



REQUIREMENTS FOR

MATERIALS AND WELDING 2003

PART 2

ALUMINUM and FIBER REINFORCED PLASTICS (FRP) (CHAPTERS 5-6)

**American Bureau of Shipping
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Requirements for Materials and Welding – Aluminum & Fiber Reinforced Plastics (FRP)

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CHAPTER 5 Materials for Hull Construction - Aluminum

SECTION 1 General

1 Testing and Inspection

1.1 General

All materials subject to test and inspection, intended for use in the construction of the hulls of craft classed or proposed for classification, are to be tested by the material producer and inspected by the Bureau's Surveyor in accordance with the following requirements or their equivalent. Materials having characteristics differing from those prescribed herein may be approved upon application, due regard being given to established practices in the country in which the material is produced and the purpose for which the material is intended, such as the parts for which it is to be used, the type of craft and intended service, and the nature of the construction of the craft. The requirements are based on the customary U.S. units shown in brackets and the metric units are derived by conversion from the U.S. units.

1.3 Witnessed Tests

All tests are to be conducted in the presence of the Surveyors at the place of manufacture prior to shipping.

1.5 Rejection of Previously Accepted Material

In the event of any material proving unsatisfactory in the process of being worked, it shall be rejected, notwithstanding any previous certificate of satisfactory testing.

1.7 Calibrated Testing Machines

The Surveyor is to satisfy himself that the testing machines are maintained in a satisfactory and accurate condition and are to keep a record of the dates and by whom the machines were rechecked and calibrated.

3 Defects

All materials are to be free from cracks, injurious surface flaws, lamination or similar defects. Welding or dressing for the purpose of remedying defects is not permitted unless and until sanctioned by the Surveyor. Discoloration characteristic of proper solution heat treatment is not cause for rejection.

5 Manufacturer's Certificates

5.1 Form of Certificate

Four copies of the mill certificates or the shipping statements of all accepted plate and shape materials indicating the aluminum alloy and temper are to be furnished to the Surveyor for his approval; one is to be forwarded to the purchaser, three are to be retained for the use of the Bureau. Before the mill certificates or shipping statements are distributed by the local Bureau office the manufacturer is to furnish the Surveyor with a certificate stating that the material has been sampled, tested and inspected in accordance with these Rules and that it has met the requirements. The following form of certificate will be accepted if printed on each mill sheet or shipping statement with the name of the firm and initialed by the authorized representative of the manufacturer:

“We hereby certify that the material described herein has been made to the applicable specifications of alloy _____; temper _____, and the required samples tested in accordance with the requirements of _____ (The American Bureau of Shipping Rules or state other specification) in the presence of a Surveyor from the American Bureau of Shipping with satisfactory results.”

At the request of manufacturers, consideration may be given to modifications to the form of certificate provided it correspondingly indicates compliance with the requirements of these Rules to no less degree than indicated in the foregoing statement.

5.3 Other Certificates

Where an aluminum alloy ingot is not produced in the plant where it is rolled, extruded or forged, a certified report is to be supplied to the Surveyor stating the name of the manufacturer, the alloy, ingot or manufacturing and inspection lot identification numbers and certification that the alloy meets the required chemical composition limits.

7 Identification Markings

7.1 Material Identification

All materials which have been sampled, tested, and have successfully passed the requirements and have been approved by the Surveyor are to be clearly ink marked or stamped by the manufacturer's name or trademark on each finished sheet, plate, shape, bar, rod casing or forging to signify that the material has satisfactorily complied with the tests prescribed.

7.3 Stenciled Material

In special cases, when approved, strapped or secured lifts or bundles of light sheet, plates, shapes, bars, rods or tubes of comparatively small size may be marked or stenciled on only the top piece or the marking may be shown on the tag attached to each lift or bundle.

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SECTION **2 Standard Test Methods**

1 General

The latest issue of the following test methods or specifications or their equivalents are to be used:

1.1 Chemical Analysis

ASTM E101 or E227 Methods of Spectrochemical Analysis or ASTM E34 Methods of Chemical Analysis of Aluminum and Aluminum Base Alloys.

1.3 Tension Testing

ASTM E8 Methods of Tension Testing of Metallic Materials or B557 Tension Testing Wrought-Aluminum and Magnesium Alloy Products.

1.5 Shear Testing

ASTM B316 Aluminum Alloy Rivet and Cold Heading Wire and Rods.

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CHAPTER **5 Materials for Hull Construction - Aluminum**

SECTION **3 Chemical Composition**

1 General

The chemical composition is to be determined by the aluminum manufacturer and is to conform to the applicable requirements of the alloys listed in 2-5-3/Table 1 or 2-5-3/Table 2 or such other requirements as may be specially approved.

3 Sampling

A control sample for chemical analysis is to be taken before starting to pour and one additional sample is to be taken during the pouring of each group of ingots poured simultaneously from the same source of molten metal. If not analyzed during pouring samples may be taken from semi-finished or finished products. When samples are taken from finished or semi-finished products, one sample is to represent each 1800 kg (4000 lb), or fraction thereof, of each alloy in a lot.

5 Definition of Lot

A lot is defined as all material of the same alloy, temper, section and size in a shipment (for sheet and plate, all material of the same thickness is considered to be of the same size).

TABLE 1
Chemical Composition Limits of Wrought Aluminum Alloys

Limits are in percent maximum unless stated otherwise.

Alloy	Silicon	Iron	Copper	Manganese	Magnesium	Chromium	Zinc	Titanium	Others		Aluminum
									Each	Total	
5052	0.25	0.40	0.10	0.10	2.2–2.8	0.15–0.35	0.10	–	0.05	0.15	Remainder
5083	0.40	0.40	0.10	0.40–1.0	4.0–4.9	0.05–0.25	0.25	0.15	0.05	0.15	Remainder
5086	0.40	0.50	0.10	0.20–0.7	3.5–4.5	0.05–0.25	0.25	0.15	0.05	0.15	Remainder
5383 ¹	0.25	0.25	0.20	0.7–1.0	4.0–5.2	0.25	0.4	0.15	0.05	0.15	Remainder
5454	0.25	0.40	0.10	0.50–1.0	2.4–3.0	0.05–0.25	0.25	0.20	0.05	0.15	Remainder
5456	0.25	0.40	0.10	0.50–1.0	4.7–5.5	0.05–0.25	0.25	0.20	0.05	0.15	Remainder
6061	0.40–0.8	0.70	0.15–0.40	0.15	0.8–1.2	0.04–0.35	0.25	0.15	0.05	0.15	Remainder

Note:

- 1 The 5383 alloy also has an allowance for a maximum of 0.20% weight of Zirconium (Zr).

TABLE 2
Chemical Composition Limits of Cast Aluminum Alloys

ASTM American Society for Testing and Materials

AA Aluminum Association

Limits are in percent maximum unless stated otherwise.

Alloy		Silicon	Iron	Copper	Manganese	Magnesium	Zinc	Titanium	Others		Aluminum
ASTM	AA								Each	Total	
SG70A	356.0	6.5–7.5	0.6 ⁽¹⁾	0.25	0.35 ⁽¹⁾	0.20–0.45	0.35	0.25	0.05	0.15	Remainder
SG70B	A356.0	6.5–7.5	0.20	0.20	0.10	0.20–0.45	0.10	0.20	0.05	0.15	Remainder
	357.0	6.5–7.5	0.15	0.05	0.03	0.45–0.6	0.05	0.20	0.05	0.15	Remainder

Note:

- 1 If the iron content exceeds 0.45%, manganese content shall not be less than one half of the iron.

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5 **Materials for Hull Construction - Aluminum**

SECTION

4 **Heat Treatment**

Alloy 6061 products are to be suitably treated to develop the mechanical properties specified in 2-5-5/Tables 2, 4, 5 and 6 for the various tempers. Alternative heat treatments will be specially considered.

T4	Solution heat treated and then naturally aged.
T451	For sheet and plate that are stress relieved by stretching after solution heat treatment.
T4511	For extruded bars, rods or shapes that are stress relieved by stretching after solution heat treatment.
T6	Solution heat treated and then artificially aged.
T651	For sheet and plate that are stress relieved by stretching after solution heat treatment and then artificially aged.
T6511	For extruded bars, rods or shapes that are stress relieved by stretching after solution heat treatment and then artificially aged.

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CHAPTER **5 Materials for Hull Construction - Aluminum**

SECTION **5 Tensile Properties**

1 General

Tensile properties are to conform to the applicable requirements of the alloys and tempers listed in 2-5-5/Tables 1 through 7.

3 Yield Strength

The yield strength is defined as that determined at 0.2% offset.

5 Standard Test Specimens

5.1 General

Tension test specimens may be substantially the full cross section of the material being tested or they may be machined as indicated for specific product forms. Test specimens in accordance with other recognized standards will be specially approved.

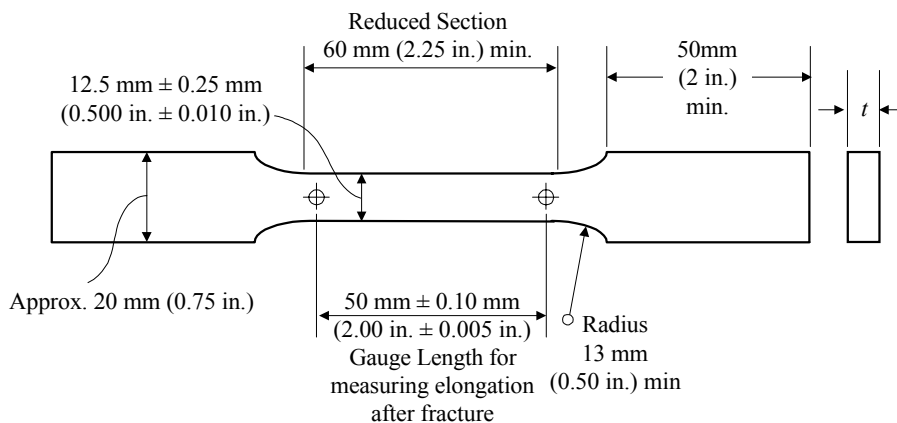
5.3 Full-Section Specimens

Tension test specimens of substantially the full cross section of the material may be used for wire, rod, bar, shapes and tubular products. It is permissible to reduce the section slightly throughout the section to insure fracture within the gauge marks. The gauge length is to be four times the diameter for round specimens and 50 mm (2 in.) for other sections.

5.5 Machined Specimens

Standard machined test specimens for tension testing of wrought aluminum mill products are of two types: Round and rectangular, with a gauge length of 50 mm (2 in.) and a width or diameter of 12.5 mm (0.5 in.). They are shown in 2-5-5/Figure 1 and 2-5-5/Figure 2. Other sizes of small round specimens may be used if the gauge length for measurement of elongation is four times the diameter of the reduced section of the specimen.

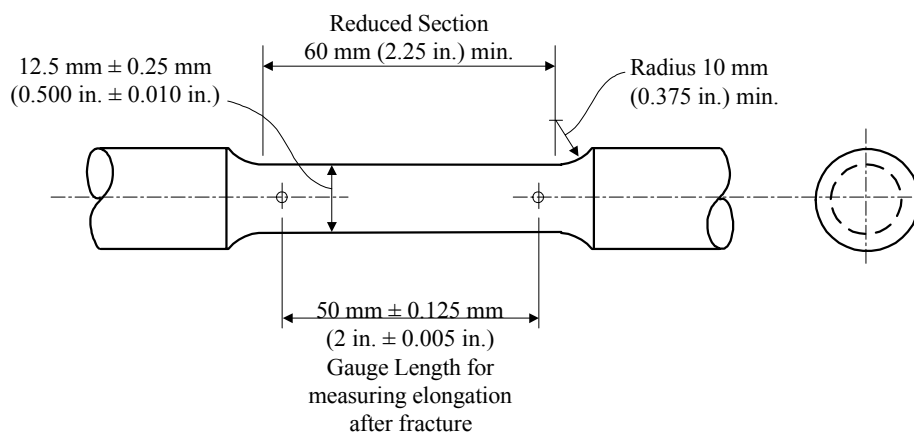
FIGURE 1
Standard Rectangular Tension Test Specimen
with 50 mm (2 in.) Gauge Length



Notes:

- 1 The dimension t is the thickness of the material.
- 2 The reduced section is to be parallel within 0.05 mm (0.0002 in.) and may have a gradual taper in width from the ends toward the center with the ends not more than 0.13 mm (0.005 in.) wider than the center. The ends of the specimens are to be symmetrical with the centerline of the reduced section within 0.25 mm (0.01 in.)

FIGURE 2
Standard Round Tension Test Specimen
with 50 mm (2 in.) Gauge Length



Notes:

- 1 The gauge length and fillets are to be as shown, but the ends may be of any shape to fit the holders of the testing machine in such a way that the load shall be axial. The reduced section may have a gradual taper from the ends toward the center, with the ends not more than 0.13 mm (0.005 in.) larger in diameter than the center.
- 2 When the size of material makes use of the full size specimen impracticable, round specimens of smaller size proportional to the standard specimen may be used provided that the diameter of such specimens is not less than 6.0 mm (0.25 in.) and the length of the reduced section is not less than 32.0 mm (1.25 in.)

7 Retests

7.1 No Test

If the percentage elongation of a tension test specimen is less than that specified, and if any part of the fracture is outside of the middle half of the gauge length or in a punched or scribed mark within the reduced section, another test specimen may be selected.

7.3 Failure to Meet Requirements

If any tension test specimen fails to conform to the requirements, two additional specimens are to be selected from other products in the lot and tested. If either of these specimens fails to conform to the applicable requirements, the material is to be rejected. If, however, the failure of the specimen to conform with the requirements is the result of an inadequate thermal treatment, the material may be reannealed or reheat treated, as applicable. Only one such retreatment of the material is to be permitted.

TABLE 1
Mechanical Property Limits of Non-Heat-Treatable Sheet
and Plate Aluminum Alloys ^{6, 7}

Mechanical test specimens are taken as detailed in 2-5-5/5.

