nor is it to affect the overall strength properties of the laminate. The percentage of fillers is not to exceed, as a rule, 10% of the mass of the resin, with a maximum of 2% for the thixotropic agents and 5% for the flame retarders. Recommendations by the resin manufacturer to adopt amounts of fillers in excess of 13% by weight of the base resin will be subject to individual approval and testing. Fillers are to be carefully and thoroughly mixed into the base resin that is then to be allowed to stand to ensure that the entrapped air is released. The resin manufacturer's recommendations regarding the method of mixing are to be followed. Fillers are not to be used in the structural laminates forming the boundaries of oil fuel and water tanks.

2.4.3 The amount of fire retardant additives may be in excess of that indicated in 2.4.2, provided that due account is taken of the reduced mechanical properties when determining scantlings in accordance with the Rules. Where laminates are required to have fire retardant or restricting properties, details of the proposals are to be submitted for approval. Test results of independently tested fire retardant and fire restricting materials are to be submitted for design purposes. All fire retardant resin systems are to be used strictly in accordance with the resin manufacturer's recommendations. The attention of Owners and Builders is drawn to the additional statutory regulations regarding fire safety that may be imposed by the National Authority of the country in which the craft is to be registered or the Governments of the states to be visited. The use of fire retardant and fire restricting materials in craft required to comply with statutory requirements, will be subject to the individual approval of the National Authority of the country in which the craft is to be registered, or LHR, where authorized to undertake this work on behalf of the National Authority.

2.4.4 Lightweight surfacing materials for reinforcing resin rich surfaces are to be compatible with the resin being used. Where peel ply materials are to be used, the finish is to be such that, after removal, it does not interfere with any subsequent bonding processes.

2.4.5 The types of color pigments used are to be such that the final cure of the resin is not affected. Pigments may be added to the resin by either the resin manufacturer or the moulder. When added by the moulder, it is to be as a paste dispersal in the same or compatible resin. Pre-pigmented gel coats are recommended. Where pigments are to be added by the Builder, thorough mixing is essential. The amount and type of pigment added is not to exceed that recommended by the resin manufacturer for a satisfactory depth of color. Proposals to use amounts of pigment solids in excess of five per cent, by weight, of the base resin, will be subject to individual approval and testing. It is recommended that pigments are not to be added to the gel coat or laminating resins used in the under-water portion of the hull laminate or in laminates forming the boundaries of oil fuel and water tanks. The addition of pigments is not to unduly affect the gelation time of the resin system or the physical properties of the gel coat layer of the laminate produced. The resin and/or pigment manufacturer's written confirmation in this respect is to be obtained and recorded in the Builder's quality control documentation.

2.4.6 Release agents are to have no inhibiting effect on the gel coat resin and are to be those

recommended by the resin manufacturer.

2.5 Fiber Reinforcements

2.5.1 All fiber reinforcements are to be of a type approved by LHR Fiber reinforcements considered are E, S or R glass fibers, and carbon and aramid fibers. The use of hybrid reinforcing materials is also acceptable. A certificate showing chemical composition is to be presented, or a chemical analysis is to be carried out showing that the requirements to the various types have been met. To be considered a reinforced plastic, the properties of the cured laminate of resin and fiber must exceed those of the cured clear resin without fiber. Where coupling agents are used, they are to be of the silane type, and are to be compatible with the laminating resins. Fiber reinforcements can be used in the form of chopped strands (emulsion bound mat), fine-meshed or coarse-grained woven cloths (woven roving), which are chopped on application or used in their continuous form, or unidirectional cloths.

2.5.2 All reinforcements are to be stored strictly in accordance with the manufacturer's recommendations. Rolls of reinforcement are to remain in their original packaging to minimize contamination. The quality control documentation is to provide traceability of all reinforcements using the manufacturer's batch numbers. The materials are to be free of imperfections, discoloration, foreign matter and other defects.

2.5.3 Pre-impregnated reinforcements are to be suitably stored in an approved area. Detailed storage records are to be maintained as part of the quality control documentation.

2.5.4 In the submerged part of the hull the reinforcement layer next to the gelcoat should contain as little water-soluble bonding components as possible, and, normally, spray roving or powder bounded mat are to be used.

2.6 Core materials

2.6.1 Core materials for sandwich constructions are to be of a type approved by LHR or other recognized Classification Society. All core materials are to be used in accordance with the manufacturer's application procedure, a copy of which is to be submitted for information, with the relevant construction plans of the craft. A second copy is to be incorporated into the quality control documentation. Core materials are to have sufficient compression and shearing strength. If the core serves only as a base for the laminates, e.g. in stiffeners, no requirements are made to the strength of the core material. Wooden cores are to be waterproof plywood or other materials, which do not swell. Solid wood is to be used as little as possible below the water line. Core materials shall have stable long time properties; continuous chemical processes, diffusion, etc. shall not affect the physical properties of the material. If considered, necessary documentation may be required. On delivery, the surface of the material shall be such that no further machining or grinding is required to obtain proper bonding of the material. Core materials shall normally be compatible with polyester, vinylester and epoxy resins. Core materials with limited compatibility may be accepted upon special consideration. Limitations will be specified in the certificate.

2.6.2 Where necessary, foam core materials are to be conditioned in accordance with the manufacturer's recommendations. Conditioning at an elevated temperature, in excess of that which may be experienced in service, may be necessary to ensure the release of any entrapped residual gaseous blowing agents from the cells of the foam core.

2.7 Core Bonding & Adhesive Materials

2.7.1 Core bonding materials for structural applications are to be of types accepted by LHR, and are to be used strictly in accordance with the manufacturer's instructions. Details of the proposed core bonding paste to be used with the core material are to be indicated on the Materials Data Sheet and the appropriate construction plans. The Builder is to demonstrate that a uniform thickness of bonding paste is obtained by use of notched trowels or comb gauges.

2.7.2 Adhesives for structural applications are to be of types accepted by LHR and are to be used strictly in accordance with the manufacturer's recommendations. Details concerning the handling, mixing and application of adhesives are to form part of the Builder's production plan. Particular attention is to be given to the surface preparation and cleanliness of the surfaces to be bonded. Where excessive unevenness of the faying surfaces exists, a suitable gap-filling adhesive is to be used, or local undulations removed by the application of additional reinforcements. The Builder's quality plan is to identify the level of training required for personnel involved in the application of structural adhesives.

2.8 Materials for Integrated Structures

2.8.1 Metallic materials, such as steel or aluminum alloys, used in the construction, are to comply with the requirements of 1.1.2. Where structural members or components manufactured from these or other materials are to be encapsulated within, or structurally bonded to, laminates, the material is not to adversely affect the cure of the resin system. The metals used are to be resistant to seawater corrosion, as well as to fuel corrosion. The surface area of the component that will be in contact with the resin is to be thoroughly cleaned, degreased and, where practicable, either shot blasted or abraded to provide a key.

2.8.2 Where metallic sections are to be bolted into a structure, the bolting requirements are to be determined by direct calculations that are to be submitted for consideration. Appropriate precautions against corrosion are to be taken.

2.8.3 Where plywood and timber members are to be used in structural applications and are to be laminated onto, or encapsulated within, the laminate, the surface of the wood is to be suitably prepared and primed prior to laminating.

SECTION 3 Approval of raw materials

3.1 General

3.1.1 The boat manufacturer is to keep documentation for raw materials, which should be available at request on inspection.

3.1.2 A type-approval for each material is granted for a period of five years. At the end of the approval period the manufacturer is to apply for renewal of the approval, which normally is assessed on the basis of random sample testing.

3.1.3 When applying for approval, the manufacturer is to submit data and information about the product and production. If the data and information submitted are considered to be satisfactory, an approval testing is to be carried out. All requirements specified for the materials in question are to be checked.

3.1.4 The manufacturer shall ensure that the production of a type approved material is carried out according to the manufacturing procedures adopted at the time of type approval and that all the produced materials bear a suitable identification mark relevant to LHR type approval. Subject to what is stated above, LHR reserves the right to require, at its discretion, checks during the production, or even to require either partial or full repetition of tests and checks required for type approval. The validity of the Type Approval

Certificate expires in the case of unsatisfactory results of the above tests and checks, and the manufacturer is to be notified by the Head Office.

3.1.5 Other internationally recognized test methods than those given for the respective materials may be adopted upon prior agreement.

3.2 Resin Systems

3.2.1 Approval of polyester is divided into the following quality grades:

(a) Grade **LHR-A**: Quality with good water resistance.

(b) Grade **LHR-B**: Quality with normal water resistance.

(c) Grade **LHR-C**: Quality with normal water resistance.

3.2.2 Resin is to be approved by the Society or other recognized Classification Society or National Authority. Requirements for resins in liquid and cured condition are given in Table 3.3.1 and Table 3.3.2 respectively.

3.2.3 Data sheets are to provide liquid and cured form physical and mechanical properties, as well as curing characteristics at a specified temperature indicating the gel time variation with air temperature and amount of catalyst and accelerator, or amount of hardener. Cured mechanical properties are to be given for un-reinforced resin. Batch data sheets are to be supplied with each delivery, indicating the physical and mechanical properties of the particular delivered batch. All resins are to be used within 90 days of their specified "batch date", unless acceptable by the materials manufacturer. Batch data sheets are to be retained by the builder for a period of three years.

3.2.4 Properties of a resin are to be for the form of the resin actually used in production, with all additives and fillers included. The amount of silicon dioxide or other materials added to provide thixotropy is to be the minimum necessary to resist flowing or draining. Liquid and cured condition properties of resins as given in Table 3.3.1 and Table 3.3.2 are to be provided, for the gel coat resin and laminating resin, and, if different, for the skin coat:

Table 3.3.1: Test requirements for resin in liquid condition

Property	Test method according to:	Required values for approval
Density	ISO 1675, ISO 2811	Manufacturer's nominal value ± 5%
Viscosity	- Brookfield: ISO 2555 - Cone/Plate: ISO 2884	Manufacturer's nominal value ± 20%
Acid value	ISO 2114, DIN 53402	Manufacturer's nominal value ± 10%
Monomer content	ISO 4901	Manufacturer's nominal value ± 10%
Mineral content	DIN 16945	Max. value 5%
Gel time	ISO 2535	Manufacturer's nominal value ± 20%
Linear curing shrinkage	ASTM D 2566	Manufacturer's nominal value

Table 3.3.2: Test requirements for resin in cured condition

Property	Test method according to:	Required values for approval testing		
		Grade LHR-A	Grade LHR-B	Grade LHR-C
Density		Manufacturer's nominal value	Manufacturer's nominal value	Manufacturer's nominal value
Tensile Strength	ISO 527	Min 55 MPa	Min 45 MPa	Min 40 Mpa
Tensile Modulus	ISO 527	Min 3000 MPa	Min 3000 MPa	Min 3000 Mpa
Tensile Elongation at Break	ISO 527	Min 2,5 %	Min 1,5 %	Min 1,2 %
Flexural Strength	ISO 178	Min 100 Mpa	Min 80 MPa	Min 80 Mpa
Flexural Modulus	ISO 178	Min 2700 MPa	Min 2700 MPa	Min 2700 Mpa
Volume Shrinkage	ISO 3521	Manufacturer's Nominal value +5%	Manufacturer's Nominal value +5%	Manufacturer's Nominal value +5%
Hardness	EN 59	Min. 35	Min. 35	Min. 35
Heat Deflection Temp.	ISO A75 Method	Min. 75°C	Min. 62°C	Min. 53°C
Water absorption	ISO 62	Max. 80 mg	Max. 100 mg	Max. 100 m

3.3 Gel Coat

3.3.1 Gelcoat and topcoat shall be produced of polyester satisfying the requirements of Grade LHR-A. The resin must not contain more than 10% pigments and other filling compounds. The gel coat is to have higher ductility than the resin employed. This requirement is deemed complied with when the difference between the elongation after fracture of the gel coat and of the resin (without glass reinforcement) is at least 1%.

3.4 Fiber Reinforcements

3.4.1 For reinforcing materials, the specification is to indicate the fiber type and form, weave, fiber orientation, weight, physical data, and mechanical properties. Detailed storage records are to be maintained as part of the quality control documentation.

3.4.2 The reinforcement is to be free from foreign matter. For E-glass type fibers, the sum of Na_2O and K_2O is to be less than 1%. A certificate showing chemical composition is to be presented, or a chemical analysis is to be carried out showing that the requirements of E-glass have been met (SiO_2 52-56%, CaO 16-25%, Al_2O_3 12-16%, B_2O_3 6-12%, Na_2O+K_2O 0-1% and MgO 0-6%). Fibers made of other glass qualities may be used, provided that their mechanical properties and hydrolytic resistance are equally good or better.