<i>Alloy and Temper</i>	<i>Thickness ¹</i>		<i>Ultimate Tensile Strength kgf/mm² (ksi)</i>		<i>Minimum Yield Strength 0.2% Offset kgf/mm² (ksi)</i>		<i>Minimum Elongation² in 50 mm (2 in.)</i>
	<i>millimeters</i>	<i>(inches)</i>	<i>minimum</i>	<i>maximum</i>	<i>minimum</i>	<i>maximum</i>	<i>percent</i>
5052-O	3.0–6.4 6.6–75.0	(0.114–0.249) (0.250–3.000)	17.6 (25.0) 17.6 (25.0)	21.8 (31.0) 21.8 (31.0)	6.7 (9.5) 6.7 (9.5)		20 18
5052-H32	3.0–6.5 6.6–12.5 12.6–51.0	(0.114–0.249) (0.250–0.499) (0.500–2.000)	21.8 (31.0) 21.8 (31.0) 21.8 (31.0)	26.7 (38.0) 26.7 (38.0) 26.7 (38.0)	16.2 (23.0) 16.2 (23.0) 16.2 (23.0)		9 11 12
5052-H34	3.0–6.5 6.6–25.0	(0.114–0.249) (0.250–1.000)	23.9 (34.0) 23.9 (34.0)	28.8 (41.0) 28.8 (41.0)	18.3 (26.0) 18.3 (26.0)		7 10
5052-H112	6.5–12.5 12.6–51.0 51.1–75.0	(0.250–0.499) (0.500–2.000) (2.001–3.000)	19.7 (28.0) 17.6 (25.0) 17.6 (25.0)		11.2 (16.0) 6.7 (9.5) 6.7 (9.5)		7 12 16
5083-O	1.3–38.0 38.1–76.5	(0.051–1.500) (1.501–3.000)	28.1 (40.0) 27.4 (39.0)	35.9 (51.0) 35.2 (50.0)	12.7 (18.0) 12.0 (17.0)	20.4 (29.0) 20.4 (29.0)	16 16
5083-H112	6.5–38.0 38.1–76.5	(0.250–1.500) (1.501–3.000)	28.1 (40.0) 27.4 (39.0)		12.7 (18.0) 12.0 (17.0)		12 12
5083-H116 ³	4.5–38.0 38.1–76.5	(0.063–1.500) (1.501–3.000)	30.9 (44.0) 28.8 (41.0)		21.8 (31.0) 20.4 (29.0)		12 12
5083-H323	1.5–3.0 3.1–6.5	(0.051–0.125) (0.126–0.249)	31.6 (45.0) 31.6 (45.0)	38.0 (54.0) 38.0 (54.0)	23.9 (34.0) 23.9 (34.0)	30.9 (44.0) 30.9 (44.0)	8 10
5083-H343	1.5–3.0 3.1–6.5	(0.051–0.125) (0.126–0.249)	35.2 (50.0) 35.2 (50.0)	41.5 (59.0) 41.5 (59.0)	27.4 (39.0) 27.4 (39.0)	34.4 (49.0) 34.4 (49.0)	6 8
5383-O	3.0 - 50	(0.114 - 1.968)	29.0 (42.1)		14.5 (21.0)		17
5383-H111	3.0 - 50	(0.114 - 1.968)	29.0 (42.1)		14.5 (21.0)		17
5383-H116	3.0 - 50	(0.114 - 1.968)	30.5 (44.2)		22.0 (31.9)		10
5383-H321	3.0 - 50	(0.114 - 1.968)	30.5 (44.2)		22.0 (31.9)		10
5383-H34	3.0 - 25	(0.114 - 1.000)	34.0 (49.3)		27.0 (39.2)		5
5086-O	1.5–6.5 6.5–51.0	(0.051–0.249) (0.250–2.000)	24.6 (35.0) 24.6 (35.0)	30.9 (44.0) 30.9 (44.0)	9.8 (14.0) 9.8 (14.0)		18 16
5086-H112	4.5–12.5 12.6–25.5 25.6–51.0 51.1–76.5	(0.188–0.499) (0.500–1.000) (1.001–2.000) (2.001–3.000)	25.3 (36.0) 24.6 (35.0) 24.6 (35.0) 23.9 (34.0)		12.7 (18.0) 11.2 (16.0) 9.8 (14.0) 9.8 (14.0)		8 10 14 14
5086-H116 ³	1.5–6.5 6.6–51.0	(0.063–0.249) (0.250–2.000)	28.1 (40.0) 28.1 (40.0)		19.7 (28.0) 19.7 (28.0)		8 10
5454-O	3.0–76.5	(0.114–3.000)	21.8 (41.0)	28.8 (41.0)	8.4 (12.0)		18
5454-H32 ^{4,5}	1.5–6.5 6.6–51.0	(0.051–0.249) (0.250–2.000)	25.3 (36.0) 25.3 (36.0)	30.9 (44.0) 30.9 (44.0)	18.3 (26.0) 18.3 (26.0)		8 12
5454-H34 ^{4,5}	4.0–6.5 6.6–25.5	(0.162–0.249) (0.250–1.000)	27.4 (39.0) 27.4 (39.0)	33.0 (47.0) 33.0 (47.0)	20.4 (29.0) 20.4 (29.0)		7 10
5454-H112 ⁵	6.5–12.5 12.6–51.0 51.1–76.5	(0.250–0.499) (0.500–2.000) (2.001–3.000)	22.5 (32.0) 21.8 (31.0) 21.8 (31.0)		12.7 (18.0) 8.4 (12.0) 8.4 (12.0)		8 11 15
5456-O	1.5–38.0 38.1–76.5	(0.051–1.500) (1.501–3.000)	29.5 (42.0) 28.8 (41.0)	37.3 (53.0) 36.6 (52.0)	13.4 (19.0) 12.7 (18.0)	21.1 (30.0) 21.1 (30.0)	16 16
5456-H112	6.5–38.0 38.1–76.5	(0.250–1.500) (1.501–3.000)	29.5 (42.0) 28.8 (41.0)		13.4 (19.0) 12.7 (18.0)		12 12
5456-H116 ³	4.5–15.5 15.6–32.0 32.1–38.0 38.1–76.5	(0.063–0.624) (0.625–1.250) (1.251–1.500) (1.501–3.000)	32.3 (46.0) 32.3 (46.0) 30.9 (44.0) 28.8 (41.0)		23.2 (33.0) 23.2 (33.0) 21.8 (31.0) 20.4 (29.0)		12 12 12 12
5456-H323	1.5–3.0 3.1–6.5	(0.051–0.125) (0.126–0.249)	33.7 (48.0) 33.7 (48.0)	40.8 (58.0) 40.8 (58.0)	25.3 (36.0) 25.3 (36.0)	32.3 (46.0) 32.3 (46.0)	6 8
5456-H343	1.5–3.0 3.1–6.5	(0.051–0.125) (0.126–0.249)	37.3 (53.0) 37.3 (53.0)	44.3 (63.0) 44.3 (63.0)	28.8 (41.0) 28.8 (41.0)	35.9 (51.0) 35.9 (51.0)	6 8

TABLE 1 (continued)
Mechanical Property Limits of Non-Heat-Treatable Sheet and Plate Aluminum Alloys

Notes:

- 1 Type of test specimen used depends on thickness of material: (See 2-5-5/5.)
- 2 or 4x specimen diameter.
- 3 5083, 5086 and 5456 in the H116 and H321 tempers are to be capable of passing an appropriate test for resistance to exfoliation corrosion. The “Aluminum Association Tentative Exfoliation Test for Aluminum Magnesium Alloys for Boat and Ship Hull Construction” is considered to be an appropriate method. Other tests will be specially considered.
- 4 For the corresponding H2 temper, limits for maximum ultimate tensile strength and minimum yield strength do not apply.
- 5 5454 is recommended for service applications where exposed to temperatures exceeding 65°C (150°F).
- 6 Use of the latest ASTM B209 specification may be approved upon application.
- 7 Where it is possible, it is to be verified that the material is intended for marine use.

TABLE 2
Mechanical Property Limits of Heat-Treatable Sheet and Plate Aluminum Alloys

Mechanical test specimens are taken as detailed in 2-5-5/5.

<i>Alloy and Temper</i>	<i>Type</i>	<i>Thickness ⁽¹⁾</i>		<i>Minimum Tensile Strength</i>	<i>Minimum Yield Strength 0.2% Offset</i>	<i>Minimum Elongation ⁽²⁾ in 50 mm (2 in.)</i>
		<i>mm</i>	<i>(in.)</i>	<i>kgf/mm² (ksi)</i>	<i>kgf/mm² (ksi)</i>	<i>percent</i>
6061-T4	Sheet	0.5–6.5	(0.021–0.249)	21.1 (30.0)	11.2 (16.0)	16
6061-T451 ^(4,5)	Plate	6.5–25.5	(0.250–1.000)	21.1 (30.0)	11.2 (16.0)	18
		25.6–76.0	(1.001–3.000)	21.1 (30.0)	11.2 (16.0)	16
6061-T6	Sheet	0.5–6.5	(0.021–0.249)	29.5 (42.0)	24.6 (35.0)	10
6061-T62 ⁽³⁾ and T651 ^(4,5)	Plate	6.5–12.5	(0.250–0.499)	29.5 (42.0)	24.6 (35.0)	10
		12.6–25.5	(0.500–1.000)	29.5 (42.0)	24.6 (35.0)	9
		25.6–51.0	(1.001–2.000)	29.5 (42.0)	24.6 (35.0)	8
		51.1–76.2	(2.001–3.000)	29.5 (42.0)	24.6 (35.0)	6

Notes:

- 1 Type of test specimen used depends on thickness of material; (See 2-5-5/5).
- 2 Or 4x specimen diameter.
- 3 These properties apply to samples of material in the O or F tempers, which are solution heat treated or solution and precipitation treated by the producer to determine that the material will respond to proper heat treatment. Properties attained by the user, however, may be lower than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.
- 4 For stress-relieved tempers, characteristics and properties other than those specified may differ somewhat from the corresponding characteristics and properties of material in the basic temper.
- 5 Upon artificial aging, T451 temper material is to be capable of developing the mechanical properties applicable to the T651 temper.

TABLE 3
Mechanical Property Limits of Non-Heat-Treatable Aluminum Alloys
for Extruded Bars, Rods, Shapes, and Tubes

Mechanical test specimens are taken as detailed in 2-5-5/5.

Alloy and Temper	Maximum Diameter or Thickness ⁽¹⁾		Maximum Area		Ultimate Tensile Strength kgf/mm ² (ksi)		Minimum Yield Strength 0.2% Offset	Minimum Elongation ⁽²⁾ in 50 mm (2 in.)
	mm	(in.)	mm ²	(in. ²)	minimum	maximum	kgf/mm ² (ksi)	percent
5083-0	to 127.5	(5.0)	2065	(32)	27.4 (39.0)	35.9 (51.0)	11.2 (16.0)	14
5083-H111	127.5	(5.0)	2065	(32)	28.1 (40.0)		16.9 (24.0)	12
5083-H112	127.5	(5.0)	2065	(32)	27.4 (39.0)		11.2 (16.0)	12
5086-0	127.5	(5.0)	2065	(32)	24.6 (35.0)	32.3 (46.0)	9.8 (14.0)	14
5086-H111	127.5	(5.0)	2065	(32)	25.3 (36.0)		14.8 (21.0)	12
5086-H112	127.5	(5.0)	2065	(32)	24.6 (35.0)		9.8 (14.0)	12
5456-0	127.5	(5.0)	2065	(32)	28.8 (41.0)	37.3 (53.0)	13.4 (19.0)	14
5456-H111	127.5	(5.0)	2065	(32)	29.5 (42.0)		18.3 (26.0)	12
5456-H112	127.5	(5.0)	2065	(32)	28.8 (41.0)		13.4 (19.0)	12

Notes:

- 1 Type of test specimen used depends on thickness of material; (see 2-5-5/5.)
- 2 Or 4x specimen diameter.

TABLE 4
Mechanical Property Limits of Heat-Treatable Aluminum Alloys
for Extruded Products

Mechanical test specimens are taken as detailed in 2-5-5/5.

Alloy and Temper	Diameter or Thickness ⁽¹⁾	area	Ultimate Tensile Strength kgf/mm ² (ksi)	Minimum Yield Strength 0.2% Offset	Minimum Elongation ⁽²⁾ in 50 mm (2 in.)
	mm (in.)		minimum	kgf/mm ² (ksi)	percent
6061-T4 ^(4,5)	All	All	18.3 (26.0)	11.2 (16.0)	16
6061-T6, T62 ⁽³⁾	to 6.5 (0.249)	All	26.7 (38.0)	24.6 (35.0)	8
and T-6511 ⁽⁴⁾	6.6 (0.250) and over	All	26.7 (38.0)	24.6 (35.0)	10

Notes:

- 1 Type of test specimen used depends on thickness of material; (see 2-5-5/5.)
- 2 Or 4x specimen diameter.
- 3 These properties apply to samples of material in the O or F tempers, which are solution heat treated or solution and precipitation treated by the producer to determine that the material will respond to proper heat treatment. Properties attained by the user, however, may be lower than those listed if the material has been formed or otherwise cold or hot worked, particularly in the annealed temper, prior to solution heat treatment.
- 4 For stress-relieved tempers, characteristics and properties other than those specified may differ somewhat from the corresponding characteristics and properties of material in the basic temper.
- 5 Upon artificial aging, T4 and T4511 temper material are to be capable of developing the mechanical properties applicable to the T6 and T6511 tempers respectively.

TABLE 5
Mechanical Property Limits of Die Forgings

Alloy and Temper	Thickness	Specimen Axis Parallel to Direction of Grain Flow			Specimen Axis Not Parallel to Direction of Grain Flow		
		Tensile Strength kgf/mm ² (ksi)		Minimum Elongation in 50 mm (2 in.)	Tensile Strength kgf/mm ² (ksi)		Minimum Elongation in 50 mm (2 in.)
	mm (in.)	ultimate	yield	percent	ultimate	yield	percent
5083-H111	to 100 (4)	29.5 (42.0)	15.5 (22.0)	14	27.4 (39.0)	14.1 (20.0)	12
5083-H112	to 100 (4)	28.1 (40.0)	12.7 (18.0)	16	27.4 (39.0)	11.2 (16.0)	14
5456-H112 ⁽¹⁾	to 100 (4)	30.9 (44.0)	14.1 (20.0)	16			
6061-T6	to 100 (4)	26.7 (38.0)	24.6 (35.0)	7 ⁽²⁾	26.7 (38.0)	24.6 (35.0)	5

Notes:

- 1 Alloy 5456 is not covered in B247-70 but use of such forgings meeting these requirements may be considered.
- 2 When sample is selected from a test coupon an elongation minimum of 10% applies.