3.4.3 Glass fibers are to be produced as continuous fibers. They are tested in that product form in which are to be used. For roving which will be applied by spraying, a demonstration is to be made in the surveyor's presence, to show that the roving is suited to this form of application.

3.4.4 Requirements for glass fiber products are given in Table 3.3.3

Table 3.3.3: Test requirements for glass fiber products

Property	Test method according to:	Required values for approval
Moisture content	ISO 3344	Max 0,2% on delivery (0,5% for CSM)
Loss on ignition	ISO 1887	Manufacturer's nominal value +20%
Weight per unit length or area	Woven Roving: ISO 1889 Chopped Mat: ISO 3374 Woven Roving: ISO 3374	Manufacturer's nominal value –5% to +10%

3.5 Core Materials

3.5.1 Core material specifications are to indicate the material specification number, material type, density, and recommendation for storage, handling and use. Materials dealt with by the requirements of the following paragraphs are the rigid expanded foam plastics and balsa wood; the use of materials other than the above, shall be considered by the Head Office on the basis of equivalence criteria.

3.5.2 Rigid expanded foam plastics

Rigid expanded foam plastics are intended to mean Expanded Polyurethane (PU) and Polyvinylchloride (PVC). Rigid expanded foam plastics are to:

- be of closed-cell types and impervious to water, fuel and oils,
- have good aging stability,
- be compatible with the resin system,
- have good strength retention at 60°C,
- have characteristics and mechanical properties of not less than those indicated in Table 3.3.4, and
- if manufactured into formable sheets of small blocks, the open weave backing material and adhesive are to be compatible and soluble, respectively, with the laminating resin.

3.5.3 Balsa wood

For type approval of balsa wood, it is to:

- be end grained,
- have been chemically treated against fungal and insect attack and kiln dried shortly after felling,
- have been sterilized,
- have been homogenized,
- have average moisture content of 12%,
- have characteristics and mechanical properties of not less than those indicated in Table 3.3.5, and
- if manufactured into formable sheets of small blocks, the open weave backing material and adhesive are to be compatible and soluble, respectively, with the laminating resin.

It is assumed that manufacturing process is such that balsa wood fibres are right-angled with respect to the fibres of surface laminates of sandwich.

3.5.4 Synthetic 'felt' type core materials are to be specially approved. Other types of core materials will be individually considered, on the basis of these Rules, in relation to their characteristics and intended application. For core materials of particular composition or structure, additional requirements may be

introduced. Expanded polystyrenes may be used only as filling or buoyancy materials. Polyester fiber or vinylester mat is not considered a lightweight structural core, and use will be subject to special consideration. Shear strength for use in the design is to be verified by test. Construction methods and procedures for core materials are to be in strict accordance with core manufacturer' recommendations.

Table 3.3.4: Minimum characteristics and mechanical properties of rigid expanded foams at 20 °C.

Material	Apparent Density (kg/m^3)	Strength (N/mm^2)			Modulus of Elasticity (N/mm^2)	
		Tensile	Compressive	Shear	Compressive	Shear
Polyurethane	96	0,85	0,60	0,50	17,20	8,50
PVC	60					

Table 3.3.5: Minimum characteristics and mechanical properties of end-grain balsa

Apparent density (kg/m^3)	Strength (N/mm^2)					Compressive modulus of elasticity (N/mm^2)		Shear modulus of elasticity (N/mm^2)
	Compressive		Tensile		Shear			
	Direction of stress					Direction of stress		
	Parallel to grain	Perpend. to grain	Parallel to grain	Perpend. to grain		Parallel to grain	Perpend. to grain	
96	5,00	0,35	9,00	0,44	1,10	2300	35,20	105
144	10,60	0,57	14,60	0,70	1,64	3900	67,80	129
176	12,80	0,68	20,50	0,80	2,00	5300	89,60	145

3.6 Materials for Integrated Structures

3.6.1 Plywood

Plywood, for structural applications, is to be of a high quality, marine grade material approved by LHR. In general, the plywood is to be manufactured to a high standard of finish in accordance with ISO or other recognized standards, and is to meet, or be equivalent to, the following general requirements:

(a) Have good quality face and core veneers of a durable hardwood species.

(b) The number of veneers is to be in accordance with Table 3.3.6.

(c) The veneers are to be bonded with a WBP (water and boil proof) type adhesive

(d) Have a moisture content not exceeding 15%.

Butts and seams are to be scarfed or butt strapped where necessary. The length of the scarf is to be no less than eight times the plywood thickness. The scarf is to be glued and, if made in situ, fitted with a backing strap of width not less than 10 times the panel thickness.

3.6.2 Timber

The acceptance of timber in the construction will be subjected to individual consideration depending upon the intended use and timber involved. Solid timber as core material in stiffeners is to be avoided as far as possible. Timber is to be of good quality and properly seasoned, free from heart, sapwood, decay, insect attack, splits, shakes and other imperfections that would adversely affect the efficiency of the material. It is also to be generally free from knots, although an occasional sound intergrown knot would be acceptable. The moisture content of timber for bonded or over-laminated applications using polyester or epoxy resins is, in general, to be nominally 15%. Contents slightly greater than this value are recommended when resorcinol glues are used, and contents slightly lower than this value are required when phenolic or urea-formaldehyde resins are used.

Table 3.3.6: Number of veneers in Plywood

Board thickness (mm)	Minimum Number of plies
Up to 9	3
10-19	5
20 and above	7

SECTION 4 Manufacturing

4.1 Manufacturing and Storage Premises & Equipment

4.1.1 Manufacturing premises are to be closed spaces properly equipped and arranged so that the raw material manufacturer's recommendations and builder's standards for handling, laminating and curing can be followed.

4.1.2 Workshops and equipment are to be in accordance with good manufacturing practice and be to the satisfaction of the Surveyor. The Surveyor is to be allowed unrestricted access during working hours to such parts of the Builder's establishment as may be necessary to ensure that the requirements of the Rules are being complied with.

4.1.3 Premises are to be fully enclosed, dry, clean, shaded from the sun, and adequately ventilated to remove fumes, overspray, and dust from the moulds and laminating area and properly and adequately lighted. Precautions are to be taken to avoid any effects on the resin cure due to direct sunlight or artificial lighting. Laminating areas are to be remote from operations creating dust, so that raw materials and moulds are not contaminated. Draught through doors, windows etc. and direct sunlight is not acceptable in places where lamination and curing are in progress.

4.1.4 The air temperature in the moulding shops is to be +15°C ÷ +28°C. The stipulated minimum temperature is to be attained at least 24 hours before commencement of lamination, and is to be maintainable regardless of the outdoor air temperature. The temperature in the moulding shops is not to vary by more than ± 3°C during 24 hours. The ventilation plant is to be so arranged that the curing process is not affected. Where the temperature exceeds 25°C, special consideration is to be given to the resin system.

4.1.5 The relative humidity of the air is to be kept constant, so that condensation is avoided, and is not to exceed 70%. In areas where spray moulding is taking place, the air humidity is not to be less than 40%. The stipulated air humidity is to be maintainable regardless of outdoor air temperature and humidity.

4.1.6 Deviations from the values given in 4.1.4 and 4.1.5 will be considered, provided temperatures and humidity are within the limits recommended by the manufacturer of the raw material and are reviewed by the Society prior to laminating.

4.1.7 Sufficient temperature and humidity monitoring equipment is to be provided and detailed records are to be kept in accordance with the Quality Assurance system. In larger shops, there is to be at least one thermohydrograph for each 1500 m^2 where lamination is carried out. The location of the instruments in the premises is to be as neutral as possible.

4.1.8 Scaffolding is to be provided, where necessary, to avoid standing on cores or on laminated surfaces. Such arrangements are to conform to the National Authority requirements and are not, in general, to be connected to the molding or impinge on the mold surface.

4.1.9 It is the responsibility of the Builder to ensure that the ventilation and working conditions, together

with discharges into the atmosphere, are such that levels of substances are within the limits specified in any pertinent National or International legislation.

4.1.10 Spaces where the boats are assembled may be allowed to be open.

4.1.11 Storage premises are to be closed spaces, properly equipped and arranged so that the material supplier's directions for storage and handling of the raw materials can be followed. The temperature and the relative humidity of the storage premises shall be controllable. Storage premises for reinforcing materials are to be kept clean and as free from dust as possible, so that the raw material is not contaminated or degraded. Materials are to remain sealed in storage, as recommended by the manufacturer.

4.1.12 Polyester, gelcoat and the like should not be stored in temperatures that will affect the qualities of the material. The storage period is not to exceed the shelf lives. Fillers and additives are to be stored in closed containers impervious to humidity and dust. Core materials are to be stored in a dry space and protected against damage. They are to be contained in their protective packaging until immediately prior to use. Where resin tanks or drums are stored outdoors, it is the Builder's responsibility to ensure that the resin manufacturer's storage conditions are complied with.

4.1.13 Before use, fiber reinforcements are to be stored for at least 48 hours at a temperature and humidity similar to that of the laminating premises.

4.1.14 Materials that may be considered hazardous to each other are to be stored separately. Catalyst is to be stored in a cool, dry location away from the manufacturing facility, in accordance with fire and insurance codes.

4.1.15 When the manufacturing and storage premises are found to be in compliance with the requirements of 4.1, a relevant certificate of fitness of the manufacturing and storage premises may be issued, upon the Builder's request.

4.2 Construction Methods

4.2.1 Fabrication

(a) The use of fabricating procedures differing from those given below will be specially considered. Normally, the laminate is to be laid-up by one of the following methods:

- Hand lay-up or contact process
- Vacuum Bagging
- Resin Impregnation
- Resin Transfer Molding (RTM)
- Resin Infusion
- Pre-preg

(b) The building process description is to be submitted for review by the builder before construction starts. Information on the following items is to be included.

- Description of construction facilities, including environmental control, material storage and handling.
- Specifications for resins, reinforcing products, and core materials, including the manufacturers recommendations.
- Lay-up procedures, including type, orientation of reinforcements, sequence, resin mixing methods, and resin pot-life limits.

- Secondary bonding procedures
- Inspection and quality control systems
- Laminate properties derived from destructive qualification testing, including sample check sheets, forms, and guides.

4.2.2 Workmanship

(a) Gelcoat is, as far as practicable, to be applied by spraying. Downwards spread of the gelcoat after application is not acceptable. Normally, the gelcoat is not to be allowed to cure for more than 24 hours before commencement of laminating. Gelcoat is not required if the laminate is coated with an equivalent surface treatment. Where the inner side of laminates may be exposed to water, a suitable coating for protection (e.g. topcoat) is to be applied. Stiffening members and accommodation components moulded into these laminates are also to have a sufficient layer of coating. Laminate edges exposed to water are to be sealed by 0,3 mm topcoat or equivalent. Where the edge of a sandwich panel can be exposed to water, it is to be covered by laminate.

(b) Moulding of important hull members is to be carried out only by skilled workers under the supervision of a foreman experienced in the judging of the workmanship of the quality of the finished laminate. The foreman is also to ensure that the production is in accordance with the Rules.

(c) Large structural parts are to be properly supported after removal from the mould.

(d) Moulding-in of stiffeners, accommodation components etc. is as far as possible to be carried out in wet laminate. Laminate which has cured for more than 24 hours has to be cleaned to remove possible deposit of wax and ground so that the fibers are exposed prior to any further lamination of structural parts.

(e) After completion of lamination, the laminates are to cure for at least 48 hours at an air temperature of +18°C minimum. Curing at a higher temperature and a shorter curing time may be accepted on the basis of control of the curing rate.

(f) A layer or ply of reinforcing material may consist of a number of pieces. The pieces are to be lapped along their edges and ends. The width of each lap is to be not less than 50 mm. Unless otherwise specifically approved, no laps in the various plies of a laminate are to be closer than 100 mm to each other. Transitions in laminate thickness are to be tapered over a length not less than three times the thickness of the thicker laminate. A gradual transition in fiber reinforcement is to be provided between bi-directional and unidirectional laminates.