TABLE 6
Mechanical Property Limits for Hand Forgings

Alloy and Temper	Thickness	Axis of Test Specimen	Minimum Tensile Strength kgf/mm ² (ksi)		Minimum Elongation in 50 mm (2 in.)
	mm (in.)		ultimate	yield	percent
5083-H111	to 100 (4)	Longitudinal Long transverse	29.5 (42.0) 27.4 (39.0)	15.5 (22.0) 14.1 (20.0)	14 12
5083-H112	to 100 (4)	Longitudinal Long transverse	28.1 (40.0) 27.4 (39.0)	12.7 (18.0) 11.2 (16.0)	16 14
5456-H112 ⁽¹⁾	to 75 (3)	Longitudinal Long transverse	30.9 (44.0) 29.5 (42.0)	14.1 (20.0) 12.5 (18.0)	16 14
6061-T6	to 100 (4)	Longitudinal Long transverse Short transverse ⁽²⁾	26.7 (38.0) 26.7 (38.0) 26.0 (37.0)	24.6 (35.0) 24.6 (35.0) 23.2 (33.0)	10 8 5
6061-T6	over 100 (4) to 200 (8)	Longitudinal Long transverse Short transverse	26.0 (37.0) 26.0 (37.0) 24.6 (35.0)	23.9 (34.0) 23.9 (34.0) 22.5 (32.0)	8 6 4

Notes:

- 1 Alloy 5456 is not covered in B247-70 but use of such forgings meeting these requirements may be considered.
- 2 Requirement applicable to thicknesses of 50 mm (2 in.) and greater.

TABLE 7
Mechanical Property Limits for Aluminum Alloy Castings

ASTM American Society for Testing and Materials

AA Aluminum Association

<i>Alloy</i>		<i>Temper</i>	<i>Casting</i>	<i>Ultimate Tensile Strength Minimum</i>	<i>Yield Strength 0.20% Offset</i>	<i>Minimum Elongation in 50 mm (2 in.)</i>
<i>ASTM</i>	<i>AA</i>			<i>kgf/mm² (ksi)</i>	<i>kgf/mm² (ksi)</i>	<i>percent</i>
SG70A	356.0	T6	Sand	21.0 (30.0)	14.0 (20.0)	3
SG70A			Permanent mold	23.0 (33.3)	15.5 (22.0)	3
SG70B	A356.0	T61				
Integral coupons				23.0 (33.3)	18.0 (26.0)	3
Separately cast coupons				26.0 (37.0)	18.0 (26.0)	5
None	357.0	T6		31.5 (45.0)		3

TABLE 8
Aluminum Alloy Equivalents

AA Aluminum Association

BS British Standard

ASTM American Society for Testing and Material

UNI Unificazione Nazionale Italiana

CSA Canadian Standards Association

JIS Japanese Industrial Standard

NF Normes Francaises

ISO International Organization for Standardization

The equivalents are approximate based on the best available information. The actual specification or standard should be consulted for full information.

<i>U.S. ASTM, AA</i>	<i>Canada CSA</i>	<i>France NF</i>	<i>U.K. BS</i>	<i>Italy UNI</i>	<i>Japan JIS</i>	<i>ISO</i>
5052	GR20		2L, 55, 2L, 56, L80, L81	PA1Mg2.5	A2-1	A1Mg2.5Mn
5083	GM41, E54S*		N8		A2-7	A1Mg4.5Mn
5086		AG4MC				A1Mg4
5454	GM31N, 55330*					A1Mg3Mn
5456			N61			
6061	GS11N		H20		A2-4	A1Mg1SiCu

Note:

* Commercial designations.

PART

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CHAPTER 5 Materials for Hull Construction - Aluminum

SECTION 6 Sheet and Plate

1 Scope

The following requirements cover non-heat-treatable and heat-treatable aluminum alloys for sheet and plate intended to be used in hull construction. The material covered is in substantial agreement with ASTM Designation B209. Sheet and plate differing in chemical composition, mechanical properties or heat treatment will be specially considered.

3 Selection of Specimens

For non-heat-treatable alloy sheet and plate, tension test specimens are to be taken parallel to the direction of rolling. For heat-treatable alloys, tension test specimens are to be taken transverse to the direction of rolling where sheet or plate widths permit. The standard rectangular tension test specimen shown in 2-5-5/Figure 1 is to be used for sheet and plate less than 12.5 mm (0.5 in.) in thickness. For plate 12.5 mm (0.5 in.) and greater in thickness, the tension test specimen shown in 2-5-5/Figure 2 is to be used. The tension test specimen is to be taken midway between the two plate surfaces for plate in thicknesses of 12.5 mm (0.5 in.) up to 38 mm (1.5 in.). For plate over 38 mm (1.5 in.) in thickness, the specimen shall be taken midway between the center and surface of the plate.

5 Number of Tests

Tension test specimens are to be selected as follows.

5.1 Sheet

For sheet under 6.3 mm (0.25 in.) in thickness, one tensile test specimen is to be taken from one random sheet representative of 900 kg (2000 pounds) or fraction thereof in each lot.

5.3 Plate

For plate 6.3 mm (0.25 in.) and over in thicknesses, one tensile test specimen from each 1800 kg (4000 lb) or fraction thereof in each lot.

7 Surface Finish

The material is to be free from injurious defects and have a workmanlike finish. It is to be surface inspected at the mill by the Surveyors only when specifically requested and so ordered by the purchaser.

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CHAPTER

5 Materials for Hull Construction - Aluminum

SECTION

7 Rods, Bars, Shapes and Tubular Products

1 Scope

The following requirements cover extruded non-heat-treatable and heat-treatable aluminum alloy rods, bars, shapes and tubular products intended to be used in hull construction. The material covered is in substantial agreement with ASTM Designation B221. Extruded rods, bars, shapes and tubular products and rolled rods and bars differing in chemical composition, mechanical properties or heat treatment will be specially considered. See Section 2-5-10 for aluminum alloy rivets.

3 Selection of Specimens

Tension test specimens are to be taken in the longitudinal direction and are to be of the full section of the material where practicable. Otherwise, the specimens shown in 2-5-5/Figure 1 or 2-5-5/Figure 2 may be used. For material 38 mm (1.5 in.) and less in diameter or thickness, the specimen is to be taken from the center of the section. For material greater than 38 mm (1.5 in.) in thickness or diameter the specimen is to be located midway between the center and an edge.

5 Number of Tests

For material with a nominal weight of less than 0.67 kg/m (1 lb/ft), one tensile test specimen is to be taken from each 450 kg (1000 lb) or fraction thereof in each lot. Otherwise, one tensile test specimen is to be taken for each 300 m (1000 ft) or fraction thereof in each lot.

7 Surface Finish

The material is to be free from injurious defects and have a workmanlike finish. It is to be surface inspected at the mill only when specifically requested and so ordered by the purchaser.

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CHAPTER 5 Materials for Hull Construction - Aluminum

SECTION 8 Forgings

1 Scope

The following requirements cover non-heat-treatable and heat-treatable aluminum alloy die and hand forgings intended to be used in hull construction. The material covered is in substantial agreement with ASTM Designation B247. Forgings differing in chemical composition, mechanical properties or heat treatment will be specially considered.

3 Selection of Specimens

3.1 Location of Specimens

Tension test specimens are to be taken from prolongations having a sectional area not less than that of the body of the forging. Tension test specimens are normally taken parallel to the direction in which the metal is most drawn out (longitudinal) but may be taken transversely. Specimens taken in the longitudinal direction are to be taken from as near to the center of the cross-section of the forging as is practicable. The midpoint of the axes of transverse specimens are to be near to the center of the cross-section of the forging.

3.3 Small Forgings

In the case of forgings weighing less than 114 kg (250 lb) each, where the foregoing procedures are impracticable, a special forging may be made for the purpose of obtaining test specimens provided the Surveyor is satisfied that these test specimens are representative of the forgings submitted for testing. In such cases the special forging should be subjected to the same amount of working and reduction as the forging represented and if applicable, be heat treated with those forgings. Alternatively, test specimens may be taken from one of the forgings in the lot.

3.5 Test Specimens

The tension test specimen shown in 2-5-5/Figure 2 is to be used.

5 Number of Tests

5.1 Large Forgings

In the case of forgings weighing over 2700 kg (6000 lb) each, one tension test specimen is to be taken from each end of the forging.

5.3 Smaller Forgings

In the case of forgings weighing less than 2700 kg (6000 lb) each, except as noted in c, one tension test specimen is to be taken from each forging.

5.5 Small Forgings

In the case of forgings weighing less than 114 kg (250 lb) each, one tension test specimen may be taken from one forging as representative of 900 kg (2000 lb) provided the forgings are of similar size, of one alloy and temper, are made from the same lot of stock and if applicable, heat treated in the same furnace charge.

5.7 Special Situations

In the case of number of pieces cut from a single forging, individual tests need not necessarily be made for each piece, but forgings may be tested in accordance with whichever of the foregoing procedures is applicable to the primary forging involved.

7 Inspection

The forgings are to be inspected by the Surveyor after final heat treatment, where applicable, to insure that the forgings are free from injurious defects.

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CHAPTER 5 Materials for Hull Construction - Aluminum

SECTION 9 Castings

1 Scope

The following requirements cover aluminum alloy castings for use in hull construction. The material covered is in substantial agreement with alloys SG70A and SG70B of ASTM Designations B26 and B108 (Aluminum Association alloys 356.0 and A356.0) and AA357.0 of the Aluminum Association. Except in cases specifically approved otherwise, all aluminum castings are to be furnished in the heat treated condition. Castings differing in chemical composition, mechanical properties or heat treatment from those covered herein will be specially considered.

3 Selection of Specimens

3.1 Large Castings

Tensile specimens are to be taken from integral test bars. Integral test bars are not to be detached until the heat treatment of the castings have been completed nor until the coupons have been stamped by the Surveyor for identification.

3.3 Small Castings

In the case of castings weighing less than 450 kg (1000 lb) each, test coupons may be cast separately provided they are poured from the same source of molten metal as the castings represented. When separate coupons are used, the Surveyor is to be furnished an affidavit by the manufacturer stating that the coupons were poured from the same source of molten metal as the castings represented and that they were heat treated with the castings.

3.5 Test Specimens

The tension test specimen shown in 2-5-5/Figure 1 is to be used.

5 Number of Tests

At least one tension test is to be made representative of the same source of molten metal and in each heat-treatment charge.

7 Inspection

The castings are to be inspected by the Surveyor after final heat treatment and thorough cleaning to insure that the castings are free from injurious defects, such as cracks, laminations, or embedded porosity. The final machined casting is to be examined to avoid the presence of surface defects.

9 Welded Repair of Defects

Defects in non-critical areas may, with the Surveyor's approval, be repaired by welding using an approved procedure. The welding is to be done before the final heat-treatment.

PART

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CHAPTER

5 Materials for Hull Construction - Aluminum

SECTION

10 Rivets

1 General

Non-heat-treatable and heat-treatable aluminum alloy cold heading rod and wire for use in manufacturing rivets should be in agreement with a specification equivalent to ASTM Designation B316. Material differing from ASTM B316 in chemical composition, mechanical properties or heat-treatment may be specially considered.

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PART

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CHAPTER 5 Materials for Hull Construction - Aluminum

APPENDIX 1 Aluminum Welding in Hull Construction

1 General

1.1 Hull Welding

Welding in aluminum hull construction is to comply with the requirements of this Appendix, unless specially approved otherwise. It is recommended that appropriate permanent welded markings be applied to the side shell of welded craft to indicate the location of bulkheads for reference. In all instances, welding procedures and filler metals are to be applied which will produce sound welds that have strength in accordance with 2-5-A1/Table 1; the chemical compositions of the filler metals are to be generally in accordance with 2-5-A1/Table 2. The selection of filler metals for welding various aluminum alloys is to be in accordance with 2-5-A1/Table 3 and 2-5-A1/Table 4.

1.3 Plans and Specifications

The plans submitted are to indicate clearly the extent to which welding is proposed to be used. The welding process, filler metal and joint design are to be shown on the detail drawings or in separate specifications submitted for approval, which are to distinguish between manual, semi-automatic and automatic welding. The shipbuilders are to prepare and file with the Surveyor a planned procedure to be followed in the erection and welding of the important structural members.

1.5 Workmanship and Supervision

It shall be the responsibility of the contractor to insure that personnel, procedures and NDT equipment used for fabrication and inspection comply with these requirements. However, the Surveyor is to satisfy himself that all welders and welding operators to be employed in the construction of craft to be classed are properly qualified and are experienced in the type of work proposed and in the proper use of the welding processes and procedures to be followed. The Surveyor is to be satisfied with the employment of a sufficient number of skilled supervisors to ensure a thorough supervision and control of all welding operations.

1.7 Welding Procedures

Procedures for the welding of all joints are to be established in writing for each welding test, process, type of electrode, edge preparation, welding technique, and position proposed. Details of proposed welding procedures and sequences are required to be submitted for review. Procedure qualifications previously prepared and approved by ABS may be submitted for consideration for the current designs, if applicable.

3 Preparation for Welding

3.1 Edge Preparation and Fitting

The edge preparation is to be accurate and uniform and the parts to be welded are to be fitted in accordance with the approved welding detail. Joint edges may be prepared by mechanical means, such as saws, millers and routers and by plasma arc cutting. Thermal cutting methods may be employed, provided it can be demonstrated to the satisfaction of the Surveyor that their use does not have deleterious effects on the base material or completed weld.

All means for correcting improper fitting are to be to the satisfaction of the Surveyor. Where excessive root openings of butt weld connections are encountered, weld build up of the plate edges may be allowed, at the discretion of the Surveyor, before welding the plates together. Unless specially approved otherwise, such build up of each plate edge, where permitted, is not to exceed $0.5t$ or 12.5 mm ($1/2$ in.) whichever is less, where t is the thickness of the thinner plate being welded. Where sections to be joined differ in thickness and have an offset on either side of more than 3 mm ($1/8$ in.), a transition having a length not less than three times the offset is to be provided. The transition may be formed by tapering the thicker member or by specifying a weld joint design which will provide the required transition.

3.3 Alignment

Means are to be provided for maintaining the parts to be welded in correct position and alignment during the welding operation. In general, strong backs or other appliances used for this purpose are to be arranged so as to allow for expansion and contraction during production welding. The removal of such items is to be carried out to the satisfaction of the Surveyor.

3.3.1 Plate Alignment Tolerances

3.3.1(a) Butt Welds. Where plates are tacked in preparation for butt welding, the deviation of alignment of surfaces at the weld joint shall meet the requirements specified below:

<i>Plate Thickness</i>	<i>Maximum Allowable Deviation</i>
Less than 9.5 mm (0.375 in)	1.5 mm (0.0625 in)
9.5 mm (0.375 in) to 19 mm (0.75 in)	3 mm (0.125 in)
19 mm (0.75 in) to 38 mm (1.5 in)	5 mm (0.1875 in)
38 mm (1.5 in)	6 mm (0.25 in)

3.3.1(b) Fillet Welds. When the opening between elements of a fillet welded joint exceeds 1.5 mm (0.0625 in) but not more than 5 mm (0.1875 in) as a nominal condition along the joint, the fillet size shall be increased by an amount equal to the excess of the opening above $1/16$ inch. Where the gap between members exceeds 5 mm (0.1875 in) as a nominal condition along the joint fillet, methods outlined below shall be used. Fillet welds shall be extended around the ends of members to form closed loops where possible.