(g) Sandwich panels may be laminated with cores that are effective in resisting bending, tension, compression, shear and deflection (e.g. plywood) or are essentially ineffective in resisting bending, tension, compression and deflection, but capable of carrying shear loads, (i.e. balsa wood and plastic foam). All cores are to be effectively bonded to the skins in accordance with the manufacturer's recommendation (e.g. vacuum bag techniques using an approved bedding putty). Joints in core materials are to be scarphed and bonded, or connected by similar effective means. Where sandwich panels with ineffective cores are used in way of mechanically connected structures, gears and equipment, a core effective in resisting bearing, shear, flexure and compression is to be inserted. The inserts are to be bonded to the skins or faces of the sandwich and to the adjacent core. The ply of skin laminate in contact with each face of a core material is to be chopped-strand mat. The mat is to be thoroughly impregnated with resin and the core is to be coated with resin before lay-up. For foam cores, the resin is to be sufficiently rolled to ensure that all voids are filled, and the coat of resin for wood cores should be enough to seal the grain of the wood.

(h) Secondary bonds should only be used when a primary bond cannot be achieved. Wherever

possible, peel-ply should be applied to the outer layer of the surface requiring the secondary bond. When preparing for a secondary bond, the following criteria, along with the manufacturer recommendations, should be adhered to:

- The area is to be clean and free from all foreign particles, such as wax, grease, dirt, and dust.
- When grinding is required, the grinding is not to damage any of the structural glass fibers, thus weakening the laminate, especially in highly stressed areas.
- In general, the first ply of the secondary lay-up is to be chopped-strand mat. The final ply of laminate along the bond line of the cured laminate is to be preferably chopped-strand mat.

4.2.3 Moulds

(a) Moulds are to be constructed of a suitable material and are to be adequately stiffened to maintain their overall shape and fairness of form. The materials used in the construction of moulds are not to affect the resin cure. During laminating, provisions shall be taken to ensure satisfactory access, to permit proper carrying out of laminating.

(b) The finish of a mould is to be such that the mouldings produced are suitable for the purpose intended. The resultant aesthetic appearance of the moulding is strictly a matter between moulder and Owner.

(c) Where multiple section moulds are used, the sections are to be carefully aligned to the attending Surveyor's satisfaction prior to moulding. Mismatch between mould sections is to be avoided.

(d) The release agent (e.g. mould wax, etc.) is to be of a type recommended by the resin manufacturer and is not to affect the cure of the resin.

(e) Prior to use, all moulds are to be cleaned, dried and conditioned to the workshop temperature.

(f) Mouldings are to be adequately supported to avoid distortion during final cure. Lifting arrangements are to be designed so that mouldings are subjected to minimal distortion and unnecessary stressing. Scaffoldings are to be erected to enable an easy access to the work and for inspection. As a rule, these scaffoldings are not to be in contact with the laminate.

(g) Where metallic moulds are used, welding is to be minimized to avoid distortion of panels.

4.2.4 Materials Handling

(a) All arrangements are to be taken by the shipyard to ensure the storage of raw materials in conditions in accordance with those required by the materials suppliers. The attention is drawn on the necessity to foresee the working up of material components sufficiently in advance, in order to use them at the workshop temperature.

(b) The arrangements for the receipt, verification against certificates of conformity, and subsequent handling of materials are to be covered by the Builder’s quality control procedures, such that the materials do not suffer contamination or degradation and bear adequate identification at all times. Storage is to be so arranged, that materials are used by batch, wherever possible, in order of receipt. Materials are not to be used after the manufacturer’s date of expiry, except with the prior agreement of LHR and new certificates of conformity being obtained from the material manufacturer. Details of the new certificates of conformity are to be entered into the quality control system.

4.3 Construction Process

4.3.1 General

(a) Provision is made in this Section for the construction of craft built of fiber reinforced plastic using thermosetting materials. Craft built of fiber reinforced thermoplastic materials will be subject to individual consideration.

(b) This Section contains the general Rule requirements to be complied with in the construction of fiber- reinforced craft being built under survey. Where detailed requirements are not defined, good boat building practices are to be applied.

4.3.2 Resin preparation

(a) Curing agents, fillers and pigments are to be added strictly in accordance with the resin manufacturer's recommendations.

(b) Before decanting, all resins are to be thoroughly mixed, deaerated and conditioned to the shop temperature in accordance with the resin manufacturer's instructions.

(c) A peroxide catalyst must never be directly mixed to the cobalt accelerator, because of their explosive reaction. In all cases, the catalyst - or accelerator - is to be carefully distributed in resin before adding the other constituent. Mixing is to be carefully carried out, and slow enough to avoid the trapping of air into the resin.

(d) All measuring / pumping equipment is to be certified and suitable for the quantity of material being measured. Valid certificates of calibration are to form part of the quality control documentation.

(e) Quality control records are to be maintained to provide traceability and identification of the resin and all additives used in the resin system. Batch numbers are to be identified.

(f) Any additive used as a production aid, must be the one recommended by the resin manufacturer and is not to alter the mechanical properties or the characteristics of the cured laminate.

4.3.3 Laminating

(a) Production is to follow all necessary approved construction plans, in accordance with the LHR accepted quality plan.

(b) Laminating is to be carried out by skilled operators, who are to be trained and qualified to the level required by the Builder's quality plan.

(c) The gel coat resin is to be applied by brush, roller or spraying equipment to give a uniform, nominal film of maximum thickness of 0,5 mm. For construction moulded on a male mould, the outer surface of the hull is to be covered with a thick layer of resin or a resin-based product before painting. The resin used is to offer the properties of a surface coating.

(d) The period of exposure of the gel coat between gelation and the application of the first layer of reinforcement is, in general, to be as short as practicable. In no case is this to be longer than that recommended by the resin manufacturer for that particular resin system. Written confirmation of this is to be obtained and recorded in the Builder's quality control documentation.

(e) All mouldings are to be manufactured from layers of reinforcement, laid in the approved sequence and orientation, each layer being thoroughly impregnated and consolidated to give the required fiber content, by weight, in accordance with the approved plans. All arrangements are to be made to ensure a sufficient elimination of air bubbles with a suitable set of tools. The elimination of bubbles is to be regularly carried out during lamination

(f) In laminates containing multiple layers of woven reinforcement, woven reinforcement may be laid

on woven reinforcement, provided that the inter-laminar shear strength is not less than 13,8 N/mm^2; otherwise, a layer of random fiber reinforcement is to be laid alternately with the woven reinforcements.

(g) Excessive exothermic heat generation, caused by thick laminate construction, is to be avoided. Where thick laminates are to be laid, the Builder is to demonstrate to the Surveyor's satisfaction, that the number of plies can be laid wet on wet and that the resultant temperature during the cure cycle does not have any deleterious effect on the mechanical properties of the cured laminate.

(h) Laminating is to be carried out in a sequence, such that the time lapse between the application of the successive layers is within the limits recommended by the resin manufacturer, and documented in the quality control procedures for the particular resin system. Similarly, the time lapse between the forming and bonding of structural members is to be kept within these limits and, where this is not practicable, the surface of the laminate is to be prepared, in accordance with the resin manufacturer's instructions, to improve the bond.

(i) When laminating is interrupted, and where a system other than epoxy resin is being used, the first of any subsequent layers of reinforcement to be laid in that area, is to be of the chopped fiber type, to enhance the interlaminar shear strength properties of the laminate.

(j) In case of local default noted during the lamination, a repair may be carried out before the laying up of the following layer. The timing and the extent of the repair have to be noted by the shipyard.

4.3.4 Fiber content

(a) To ensure that the resultant thickness of the structure is not less than that indicated on the approved plans, the nominal fiber content, by weight, of the individual plies and overall laminate is to be controlled on the basis of the weight of the constituent materials.

(b) A method of validating the completed laminate thickness is to be agreed between the Builder and Surveyor. Where electronic thickness measurement methods are employed, the equipment is to be calibrated against a laminate of identical construction. Alternatively, a series of areas are to be identified within the craft, where samples can be taken to validate the thickness of the laminate (e.g. in way of overboard discharges/ seawater intakes/deck openings etc.).

4.3.5 Laminate schedule

(a) The laminate schedule is to clearly define the sequence of production, identify the specific materials to be used, and state relevant details regarding overlapping, staggering thickness and tailoring of reinforcements.

(b) Areas of local deficiency requiring additional reinforcement and areas that have been found to be of increased thickness are to be recorded in the quality control documentation.

4.3.6 Spray laminating

(a) The equipment for spray deposition of resin and glass fibres is to be inspected during the Workshop Inspection and a sample panel produced. Documentary evidence of maintenance, calibration, catalyst content, fiber length and overall fiber content by weight are to be entered into the quality control documentation. The spray pattern is to give an even distribution, as recommended by the manufacturer of the equipment, and is to be to the satisfaction of the attending Surveyor.

(b) Unless the mechanical properties are confirmed by testing, the chopped fiber length for a structural laminate is to be not less than 35 mm. In no case is the fiber length to be less than 25 mm.

(c) Spray equipment is only to be operated by trained and competent personnel. Training certification is to form part of the quality control documentation. The use of spray lay-up is to be limited to the parts of the structure to which sufficient access can be obtained, to ensure satisfactory laminating.

(d) Consolidation is to be carried out as soon as it is practicable after spray deposition. In general, this is to be carried out when a weight of reinforcement, equivalent to a thickness of 2-3 mm, has been deposited. Next to the gelcoat, rolling out is to be done for maximum 1,5 mm thickness of finished laminate. The thickness of the resulting laminate is to be periodically checked and recorded.

(e) Particular attention is to be given to localized thinning of the laminate in way of chines, coamings, knuckles and openings. Further deposition may be required in such areas, to compensate for any reduction in thickness. Alternatively, layers of other equivalent reinforcements may be laid to achieve the required local thickness.

4.3.7 Release and curing

(a) After completion of the lay-up, the moulding is to be left in the mould for a period to allow the resin to cure before being removed. This period can vary with ambient temperature, the type of resin and the complexity of the moulding, but is to be not less than 12 hours or that recommended by the resin manufacturer.

(b) Care is to be exercised during removal from the mould to ensure that the hull, deck and other large assemblies are adequately braced and supported, to avoid being damaged and maintain the form of the moulding.

(c) Upon release from the mould, the surface coating is to be examined and is not to show defaults such as bubbles, blisters, pinholes and wrinkles.

(d) Where female moulds are adopted, all primary stiffening and transverse bulkheads are to be installed prior to removal from the mould, unless otherwise agreed on the approved construction schedule and plans.

(e) Mouldings are not to be stored outside of the workshop environment until they have attained the stage of cure recommended by the resin manufacturer for that particular resin. Provision is to be made for mouldings to be protected against adverse weather conditions.

(f) Mouldings are, in general, to be stabilized in the moulding environment for at least 24 hours, or that recommended by the resin manufacturer, before the application of any special cure treatment, details of which are to be submitted for approval. Care is to be taken to avoid any sudden difference in temperature and the increase in temperature during the heating process is to be progressive, due to this fact, the recommendations of the manufacturers of resin are to be respected.

(g) Removal from the mould is not to be attempted, until a minimum Barcol reading recommended by the resin manufacturer or a value of 20 has been attained. Subsequently, the moulding is not to be moved outside of the controlled environment until the minimum Barcol reading recommended by the resin manufacturer or 35, whichever is less, has been recorded.

4.3.8 Sandwich construction

(a) The methods used in sandwich construction are, in general, to be either wet or dry core bonding techniques or by laminating directly onto the core (e.g. plug moulding).

(b) Where the core material is to be laid onto a pre-moulded skin, it is to be laid as soon as practicable after the laminate cure has passed the exothermic stage.

(c) Where the core is applied to a laminated surface, particular care is to be taken to ensure that a uniform bond is obtained. Where a core is to be applied to an uneven surface, the Surveyor may request additional building up of the surface or contouring of the core to suit. The manufacturing process and workmanship should be such that gaps or joints in the core are filled up with polyester, cement or filler materials.

(d) Where resins other than epoxy are being used, the reinforcement against either side of the core is

to be of the chopped strand mat type.

(e) Prior to bonding, the core is to be cleaned and primed (sealed), in accordance with the manufacturer's recommendations. The primer is to be allowed to cure, and is not to inhibit the subsequent cure of the materials contained within the manufacturer's recommended bonding process. The primer is to seal the panels, including all the surfaces between the blocks of contoured material, without completely filling the surface cells.

(f) Where panels of rigid core material are to be used, then dry vacuum bagging techniques are, in general, to be adopted. The core is to be prepared by providing 'breather' holes to ensure efficient removal of air under the core. Bonding paste is to be visible at such breather holes after vacuum bagging. The number and pitch of such 'breather' holes is to be in accordance with the core manufacturer's application procedure and any specific requirements of the core bonding paste manufacturer.

(g) Thermoforming of core materials is to be carried out in accordance with the manufacturer's recommendations. Maximum temperature limits are to be strictly observed.