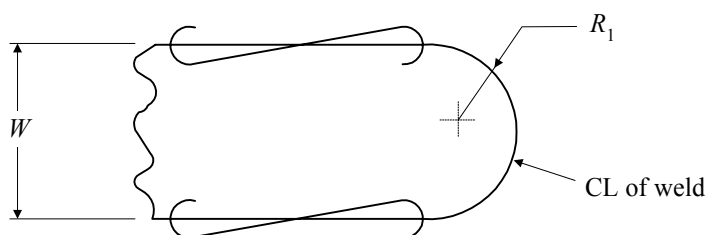
- i) *Buttering and Buildup.* Buttering or buildup by welding on the weld joint surface to correct oversized root opening or errors in joint preparation is allowed provided such buildup of each joint edge shall not exceed t or 12 mm (0.5 in), whichever is less, where t is the thickness of the thinner member being welded. Where one side of a joint may not be accessible, the total buttering or buildup (that is $2t$ or 25 mm (1 in), whichever is less) may be deposited on one member. Temporary backing may be used to assist in the buttering or buildup. When root openings cannot be corrected within this limitation, repair shall be made using patches, make-up plates and so forth, in accordance with ii) and iii) below

Buttering or buildup may be employed for fairing or for other corrections over or adjacent to welds, provided the above restrictions are not exceeded. This buildup shall be considered part of the involved weld.

- ii) *Make-up Plates.* Make-up plates welded into primary structure shall have a minimum width of three (3) inches and shall have full penetration, 100 percent efficient butt welds.
- iii) *Access and closure plates.* Boundaries of access and closure plates shall be located between principal boat framing or bulkheads, and shall be at least 75 mm (3 in) from any of these members. When variance from this 75 mm (3 in) minimum is required by special circumstances, such variances shall be subject to approval by the Surveyor. The boundaries of access and closure plates should land on existing butts or seams wherever practical, see 2-5-A1/Figures 1a and 1b below.

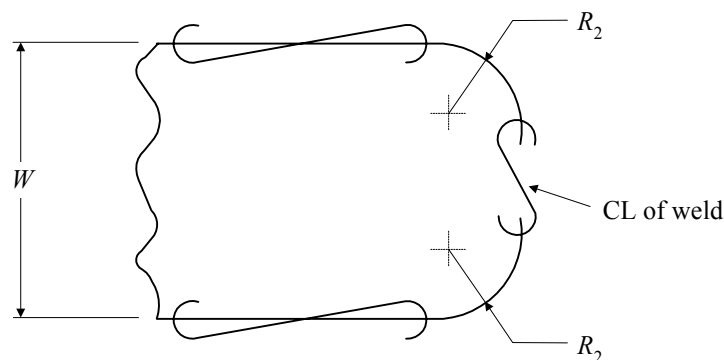
Corners of access or closure plates shall have a minimum radius of three 75 mm (3 in), except when a boundary lands on an existing hull longitudinal or transverse butt joint. In the latter instance, the corners shall intersect the weld at an angle of 90 ± 15 degrees (see 2-5-A1/Figures 1a and 1b below). Closure plate weld joints shall be full penetration 100 percent efficient butt welds.

FIGURE 1a
Inserts and Patches in Plating



WHEN $W = 3"$ min.
Then $R_1 = W/2$

FIGURE 1b
Inserts and Patches in Plating



WHEN $W = 6"$ min.
Then $R_2 = 3"$ or $2t$, whichever is larger

3.5 Cleanliness

Suitable solvents or mechanical means are to be used to remove oil, grease, indelible markings and all other contaminants from the vicinity of all joints prior to welding. In addition, oxide films including any water stains are to be removed from joint and faying surfaces as well as adjacent surfaces within 1 inch of the weld by mechanical means, such as a power-driven, clean stainless-steel wire brush, sanding with a 36-100 grit aluminum oxide sanding disk or by approved chemical means. Welding shall take place within 8 hours after oxide file removal. Interpass cleaning to remove slag, soot, overlap conditions, spatter, etc. is required. Degreasers are not to be used when the joint is such that the degreaser can collect in crevices such as faying surfaces between plate and backing bars or in way of lapped connections. Fusion welding is not to be performed on anodically treated aluminum except when the surface oxide is removed from the joint areas to be welded.

3.7 Tack Welds

Tack welds shall be made with the same type of electrode as the final weld and should be deposited to facilitate incorporation into the final weld. Tack welds of poor quality or workmanship shall be removed.

3.9 Stud Welding

The attachment of pins, hangers, studs and other related items by stud welding may be approved at the discretion of the Surveyor. Prior to actual production work, trial stud welds are to be destructively tested to demonstrate their suitability for the intended application. The use of stud welding for structural attachments is subject to special approval and may require special procedure tests appropriate to each application.

3.11 Temporary Back-up Plates and Tapes

A temporary back-up plate may be applied to the opposite side of the joint during welding to assist in reducing distortion and to decrease heat concentration. Anodized “hard” aluminum back-up plates are recommended for this purpose, although clean stainless steel or rust-free mild steel plates may also be used. Back-up plates when used are to be free of contaminants and oxides which would interfere with welding. Welding is to be controlled so as not to allow arcing of the aluminum filler metal to the temporary back-up plate. Any accidental arcing to the back-up plate is to be corrected by removal of all contaminated weld or base metal. Approval of procedures involving the use of backing tapes may be considered provided it is demonstrated to the Surveyor’s satisfaction that their use results in satisfactory welding and that plate distortion is not excessive.

3.13 Run-on and Run-off Tabs

When used, run-on and run-off tabs are to be designed to minimize the possibility of high-stress concentrations and cracking of the base metal and weld metal.

3.15 Forming

Cold forming of 5000 series aluminum alloys is to be conducted at temperatures below 52°C (125°F), except for the 5454 alloy, where the maximum temperature may be 149°C (300°F). See 2-5-A1/Table 1 below for minimum cold-forming radii. When the extent of cold forming is such that base plate properties are changed beyond acceptable limits, appropriate reheat or stress relief treatments are to be used to reestablish acceptable properties. Hot forming of 5000 series aluminum alloys is generally conducted at temperatures between 260°C and 425°C (500°F and 800°F). Hot or cold forming is not to be performed in structures of any aluminum alloy unless supporting data is presented to the Surveyor’s satisfaction indicating that significant material property changes will not result. Appropriate temperature control methods are to be used in all hot forming and stress relieving operations. In hot forming or stress relieving, exposure of the 5000 series alloys to the 65°C (150°F) to 200°C (400°F) temperature range is to be minimized by the use of appropriate cooling techniques. Typically 6000 series aluminum is not to be formed. For 6000 series aluminum to be considered for forming, supporting technical data is to be submitted for review and approval prior to forming.

TABLE 1
Minimum Cold-forming Radii for Aluminum Alloys (1, 2, 3)

<i>Alloy and temper</i>	<i>3mm (0.125in)</i>	<i>5mm (0.1875in)</i>	<i>6mm (0.25in)</i>	<i>9.5mm (0.375 in)</i>	<i>12mm (0.50in)</i>
5083-0	1t	1, 2t	1, 2t	2t	2t
H113	1, 1½t	1, 2t	1, 2t	1½, 2t	2, 3t
H323	1½, 3t	1½, 3½t	2, 4t	-----	-----
H343	1½, 3t	2, 4t	2½, 4½t	-----	-----
5052-0	1t	1t	1t	1, 1½t	1, 2t
H32	1, 1½t	1, 1½t	1, 1½t	1, 2t	1½, 2½t
H34	1½, 2½t	1½, 2½t	2, 3t	2, 3t	2½, 3½t
H36	1½, 3t	2, 4t	2, 4t	2½, 5t	3½, 5½t
H38	2, 4t	3, 5t	4, 6t	4, 7t	5, 8t
5086-0	1t	1t	1t	1, 1½t	1, 2t
H32,H116,H117	1, 2t	1, 2t	1½, 2½t	2, 2½t	2½, 3t
H34	1½, 2½t	2, 3t	2, 3t	2½, 3½t	3, 4t
H36	2, 3½t	2½, 4t	3, 4½t	3, 5t	3½, 5½t
H112			1, 2t	1, 2t	1½, 2½t
5456-0	1t	1, 2t	1, 2t	2t	2t
H116,H117	2, 3t	2, 3t	2, 3t	3, 4t	3, 4t
H323	1½, 3t	1½, 3½t	2, 4t	-----	-----
H343	1½, 3t	2, 4t	2½, 4½t	-----	-----

Notes:

- Where two radii are shown, the larger radius is applicable when the bend is parallel to the direction of rolling.
- These bending radii are applicable to aluminum alloys which are free of visible oxide coating.
- The radii shall be the mandrel radii or inside radii.

5 Production Welding

5.1 Environment

Proper precautions are to be taken to insure that all welding is done under conditions where the welding site is protected against deleterious effects of moisture, wind and severe cold. Paint or oil mist and other contaminants which tend to cause weld porosity are to be excluded from the vicinity where welding is in progress.

5.3 Preheat

Preheating is not generally required for aluminum alloys. The use of preheat may be desirable when welding materials of thick cross section, materials subject to high restraint, and when welding is performed under high humidity conditions or when the temperature of the aluminum alloy is below 0°C (32°F). When preheating is used appropriate production controls are to be used to maintain the specified temperatures, in accordance with accepted procedures and to the satisfaction of the Surveyor. Preheating temperatures which sensitize an alloy to corrosion are to be avoided. For the 5000 series alloys it is generally recommended to avoid prolonged exposure to the 65°C to 200°C (150°F to 400°F) temperature range. The welding procedure is to be qualified at the lowest temperature expected in production. Preheat and interpass temperatures shall be verified by temperature sticks, small contact thermometer, pyrometer, etc. a minimum of 25 mm (1 in) away from the weld area.

5.5 Postheating

Weldments of work hardenable 5000 series aluminum alloys are not to be postweld heat treated unless the procedures have been specially approved. Where use of a heat treatable alloy has been approved, any postweld heat treatment proposed is to be as established in procedure qualification tests. Post weld heat treatment is not required on 5000 series aluminum materials, stainless steels, copper alloys or nickel alloys.

5.7 Accessibility

Assembly and welding is to be arranged to provide sufficient accessibility to the joint by the welder, the welding equipment, and for inspection.

5.9 Sequence

Welding is to be planned to progress symmetrically so that shrinkage on both sides of the structure will be equalized. The ends of frames and stiffeners are to be left unattached to the plating at the sub-assembly stage for a distance of about 300 mm (12 in.) until connecting welds are made in the intersecting systems of plating, framing and stiffeners at the erection stage. Welds are not to be carried across an unwelded joint or beyond an unwelded joint which terminates at the joint being welded unless especially approved.

5.11 Back Gouging

Chipping, routing, milling, grinding or other suitable methods are to be employed at the root or underside of the weld to obtain sound metal before applying subsequent beads for all full-penetration welds.

5.13 Fairing and Flame Shrinking

Shrink welds may be used, but fairing by heating or flame shrinking to correct distortion or defective workmanship in fabrication of main strength members within the midships portion of the craft and other plating which may be subject to high stresses, is not generally recommended. But if intended to be used, is to be carried out only with the expressed approval of the Surveyor. For the 5000 series alloys it is generally recommended that heating and cooling through the sensitizing range of 65°C–200°C (150°F–400°F) is to be as rapid as practicable.

5.15 Inspection of Welds

5.15.1 Visual Inspection

Visual inspection during construction is to consist of inspecting the surface appearance of welds for the existence of flaws or defects as stated below. The inspection zone includes the weld face and 12 mm (0.5in) of adjacent base metal. The surface of the welds is to be regular and uniform with proper contour, a minimum amount of reinforcement and reasonably free from undercut and overlap, slag, paint and weld splatter.

5.15.1(a) Appearance. Welds shall be free of cracks, incomplete fusion, and burn-through. Visible arc-strikes on welds and the adjacent base metal are not allowed and shall not exceed 1 mm ($1/32$ in) in depth after removal. Weld spatter greater in diameter than 1 mm ($1/32$ in) is not acceptable. Gouge marks, nicks and other fabrication scars in the weld inspection zone shall not exceed the requirements for undercut. Weld surfaces shall be free of slag to the extent that there is no interference with visual or other required non-destructive test. Crater pits are considered acceptable provided the area contains no cracks, and the root concavity and convexity limits are not exceeded and the minimum weld thickness requirements are met.

5.15.1(b) Melt-through. Melt-through and repaired burn-through areas are acceptable provided the areas do not contain cracks, crevices, excessive oxidation or globules, and provided the root convexity and concavity limits are not exceeded.

5.15.1(c) *Suckback*. Suckback is unacceptable in a weld or base metal when it occurs as a sharp notch or where the depth reduces the weld thickness below the minimum base metal thickness.

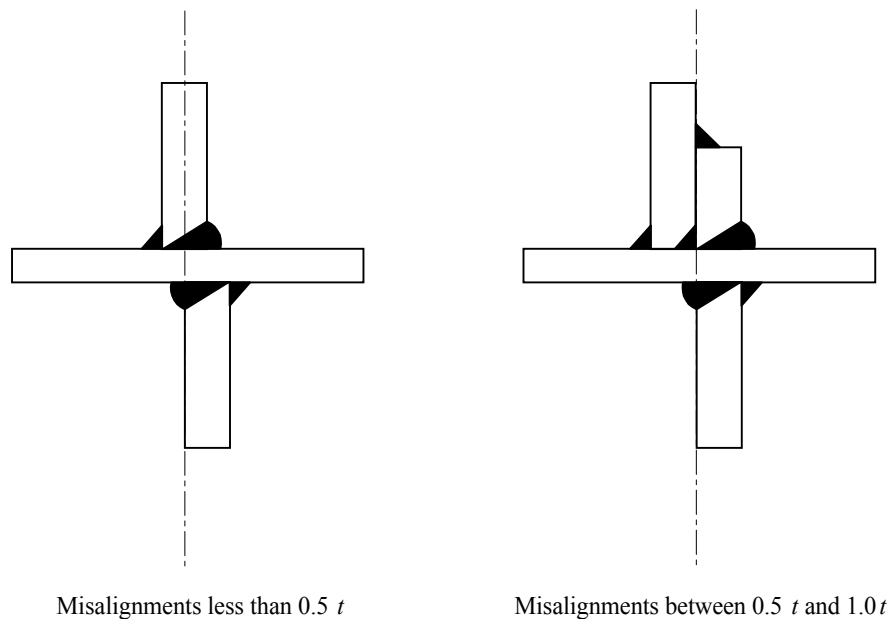
5.15.1(d) *Undercut*. The minimum undercut shall be 1 mm ($1/32$ in) or 10% of the adjacent base metal thickness, whichever is less. For base metal thickness 12 mm (0.5 in) and greater, undercut from 1 mm ($1/32$ in) to 1.5 mm (0.0625 in) is allowed if the accumulated length of undercut does not exceed 15% of the joint length or 300 mm (12 in), whichever is less.