(h) Where panels of contourable core material are to be used, it is necessary to ensure that the core is cut/scored through the entire thickness, such that the panels will conform to the desired shape of the moulding. The Builder is to demonstrate that the quantity of bonding material indicated in the core manufacturer's application procedure is sufficient to penetrate the full depth of the core between the blocks. It is recommended that grid scored panels using a carrier scrim cloth are adopted.

(i) Where the edges of a panel are to be beveled to single skin, the rate of tapering is to be not greater than 30°. In areas where an insert (e.g. higher density foam or plywood) is to be used, the rate of taper is not to be greater than 45°.

(j) In all application procedures cured, excess bonding material is to be removed and the panel cleaned and primed prior to the lamination of the final sandwich skin.

(k) Backing or insert pads, where fitted in way of the attachment of fittings, are to be arranged so that the load can be satisfactorily transmitted into the surrounding structure. The contact area of these pads is to be suitably prepared and free from contamination.

(l) Inserts in sandwich laminates are to be of a material capable of resisting crushing. Inserts are to be well bonded to the core material and to the laminate skins, in strict accordance with the approved plans.

(m) Where plywood inserts are to be used, all edges are to be beveled at an angle of 45°. A small gap is to be provided around each insert to ensure the passage of bonding paste during the vacuum bagging process.

(n) The level of vacuum applied for initial consolidation and during the cure period is not to be higher than that recommended by the relevant manufacturer of the materials being used, to avoid the possibility of evaporative boiling and excessive loss of monomer.

(o) Shear ties between the inner and outer skins are to be provided at intervals and are to be detailed on the plans submitted for approval. Alternative shear tie arrangements will be individually considered.

4.3.9 Defects in the laminates

(a) The manufacturing process of laminates shall be such as to avoid defects, of which the main ones are the following: surface cracks, surface or internal blistering due to the presence of air bubbles, cracks in the surface coating, internal areas with non impregnated fibres, surface corrugation, surface areas not

covered by resin or glass fiber reinforcement directly exposed to the external environment. Possible defects may be rectified by means of appropriate repair methods, to the satisfaction of the LHR Surveyor.

4.4 Quality System

4.4.1 Inspection

(a) Inspection is to be carried out by the builders and Surveyors, as indicated and approved in the building process description and building quality control manual. A constant visual inspection of the laminating process is to be maintained by the builder. If improper curing or blistering of the laminate is observed, immediate remedial action is to be taken. Inspections of the following are to be carried out:

- Check the mould to ensure it is clean and releasing agent is properly applied.
- For gel coat, check thickness, uniformity, application and cure, before applying the first layer of reinforcement.
- Check resin formulation and mixing, check and record amounts of base resin, catalysts, hardeners, accelerators, additives and fillers**.**
- Check that reinforcements are uniformly impregnated and well wet-out, and that lay-up is in accordance with approved drawings, and standards of overlaps are complied with. All variation in materials should be brought to the attention of LHR.
- Check and record resin/fiber ratios.
- Check that curing is occurring as specified. Immediate remedial action is to be taken when improper curing or blistering is noted.
- Visual overall inspection of completed lay-up for defects that can be corrected before release from the mould.
- Check and record hardness of cured hull prior to the release from mould.
- The ambient temperature, humidity, and gel time is to be monitored and recorded.

4.4.2 Faults

a) All faults are to be classified according to their severity and recorded, together with the remedial action taken, under the requirements of the Quality Assurance systems. Production faults are to be brought to the attention of the attending Surveyor and a rectification system is to be agreed upon.

4.4.3 Acceptance criteria

a) Classification is dependent upon the work being carried out in accordance with the approved plans and the requirements of an accepted quality system. The workmanship is to be to the satisfaction of the attending Surveyor. This will include the verification of the quality control documentation and the remedial action associated with all defects and deficiencies recorded. Proposed deviations from the approved plans are subject to LHR approval. An amended plan is to be submitted to the plan appraisal office, prior to any such changes being introduced.

4.4.4 Internal production control

(a) The manufacturer is to have an efficient system for quality control, to ensure that all units in the proceeding production satisfy the specified requirements.

(b) For each stage in the process, written instructions, i.e. building, specification, working drawings or equivalent should be available, which enables each individual operator to carry out the instructions

in accordance with the approved standard specifications.

(c) The results of controls should be reported and signed in a journal. Each unit shall be marked with a production number, which should be used for identification in the control journal.

(d) The person responsible for the quality control should have necessary qualifications to value workmanship and quality of constructions in FRP.

(e) The system for quality control should include routines for the following controls:

- Raw materials
- Storage and production conditions
- Workmanship for lamination and core build-up
- Compliance with the building specification

(f) After de-moulding, each moulded part should be weighed and the thickness measured to the extent specified in the approval.

CHAPTER 4 Wood

Contents

SECTION 1 General

SECTION 1 General

1.1 Timber Species

1.1.1 The species of timber which are used for the various constructional members are to have the following properties:

1.2 Timber Quality

1.2.1 The timber is to be of good quality and properly seasoned and is to be free from sapwood and any noxious organisms (moulds, insects attack, larvae, splits, shakes, bacteria, etc.) which might impair its durability and structural efficiency. The timber for the centerline members is to be reasonably seasoned and where there is a risk of excessive drying-out, it is to be coated with boiled linseed oil or varnish, as soon as erected, to prevent splitting.

1.2.2 The moisture content at the time of use is to be not greater than 20%

1.2.3 Knots may be tolerates when they are intergrown, provided that their diameter is less than $^1/_5$ of the dimension parallel to such diameter, measured on the section of the knot. The grain is to be straight

1.2.4 For marine plywood, the elevated temperatures reached during drying and pressing rule out the possibility of survival of insects and larvae in the finished panels. Moreover this factor contributes in enabling the marine plywood to have lower moisture content than that of solid timber of the same species in the same ambient conditions, tendering it less prone to attacks of mould. In any case the thickness of the individual layers constituting the plywood or the lamella structure is to be reduced in direct proportion to the durability of the species used. The minimum number of plywood layers used in the construction is 3 for thickness not greater than 6 mm and 5 for greater thickness.

1.2.5 Plywood sheets are to be stored flat on a level bed and under dry, well ventilated conditions. The moisture content is not to exceed 15%.