5.15.1(e) *Welded Joint Offset*. The maximum offset for all welded joints shall be as follows:

Base Metal Thickness	Maximum Offset
$1/4$ in and less	25% of joint thickness
Over $1/4$ in to $3/4$ in	25% of joint thickness, but not to exceed $1/8$ in.
Over $3/4$ in to $1 1/2$ in	$3/16$ in
Over $1 1/2$ in	12 1/2% of joint thickness, but not to exceed $1/4$ in.

For misalignments that exceed the table above and less than $0.50t$, the structure may be fixed by using deep penetration welds. For misalignments that exceed $0.50t$ and are less than $1.0t$, the structure may be fixed by aligning flat bar doubling strips. Misalignments greater than $1.0t$ are to be corrected by realignment of the structure. See 2-5-A1/Figure 2.

FIGURE 2
Repairs of Misalignments



5.15.2 Dye Penetrant

Dye penetrant inspection is to be used when investigating the outer surface of welds or may be considered for use as a check of intermediate weld passes, such as root passes and also to check back-chipped, ground or gouged joints prior to depositing subsequent passes. Any dye penetrant used is to be thoroughly removed from the area before re-welding. Dye penetrant is not to be used where complete removal of the dye penetrant materials cannot be assured.

5.15.2(a) *Type of Dye Penetrant*. Penetrant materials consist of solvent-removable visible dye penetrant with associated penetrant remover (solvent) and nonaqueous wet developer.

5.15.2(b) Surface Preparation. Surfaces to be inspected shall be free from scale, slag and adhering or imbedded sand or other extraneous materials. With the exception of undercuts which are within allowances, the contour of welds shall blend smoothly and gradually into the base metal. Weld surface irregularities shall be removed to the extent that they will not interfere with interpretation of the test results. The final liquid penetrant inspection shall be performed in the final surface condition as specified herein.

Peening, shot, sand, grit and vapor blasting shall not be performed on surfaces before liquid penetrant inspection.

Surfaces, for which a specific finish is required, shall be given this surface finish prior to the final liquid penetrant inspection.

5.15.2(c) Test Procedure Requirements. All surfaces being tested shall be thoroughly cleaned of extraneous material. If a nonvolatile liquid is used for cleaning, the surface shall be heated or dried with hot air to assure complete removal of the cleaner. As a final cleaning operation each surface shall be dipped, sprayed, wiped or brushed with an acceptable and thoroughly dried by removing the excess with a clean dry cloth or absorbent paper, and allowing the remainder to evaporate for a minimum of five minutes. Prior to liquid penetrant inspection, the surface to be tested and any adjacent area within one (1) inch of the surface to be tested shall be dry and free of any dirt, grease, lint, scale and salts, coatings or other extraneous matter that would obscure surface openings or otherwise interfere with the test.

Maximum penetration into extremely small openings requires that the penetrant and the test surface be maintained at the temperature recommended by the penetrant manufacturer but in no case shall be less than 50°F. The temperature of the penetrant and the test surface shall not exceed 100°F. Due to the flammable nature of liquid penetrant inspection materials, the use of an open flame for heating purposes shall be prohibited. Special conditions requiring deviation from the above requirement requires approval of the Surveyor.

The surface to be tested shall be thoroughly and uniformly coated with penetrant by flooding, brushing, immersion or spraying. Unless otherwise recommended by the manufacturer, and approved by the Surveyor, dwelling time for the penetrant shall be not less than 15 minutes and no greater than 20.

The excess penetrant shall be removed from all surfaces as follows:

- i) As much excess penetrant as possible shall be removed by wiping the surface thoroughly with a clean dry cloth or absorbent paper.
- ii) The remaining excess penetrant shall be removed by wiping the surface with a clean cloth or absorbent paper dampened with a penetrant remover specified by the penetrant material manufacturer.

Flushing of the surface with any liquid following application of the penetrant and prior to developing is prohibited.

The drying of the test surface after the removal of the excess penetrant shall be accomplished only by normal evaporation, or by blotting with absorbent paper or clean, lint-free cloth. Forced air circulation in excess of normal ventilation in the inspection area shall not be used. Unless otherwise specified by the penetrant manufacturer, the time for surface drying after removal of excess penetrant and prior to application of the developer shall be limited to a maximum of ten (10) minutes.

A nonaqueous wet developer specified by the penetrant manufacturer shall be used. Immediately prior to application, the developing liquid shall be kept agitated in order to prevent settling of solid particles dispersed in the liquid. The developer shall be uniformly applied in a thin coating to the test surfaces by spraying. Pools of wet developer in cavities on the inspection surface is not permitted since these pools will dry to an excessively heavy coating in such areas resulting in the masking of indications. Inspection shall be made a minimum of 7 minutes and not later than 30 minutes after the developer has dried.

When the inspection is concluded, the penetrant materials shall be removed as soon as possible by means of wiping, water wetted clean cloth or solvents as described above and with applicable cleaning procedures.

5.15.3 Radiographic or Ultrasonic Inspection

Radiographic or ultrasonic inspection or both may be used when the overall soundness of the weld cross section is to be evaluated. Finished welding is to be sound and thoroughly fused throughout its cross section and to the base material. Production welds are to be crack free. Other discontinuities, such as incomplete fusion or incomplete penetration, slag and porosity are only to be present to the degree permitted by the pertinent inspection standard. The procedures and standards for radiographic and ultrasonic inspection is to be in accordance with the Bureau's separately issued publication *Guide for Nondestructive Inspection of Hull Welds*, or other approved acceptance standards.

5.15.4 Weld Plugs or Samples

The practice of taking weld plugs or samples by machining or cutting from the welded structure is not recommended and is to be considered only in the absence of other suitable inspection methods and is to be subject to the special approval of the Surveyor. When such weld plugs or samples are removed from the welded structure, the holes or cavities formed are to be properly prepared and welded, using a suitable welding procedure approved by the Surveyor and as established for the original joint

5.17 Workmanship Requirements

The workmanship requirements include the visual acceptance criteria stated in 2-5-A1/5.15.1 above plus the following structural fairness requirements provided below. In addition, welded attachments shall be removed to a minimum of 1.5 mm (0.0625 in) away from the permanent member to which they are attached by chipping, sawing or cutting, followed by grinding or sanding to restore the plate surface.

5.17.1 Structural Fairness for Plating

Unfairness (deviation from the design molded line) of welded plating shall not exceed the tolerances shown on 2-5-A1/Figure 3 and 2-5-A1/Figure 4. Permissible unfairness should result in a generally fair curve across the panel, except that for aluminum structure, an additional deviation of 3 mm (0.125 in) from the fair curve is permitted in way of welded butts and seams. Sharp knuckling or bend in way of stiffeners shall be avoided. A procedure for measuring fairness and taking corrective actions shall be developed and available for review by the surveyor.

If aid is necessary in determining the acceptability of the fairness of welded structure, a measurement of the unfairness of plating may be made in the area of interest. In such cases, the measurement shall be made across the minor dimension of the panel. The tolerances specified on 2-5-A1/Figure 3 and 2-5-A1/Figure 4 are plus or minus the dimensions from a fair line.

For stiffener spacings greater or less than those shown on 2-5-A1/Figure 3 and 2-5-A1/Figure 4, the curves shall be extrapolated proportionately.

5.17.2 Structural Fairness for Framing and Stiffeners

Frame, beam and stiffener bows in primary strength structure or structure subject to dynamic loading shall be corrected when it varies plus or minus from the designated or molded line in excess of the following:

$$T = C \left(\frac{\ell}{dw} \right) \text{ mm (in)}$$

where

T = tolerance in mm (in)

C = 530 (0.25)

ℓ = span of member between the fixed ends at the support structure in m (ft)

dw = depth of the stiffening member measured from the underside of the flange in mm (in)

5.17.3 Underwater Exterior Surfaces

In general, weld surfaces shall not extend greater than 1.5mm (0.0625in) above the plate surface.

5.19 Quality Control

To maintain quality control, sample welds may be required to be made by welders and operators during each 3 month period, at the discretion of the Surveyor and at the location of production welding, using the same equipment, material and filler metal as intended for production. The sample welds are to be examined for acceptable workmanship and may be required to be sectioned, etched and examined for weld soundness. When necessary, measures are to be taken to correct unacceptable workmanship.

5.21 Repair Welding

Unsatisfactory welding as determined by visual inspection, non-destructive test methods, or leakage under hydrostatic tests is to be corrected by the removal of the defective weld or adjacent material or both and corrected by rewelding, using a suitable repair welding procedure consistent with the material being welded. The repair procedures shall be available for the welder. Multiple repairs (weld cycles) to 5000 series aluminum alloys in the same general area is allowed. Removal by mechanical means, of minor surface defects such as arc strikes, scratches or shallow gouges may be permitted at the discretion of the attending Surveyor. Repaired welds must meet the inspection requirements for the original weld.

7 Butt Welds

7.1 Joint Design

Hull plating up to 5.0 mm ($3/16$ in.) in thickness may be square-butt welded without beveling the abutting plate edges. Plates exceeding 5.0 mm ($3/16$ in.) may be prepared for welding by similarly beveling the edges of both plates from one or both sides to form a single-Vee or double-Vee butt joint with an included angle from 60 degrees to 90 degrees. For single-Vee butt joints in material 5.0 mm ($3/16$ in.) and thicker the root face or land may be up to 3.0 mm ($1/8$ in.) in depth. Root faces or lands below 1.5 mm ($1/16$ in.) are not generally recommended. For double-Vee butt joints in material 8.0 mm ($5/16$ in.) and thicker the gap may vary from 0 to 5.0 mm ($3/16$ in.). Joints of other designs and root openings, such as the square butt joints in heavy thicknesses used with automated procedures will be subject to special consideration. In general, use of double-Vee in lieu of single-Vee joints and the narrowest root gap practicable is recommended to minimize distortion.

Butt-type permanent backing strap joints welded from one side shall not be used. For both single-Vee and double-Vee joints, the weld metal at the root on the reverse side of a weld made without permanent backing is to be removed to sound metal by an approved method before applying subsequent weld passes. See 2-5-A1/5.11. Welded butt joints made against removable backing and on which the root is inspected in accordance with these requirements shall be considered the equivalent of a joint welded from both sides.

9 Fillet Welds

See Section 3-2-13.

11 Filler Metals

11.1 General

Filler metals are to be of a type suitable to produce sound welds that have strength, ductility and corrosion resistant properties comparable to the materials being welded. Appropriate precautions are to be used to prevent any critical property change of filler wire quality during storage and handling. A list of recommended filler metals for different alloys is given in 2-5-A1/Table 4 and 2-5-A1/Table 5.

11.3 Approval Basis

Filler metals will be approved and listed subject to tests conducted at the manufacturer's plant. Upon satisfactory completion of tests, a certificate will be issued for general approval indicating the grade or classification to which the filler metal was tested and the relevant characteristics of the filler metal. Test assemblies are to be prepared in the presence of the Surveyor and all tests are to be attended by and carried out to the satisfaction of the Surveyor. Procedure and testing is to comply with either of the following standards.

- i) Filler metals will be considered for approval based upon tests conducted to standards established by the American Welding Society or other recognized agency.
- ii) Special approvals to manufacturer's specifications.

13 Approval of Welding Procedures

13.1 Approved Filler Metals

Approval of aluminum alloy filler metals used on Bureau classed weldments will depend on the specific application and alloys for which the filler metal is intended. Procedure tests may be required as a general condition of approval or at the discretion of the attending Surveyor to determine the shipyard's or fabricator's capability in the application of the proposed filler metal to the base material. The extent of such tests may vary depending upon the intended application, but generally would follow those tests outlined in 2-5-A1/13.7, and are to be carried out under production conditions.

13.3 Surveyor's Acceptance

The Surveyor may, at his discretion, accept a filler metal, welding procedure, or both, in a shipyard or fabricator's plant where it is established to his satisfaction that they have been adequately used for similar work under similar conditions.

13.5 New Procedures and Methods

Weld tests as outlined in 2-5-A1/13.7 and 2-5-A1/13.9 and 2-5-A1/Figure 5 to 2-5-A1/Figure 17, using procedures and materials similar to those intended for production welding, and carried out under production conditions, may be required to be prepared by each shipyard or fabricator when new or unusual methods, base metals, or filler metals are proposed.

All tests are to be made in the presence of the Surveyor and carried out to his satisfaction.

13.7 Tests

Tests Nos. 1 and 2 are to be carried out for procedures involving butt welds. Test No. 3 is to be carried out for procedures involving fillet welds. Unless otherwise specified, the number of specimens is to be as indicated. The minimum test results required are stated with the figures:

Test No. 1 – Reduced Section Tension Test (with reinforcement removed) (2-5-A1/Figure 7 or 2-5-A1/Figure 8). Two specimens made in each position involved. The test specimens are to meet or exceed the ultimate tensile strength shown in 2-5-A1/Table 1.

Test No. 2 – Guided Bend Test (2-5-A1/Figure 9 or 2-5-A1/Figure 10). For material 12.5 mm (0.5 in.) thick and under, two face-bend and two root-bend specimens for each position; for material over 12.5 mm (0.5 in.) thick, four side-bend specimens for each position involved. The bending jig and test requirements are indicated in 2-5-A1/Figure 11. Equivalent bending jigs, such as wrap around bend test fixtures may also be used.

Test No. 3 – Fillet Weld Test (2-5-A1/Figure 13).

13.9 Special Tests

All-weld-metal tensile, macro-etch, radiographic inspection, or other relevant tests may be required for certain applications, and the results submitted for consideration.

15 Welder Qualifications

15.1 General

The Surveyor is to be satisfied that the welders and operators are proficient in the type of work which they are called upon to perform either through requiring any or all of the tests outlined in the following paragraphs or through due consideration of the system of employment, training, apprenticeship, plant testing, inspection, etc., employed.