1.3 Certification and Checks of Timber Quality

1.3.1 The quality of timber, plywood and lamella structures is to be certified as complying with the provisions of 1.2 by the Builder to the LHR Surveyor who, in the event of doubts or objections, will verify the circumstances by performing appropriate checks. Such certification is to refer to the checks carried out during building survey in the yard relative to the following characteristics:

(a) for solid timber, mass density and moisture content,

(b) for plywood and lamella structures, glueing test.

1.4 Manufacturing

1.4.1 The craft is to be suitably protected during the building period from adverse weather and climatic conditions. The minimum protection to be provided is normally a substantial and efficient roof projecting beyond the length and breadth of the craft.

1.4.2 All edges and cut-out areas are to be thoroughly sealed by glues, varnishes, paints or other suitable compositions to prevent moisture penetrating along the end- grain.

1.4.3 The layers forming the lamination are generally to be of the same timber species and are to be of even moisture content. The grain of the layers is to be approximately parallel to the length of the member, and special attention is to be paid in the selection and assembly of the timber.

1.4.4 Where practicable the layers are to be continuous and if this is not possible the layers are to be

scarph jointed, the slope if the scarph being not greater than 1 in 10.

1.4.5 Attention is to be paid to the fastenings throughout particularly the size and disposition. The boring of the timber to receive the fastenings is to be properly executed according to the density of the timber and the type and material of the fastening.

1.5 Mechanical Properties

1.5.1 The species of timber suitable for construction are listed in Table 4.1.1 and Table 4.1.2 together with the following details:

(a) commercial and scientific denomination,

(b) natural durability and ease of impregnation,

(c) average physical-mechanical characteristics at 12% moisture content

(d) the durability classes are relative to the solid timber's resistance to moulds

1.5.2 The use of timber species other than those stated in Table 4.1.1 may be accepted provided that the characteristics of the species proposed correspond with those of one of the species listed.

Table 4.1.1: Basic Physical-Mechanical Characteristics of Timbers for Construction

Commercial name	Origin (1)	Natural durability (2)	Mass density (kg/m^3)	Ease of impregnation (2)	Mechanical characteristics (3)			
					R_f (N/mm^2)	E_f (N/mm^2)	R_c (N/mm^2)	R_t (N/mm^2)
Larice	Europe	C/D	550	3/4	89	12800	52	9,4
Castagno	Europe	B	600	4	59	8500	37	7,4
Olmo	Europe	D	650	2/3	89	10200	43	11,0
Quercia	Europe	B	710	4	125	15600	68	13,0
Teck	Asia	A	680	4	100	10600	58	13,0
Douglas Fir	America	C/D	500	3/4	85	13400	50	7,8
Cedar	America	B/C	380	3	51	7600	31	6,8
White Oak	America	B/C	730	4	120	15000	65	12,6
Mogano	America	B	550	4	79	10300	46	8,5
Doussie	Africa	A	800	4	114	16000	62	14,0
Iroco	Africa	A/B	650	4	85	10000	52	12,0
Khaya	Africa	C	520	4	74	9600	44	10,0
Makore	Africa	A	660	4	86	9300	50	11,0
Okoume	Africa	D	440	3	51	7800	27	6,7
Sapeli	Africa	C	650	3	105	12500	56	15,7
Sipo	Africa	B/C	640	3/4	100	12000	53	15,0

NOTES:

1. Area of natural growth
2. Level of natural durability and ease of treatment for impregnation according to Standard EN 350
3. Mechanical characteristics with 12% moisture content source Wood Handbook: Wood as an Engineering Material-1987, USDA
   - Ultimate flexural strength, R_f (strength concentrated amidships)
   - Bending modulus of elasticity, E_f (strength concentrated amidships)
   - Ultimate compression strength R_c (parallel to the grain)
   - Ultimate shear strength, R_t (parallel to the grain)

Abbreviations:

Natural durability

A = Very durable

B= durable (maximum permissible thickness for the fabrication of marine plywood 5mm)

C= not very durable (maximum permissible thickness for the fabrication of marine plywood 2,5mm

D= not durable (maximum permissible for the fabrication of marine plywood 2mm)

Ease of treatment for impregnation

1= permeable

2= very nor resistant

3= resistant

4= very resistant

Table 4.1.2: Guide for Selections of Construction Timbers

Species of timber / Structural item	Douglas	Cedar	Iroko	Latch	Makore	Mahogany	Elm english	White oak	Oak	Sapele	Teak
Keel, hog, sternpost, deadwood			II		II	II	II	II	II	III	I
Stern					II	II	II	II	II	III	I
Bilge stringer	III			II				II		III	I
Beam shelves, clamps, waterways	III		II	II				II	II	III	I
Floors					II	II		II	II		I
Frames grown or web frames				II (2)	II			II (1)	II (1)	III	I
Frames bent frames								II (1)	II (1)		
Planking below waterline	III		II	II		II		II	II	III	I
Planking above waterline	III		II	III		II		II		III	I
Deck planking	II	III	II								I
Beams, bottom girders	II			II	II (2)	II (2)		II (1)	II (1)		I
Brackets vertical				II				II (1)	II		
Brackets horizontal				II				I	I		
Gunwhale, margin planks			II			II		II	II		

NOTES:

1. The timber concerned may be employed either in the natural of in the laminated form
2. The timber may be employed only in the laminated form

Suitability of timber for use:

I = very suitable

II = fairly suitable

III = scarcely suitable

1.6 Scantlings Correction

1.6.1 The structural scantlings apply to timber with the following density δ, in kg/m³, at a moisture content not exceeding 20%:

(a) bent frames: δ=720

(b) non-bent frames, keel and stem: δ=640

shell and deck planking, shelves and clamps, stringers and beams: δ=560

The scantlings given in the following articles may be modified as a function of the density of the timber employed and its moisture content in accordance with the relationship:

$$S_1 = \frac{S}{K}$$

$$K = \frac{\delta_e}{\delta} + (U - U_e) \times 0{,}02$$

Where:

S_1 = corrected section (or linear dimension)

S = Rule section (or linear dimension), obtained in accordance with the following articles.

δ_e = density of the timber species (or plywood) used.

δ = standard density of the timber species.

U = standard moisture content percentage (20% for solid timber, 15% for plywood or lamella structures).

U_e = maximum expected moisture content balance for the part considered, in service conditions.

Reductions in scantlings exceeding those obtained using the formula above may be accepted on the basis of the mechanical base characteristics of the timber, plywood or lamella structures actually employed.