15.3 Qualification Tests

The tests, if required for qualification for various welding processes are given in 2-5-A1/Table 6. Such tests are based on the material thicknesses and welding processes involved. Qualification of welders for a particular alloy may be acceptable for qualification of the welder for other aluminum alloys. Separate qualification tests are to be made for the gas metal arc and gas tungsten arc processes. The tests are referred to by Nos. Q1, Q2, Q4, and QS, for which specimens are to be prepared and tested in accordance with 2-5-A1/Figure 14 to 2-5-A1/Figure 17 respectively. Specimens for qualification tests are to be bent in a bending jig having the profile shown in 2-5-A1/Figure 11 or in a bending jig having an equivalent wrap around design. Alternatively, upon the request of the employer, the welder may be qualified by use of radiography, provided the complete particulars of the equipment available and the procedures are demonstrated to be satisfactory. Test assemblies for either mechanical testing or radiographic examination are to be prepared according to material thickness and welding position as indicated in 2-5-A1/Table 6.

17 Alternatives

The foregoing are considered minimum requirements for aluminum welding in hull construction, but alternative methods, arrangements and details may be considered for approval.

TABLE 2
Minimum Mechanical Properties for Butt-Welded Aluminum Alloys

The adoption of test values higher than given in this table will be subject to special consideration. Filler wires are those recommended in 2-5-A1/Table 3. Values shown are for welds in plate thicknesses up to 38 mm (1.5 in.) unless otherwise noted.

Alloy	Ultimate Tensile Strength (U_{al})	Yield Strength (Y_{al}) ⁽²⁾	Shear Strength (τ_a) ⁽²⁾
	N/mm ² (psi)	N/mm ² (psi)	N/mm ² (psi)
5083 - H111	269 (39000)	145 (21000)	83 (12000)
5083 - H116, H321	276 (40000)	165 (24000)	96 (14000)
5083 - H323, H343	276 (40000)	165 (24000)	96 (14000)
5086 - H111	241 (35000)	124 (18000)	69 (10000)
5086 - H112 6 mm (0.25 in) –12 mm (0.50 in)	241 (35000)	117 (17000)	65 (9500)
5086 - H112 12 mm (0.5 in) –25 mm (1.0 in)	241 (35000)	110 (16000)	62 (9000)
5086 - H112 Greater than 25 mm (1.0 in)	241 (35000)	96.5 (14000)	55 (8000)
5086 - H32, H34, H116	241 (35000)	131 (19000)	76 (11000)
5383 - O, H111	290 (42000)	145 (21000)	83 (12000)
5383 - H116, H321	290 (42000)	145 (21000)	83 (12000)
5383 - H34	290 (42000)	145 (21000)	83 (12000)
5454 - H111	214 (31000)	110 (16000)	65 (9500)
5454 - H112	214 (31000)	83 (12000)	48 (7000)
5454 - H32, H34	214 (31000)	110 (16000)	65 (9500)
5456 - H111	283 (41000)	165 (24000)	96 (14000)
5456 - H112	283 (41000)	131 (19000)	76 (11000)
5456 - H116, H321	290 (42000)	179 (26000)	103 (15000)
5456 - H323, H343	290 (42000)	179 (26000)	103 (15000)
6061-T6 ⁽¹⁾ under 9.5 mm (0.375 in)	165 (24000)	138 (20000)	83 (12000)
6061-T6 ⁽¹⁾ over 9.5 mm (0.375 in)	165 (24000)	103 (15000)	62 (9000)

Notes:

- 1 Values when welded with 4043, 5183, 5356 or 5556 filler wire.
- 2 Yield and shear strength is not required for weld procedure qualification.

TABLE 3
Aluminum Alloy Filler Metal Composition

Composition in percent maximum unless shown as a range or specified.

Alloy	Silicon	Iron	Silicon and Iron	Copper	Manganese	Magnesium	Chromium	Zinc	Titanium	Other*		Aluminum
										Each	Total	
4043	4.5–6.0	0.80	0.50	0.30	0.05	0.05		0.10	0.20	0.05	0.15	Remainder
5183	0.40	0.40	0.40	0.10	0.50–1.0	4.3–5.2	0.05–0.25	0.25	0.15	0.05	0.15	Remainder
5356			0.40	0.10	0.05–0.20	4.5–5.5	0.05–0.20	0.10	0.06–0.20	0.05	0.15	Remainder
5554				0.10	0.50–1.0	2.4–3.0	0.05–0.20	0.25	0.05–0.20	0.05	0.15	Remainder
5556				0.10	0.50–1.0	4.7–5.5	0.05–0.20	0.25	0.05–0.20	0.05	0.15	Remainder

*The maximum Beryllium content of all filler wires is to be 0.0008%.

TABLE 4
Filler Metals for Welding Aluminum Alloy – Sheet, Plate and Extrusions

Recommendations in this table apply to gas shielded-arc welding processes.

Filler metal alloys 5183, 5356 and 5556 may be used interchangeably provided that strength, ductility and corrosion resistance are suitable for the service conditions.

<i>Base Metal Alloys</i>	<i>5083</i>	<i>5086</i>	<i>5383</i>	<i>5454 ⁽¹⁾</i>	<i>5456</i>	<i>6061</i>
5083	5183	5356	5183	5356	5183	5356
5086	5356	5356	5356	5356	5356	5356
5383	5183	5356	5183	5356	5183	5356
5454 ⁽¹⁾	5356	5356	5356	5554 ⁽¹⁾	5356	5356
5456	5183	5356	5183	5356	5556	5356
6061	5356	5356	5356	5356 ⁽²⁾	5356	4043 ⁽²⁾

Notes:

- 1 5454 aluminum alloy welded with 5554 filler metal is generally recommended for above 65°C (150°F) such as for smoke stacks and engine room enclosures
- 2 5183 or equivalents may be used.

TABLE 5
Filler Metals for Welding Aluminum Alloy Castings to Castings and Plate

ASTM American Society for Testing and Materials

AA Aluminum Association

<i>Castings</i>		<i>SG70A SG70B, 357</i>	<i>5154, 5454, 6061</i>	<i>5456, 5083, 5086</i>
<i>ASTM</i>	<i>AA</i>	<i>(Note 1)</i>	<i>(Note 2)</i>	<i>(Note 3)</i>
SG70A	356.0	4043	4043	5356
SG70B	A356.0	4043	4043	5356
	357.0	4043	4043	5356

Notes:

- 1 Filler metal with same analysis as base metal is sometimes used.
- 2 5183, 5356, 5554, 5556 and 5654 may be used. In some cases they may provide higher weld ductility and higher weld strength. 5554 is suitable for elevated temperature service.
- 3 5183, 5356 or 5556 may be used. 4043 may be used for some applications where filler metal properties are not of primary concern.

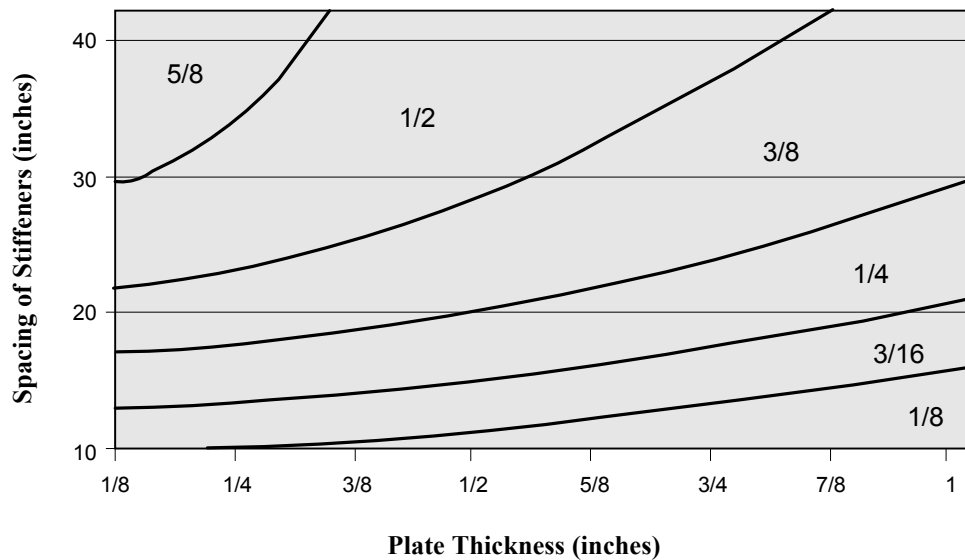
TABLE 6
Welder Qualification Tests

<i>Construction Material</i>	<i>Position in Which Welding is to be Done on Job</i>		
	<i>Flat, Horizontal, Vertical and Overhead</i>	<i>Flat and Vertical</i>	<i>Flat Position Only</i>
On material of limited thickness 19.1 mm ($\frac{3}{4}$ in.) or less. See Note 1.	Test No. Q1 in vertical and overhead positions	Test No. Q1 in vertical position	Test No. Q1 in flat position
On material of unlimited thickness (any thickness) See Notes 1 and 2.	Test No. Q2 in vertical and horizontal positions	Test No. Q2 in vertical position	Test No. Q2 in flat position
On piping or tubing. See Note 3.	Test No. Q3 in horizontal and vertical positions	Test No. Q3 in horizontal and vertical fixed positions	Test No. Q3 in horizontal rolled position
For tack welders	Test No. Q5 in vertical and overhead positions	Test No. Q5 in vertical position	

Notes:

- 1 Where the maximum thickness of material on which a welder may have occasion to work throughout the period governed by a test is indeterminate, the Surveyor may, if desired, require the welder to qualify under unlimited thickness requirements.
- 2 Where the maximum plate thickness to be welded is between 19.1 mm ($\frac{3}{4}$ in.) and 38.1 mm ($1\frac{1}{2}$ in.) qualification Test No. Q2 may, with the permission of the Surveyor, be conducted on plate of maximum thickness involved.
- 3 Welding operators qualified under the requirements of Test No. Q4 will be considered as qualified to make welds governed by Tests Nos. Q1 and Q2. Welding Operators qualified to weld on plate in the vertical position may be permitted to weld on pipe in the horizontal rolled position.

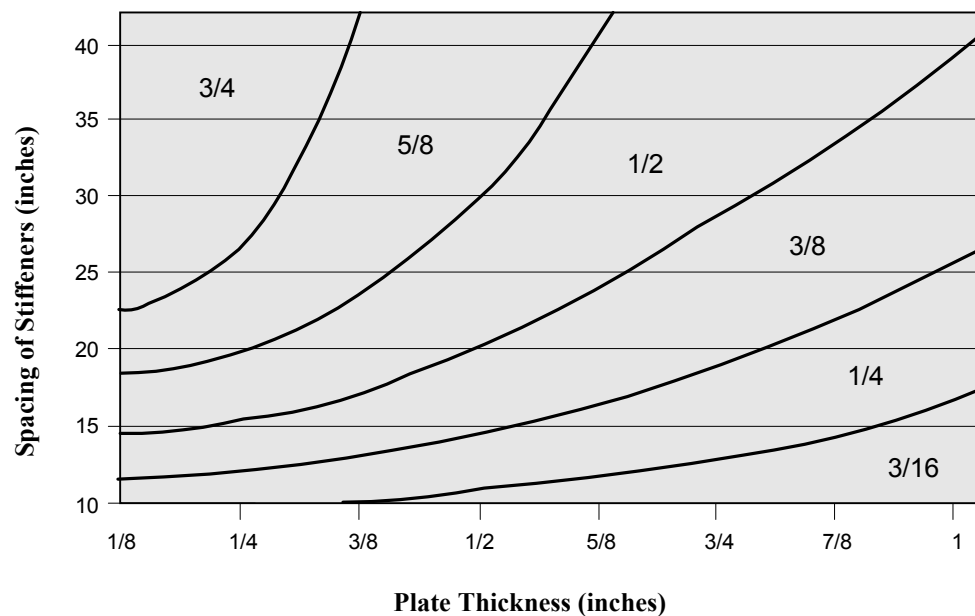
FIGURE 3
Permissible Unfairness in Aluminum Welded Structure



Applicability of tolerances:

- 1 Entire shell plating
- 2 Uppermost strength deck
- 3 Longitudinal strength Deck structure which includes inner-bottom tank tops
- 4 Bulwarks and exterior superstructure bulkheads

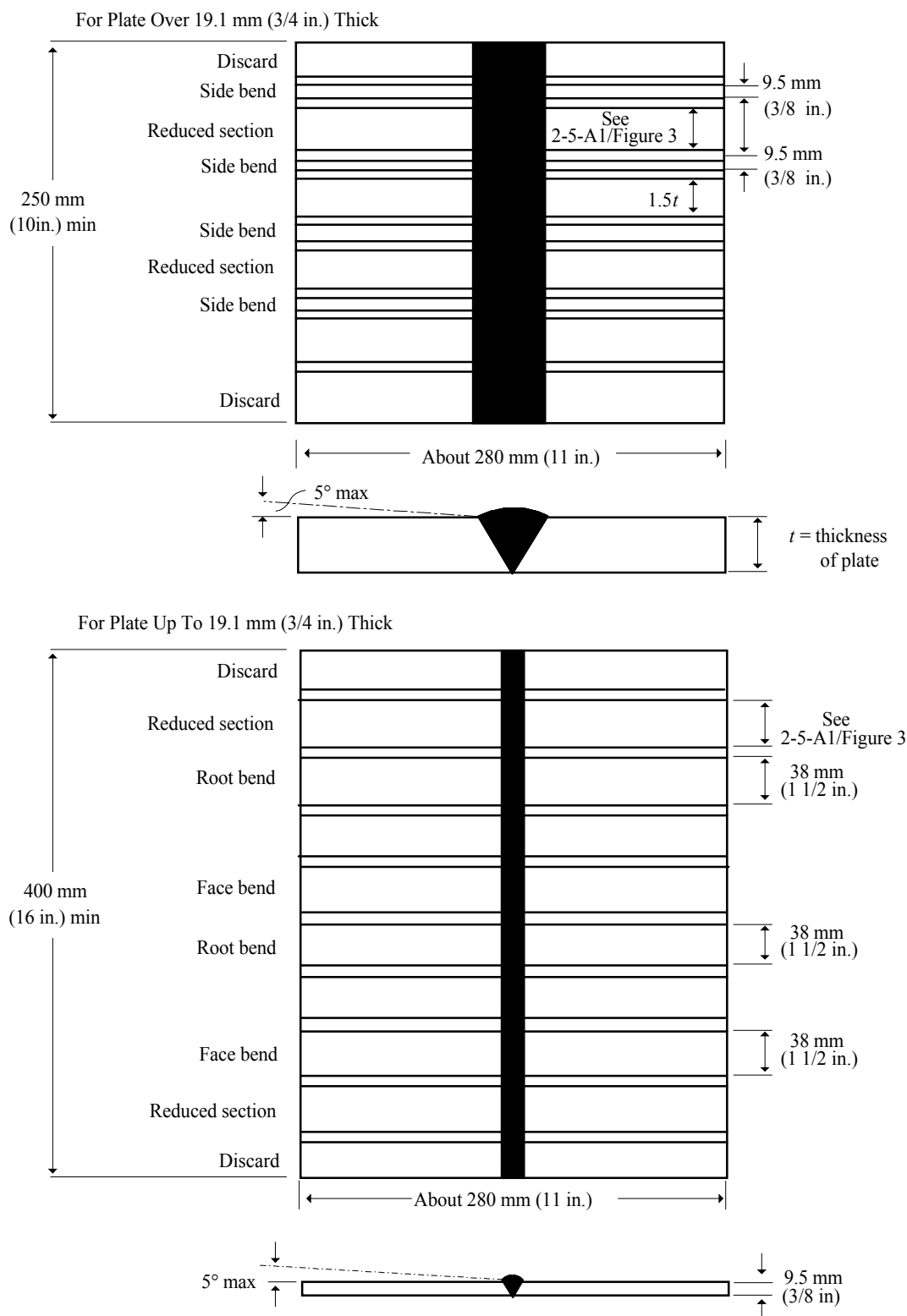
FIGURE 4
Permissible Unfairness in Other Aluminum Welded Structure



Applicability of tolerance

- 1 Structural bulkheads forming a boundary of living space (stateroom, office, berthing, messing or lounge area) and passageways contiguous to such spaces.
- 2 Decks within the hull and superstructure in way of the above living spaces.
- 3 Decks exposed to the weather.
- 4 Tank and main transverse bulkheads
- 5 Inner-bottom plate and longitudinals and transverses.

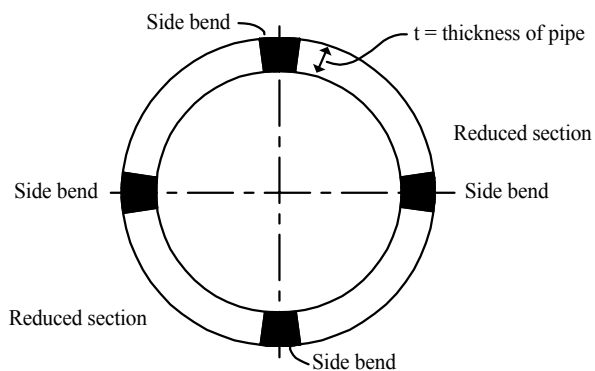
FIGURE 5
Preparation of Test Plates and Pipes for Weld Tests Nos. 1 and 2



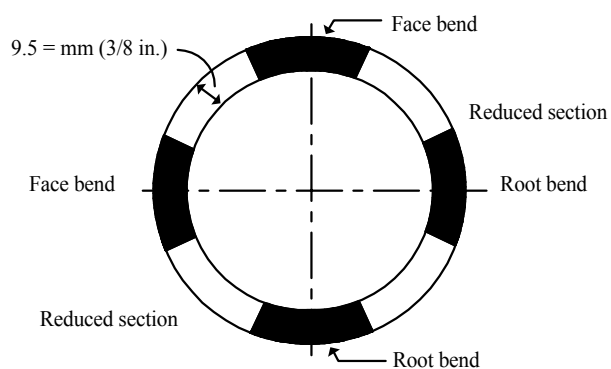
Note: Edge preparation, welding procedure and postweld heat treatment, if any, are to be the same as those for the work represented.

FIGURE 5 (continued) Preparation of Test Plates and Pipes for Weld Tests Nos. 1 and 2

For Pipe Over 19.1 mm (3/4 in.) Thick

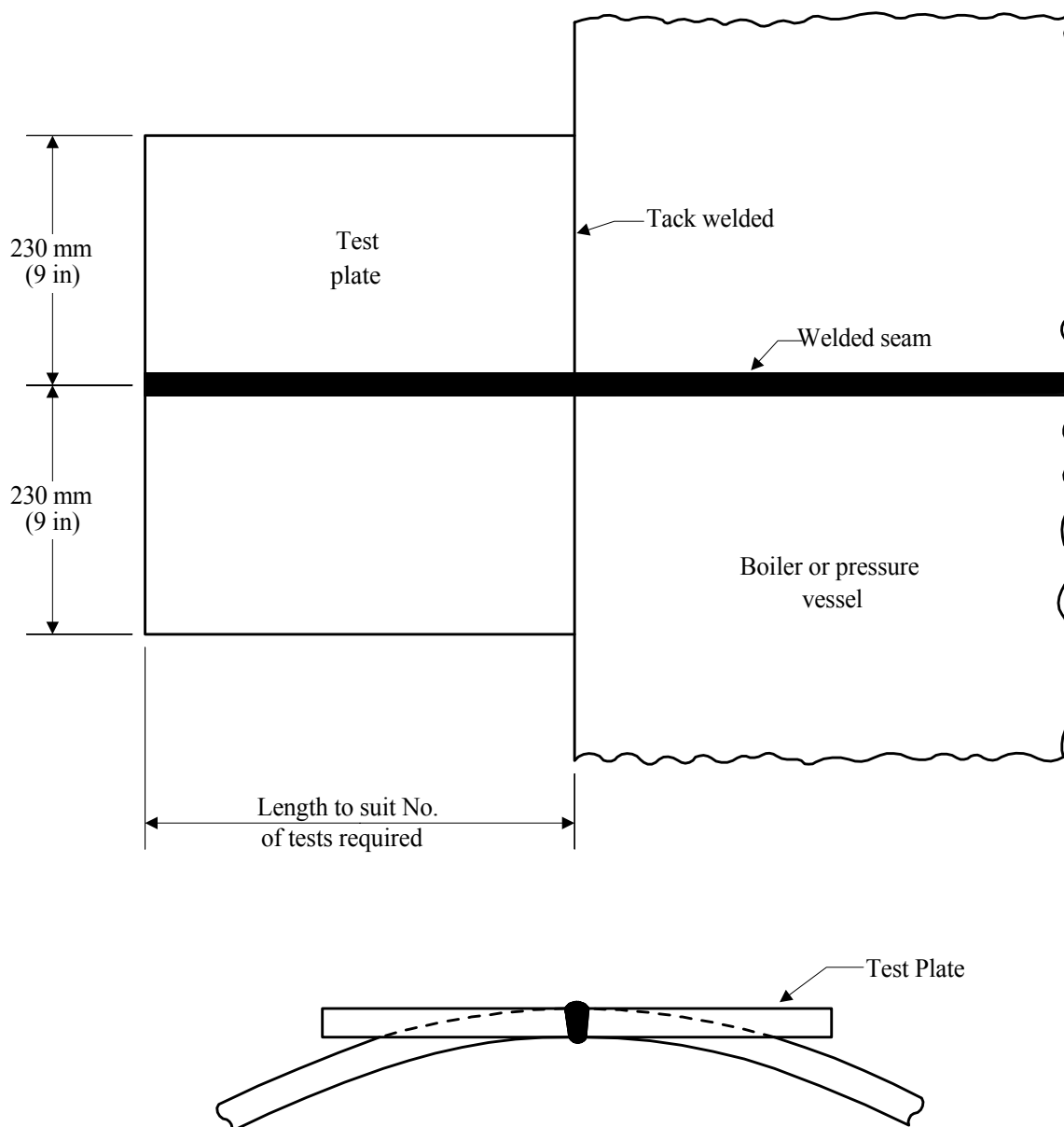


For Pipe Up To 19.1 mm (3/4 in.) Thick



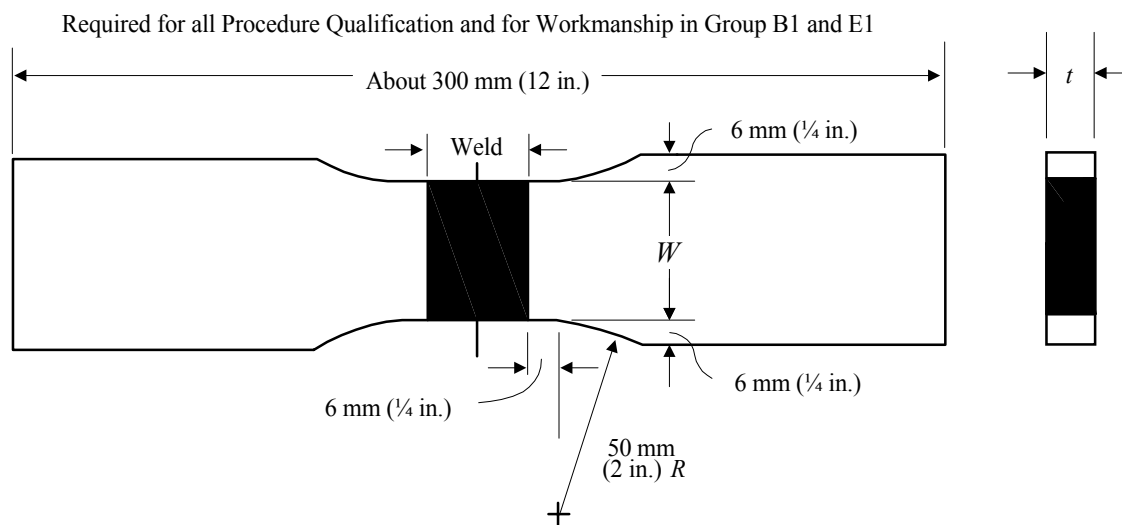
Note: Edge preparation, welding procedure and postweld heat treatment, if any, are to be the same as those for the work represented.

FIGURE 6
Typical Arrangement of Test Plates for Workmanship Tests in Group B1



Note: Tack weld test plates together and support test assembly so that warping due to welding does not cause deflection of more than 5 degrees. Should straightening of any test assembly within this limit be necessary to facilitate making test specimens, the test assembly is to be straight-ended after cooling and before any postweld heat treatment.

FIGURE 7
Test No. 1 – Reduced-section Tension Test for Plate



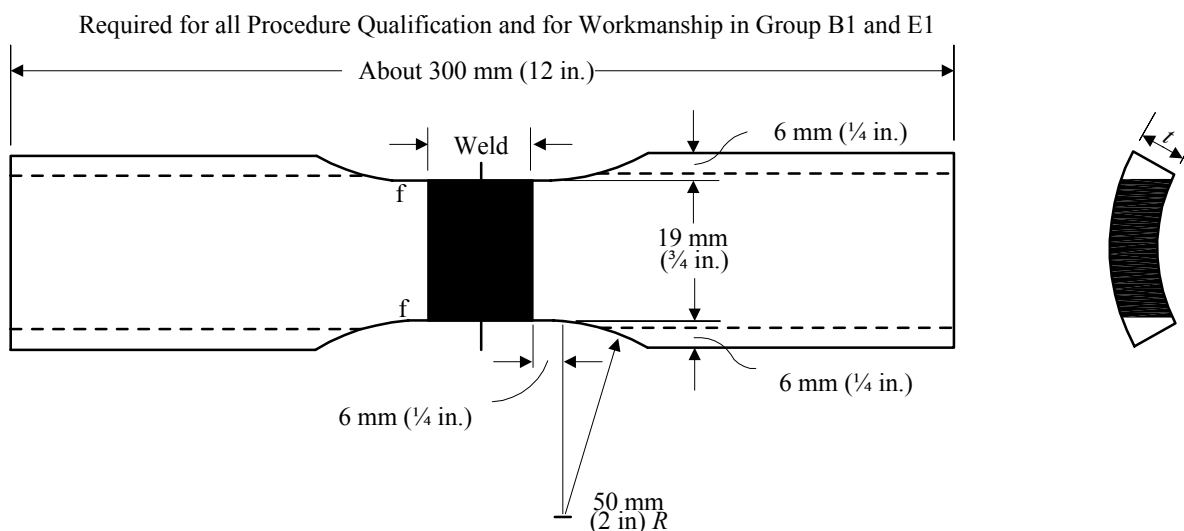
Notes

- 1 Both faces of weld are to be machined flush with base metal.
- 2 For procedure qualification t is to be representative of thickness welded in production.
- 3 W = approximately 38 mm (1.5 in.) where t is 25.4 mm (1 in.) or less. w = 25.4 mm (1 in.) where t is more than 25.4 mm (1 in.)
- 4 When the capacity of the available testing machine does not permit testing the full thickness specimen, two or more thinner than full thickness specimens may be prepared by cutting the full thickness specimen into sections, each of which is to meet the requirements.

Requirement

The tensile strength of each specimen, when it breaks in or adjacent to the weld, is not to be less than the minimum specified tensile strength as indicated in 2-5-A1/Table 2.

FIGURE 8
Test No. 1 – Reduced-section Tension Test for Pipe



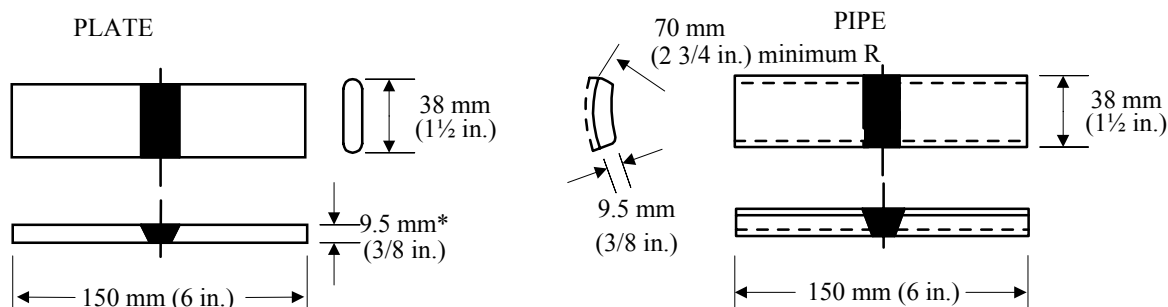
Notes

- 1 Both faces of weld are to be machined flush with base metal. The minimum amount needed to obtain plane parallel faces over 19 mm (3/4 in.) wide reduced section may be machined at the option of the testing facility.
- 2 For procedure qualification $t = 9.5$ mm (3/4 in.) for construction materials up to 19.1 mm (3/4 in.). For construction material over 19.1 mm (3/4 in.) $t =$ thickness of material.
- 3 For workmanship tests $t =$ thickness in material.
- 4 When the capacity of the available testing machine does not permit testing the full thickness specimen, two or more thinner than full thickness specimens may be prepared by cutting the full thickness specimen into sections each which is to meet the requirements.

Requirements

- 1 The tensile strength of each specimen, when it breaks in or adjacent to the weld, is not to be less than the minimum specified tensile strength as indicated in 2-5-A1/Table 2.
- 2 The tensile strength of each specimen, when it breaks in the base metal and the weld shows no signs of failure, is not to be less than 95% of the minimum specified tensile strength of the base material.

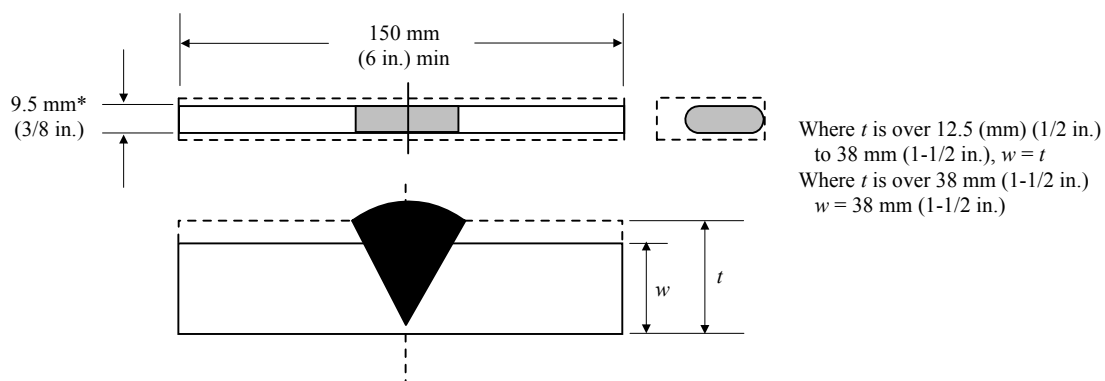
FIGURE 9
Test No. 2 – Guided Bend Test for Root Bend and Face Bend
(Plate or Pipe)



*For alloy 6061 the thickness of the bend specimen may be reduced to 3 mm ($1/8$ in.).

Note: Both faces of weld to be machined flush with base metal.

FIGURE 10
Test No. 2 – Guided Bend Test for Side Bend (Plate or Pipe)

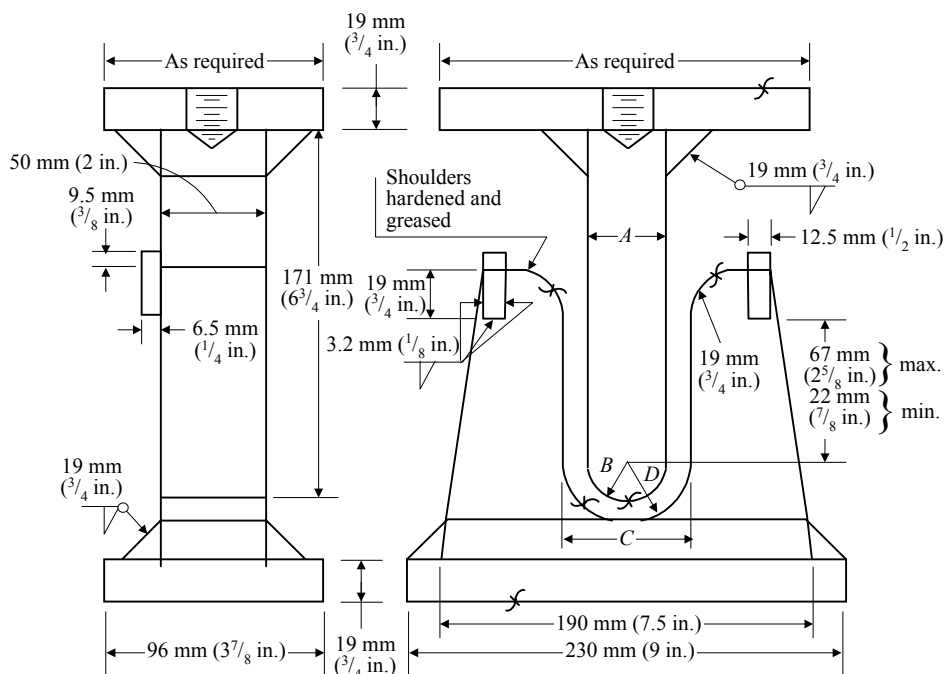


*For alloy 6061 the thickness of the bend specimen may be reduced to 3 mm ($1/8$ in.).

Note: Both faces of weld to be machined flush with base metal.

FIGURE 11
Guided Bend Test Jig

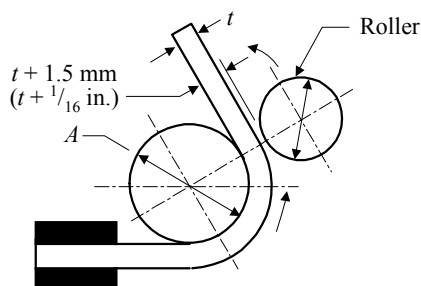
Test Requirement After bending, the specimen is not to show any cracking or other open defects exceeding 3.2 mm ($\frac{1}{8}$ in.) on the convex side except at the corners.



Applicable to material	Thickness of specimens	A	B	C	D
All alloys except 6061	t	$6\frac{2}{3}t$	$3\frac{1}{3}t$	$8\frac{2}{3}t + \frac{1}{8}$	$4\frac{1}{3}t + \frac{1}{16}$
Alloy 6061	3.2 mm ($\frac{1}{8}$ in.)	51.6 mm (2 $\frac{1}{16}$ in.)	26.2 mm (1 $\frac{1}{32}$ in.)	59.9 mm (2 $\frac{3}{8}$ in.)	30.2 mm (1 $\frac{3}{16}$ in.)

Note: Mandrel radius may be increased up to $8.25t$ maximum for alloy 6061.

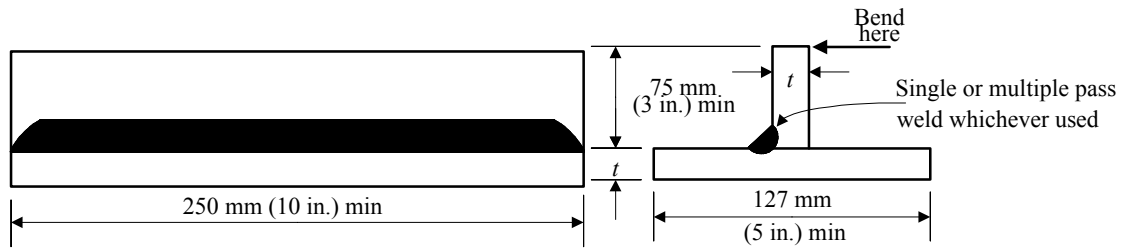
FIGURE 12
Alternative Guided Bend Test Jig



Notes:

- 1 The dimension t is the thickness of the material.
- 2 The reduced section is to be parallel within 0.05 mm (0.002 in.) and may have a gradual taper in width from the ends toward the center with the ends not more than 0.13 mm (0.005 in.) wider than the center. The ends of the specimens are to be symmetrical with the centerline of the reduced section within 0.25 mm (0.01 in.).
- 3 Mandrel radius may be increased up to $8.25t$ maximum for alloy 6061.
- 4 For aluminum alloy bend requirements, see 2-5-A1/Figure 10.

FIGURE 13 Test No. 3 – Fillet Weld Test



Notes:

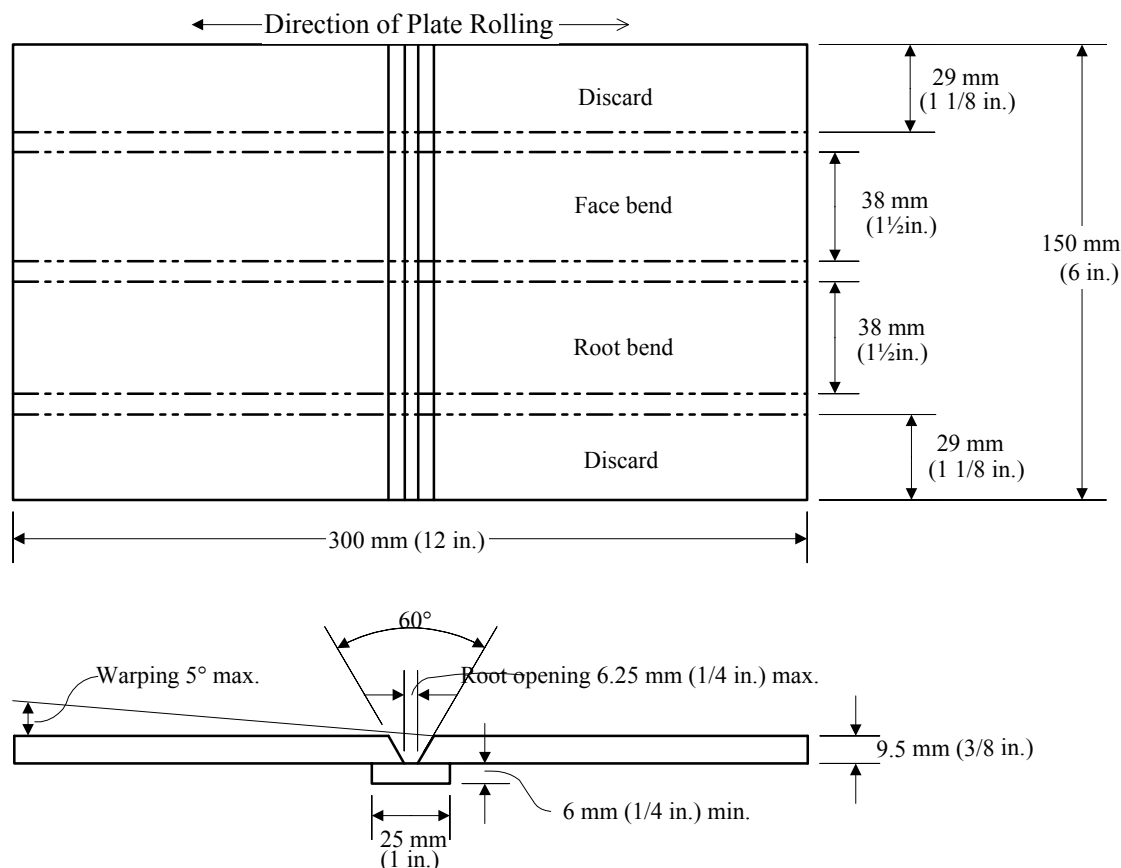
- 1 For procedure qualifications t is to be representative of thicknesses welded in production. Base and standing web is to be straight and in intimate contact and securely tacked at ends before fillet-weld is made, to insure maximum restraint.
- 2 The test plate may be flame cut into short sections to facilitate breaking open.

Requirements:

The fillet is to be the required contour and size, free from undercutting and overlapping. When broken as indicated, the fractured surface is to be free from cracks, and reasonably free from visible porosity and lack of root infusion, except that porosity or incomplete fusion at the root corners of fillets may be acceptable, provided the total length of the incompletely fused areas is less than approximately 10% of the total length of the weld.

FIGURE 14
Welder Qualification Test No. Q1

For plate material 19.1 mm ($\frac{3}{4}$ in.) or less.

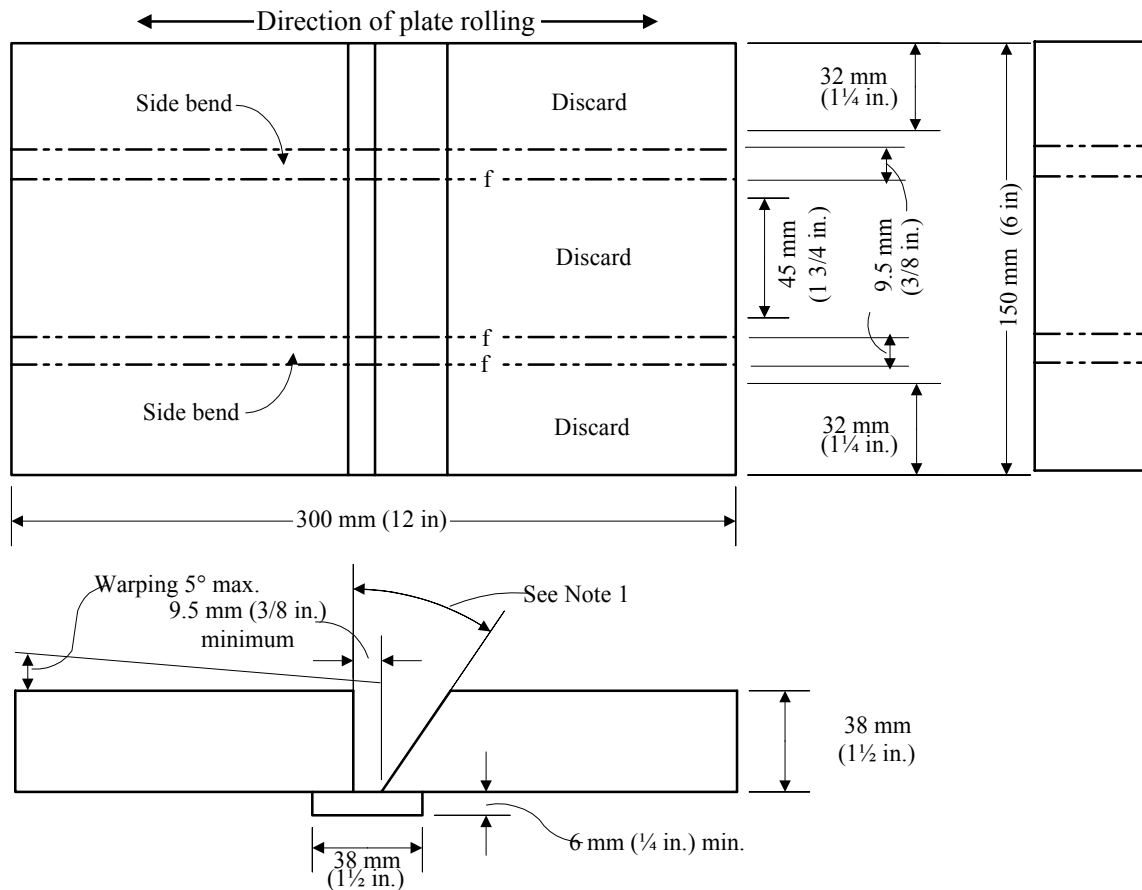


Notes:

- 1 Weld is to be made with the maximum size electrode that will be used in production and a maximum interpass temperature of 66°C (150°F).
- 2 Machine reinforcement and backing strap flush. Do not remove any undercutting.
- 3 Machining is to be done transverse to weld.
- 4 All specimens are to be machined or sawed from plate.
- 5 Backing strap is to be contiguous with plates.
- 6 Joints welded in the vertical position are to be welded upwards.
- 7 Welding is to be done from one side only.
- 8 Bend specimens in Guided Bend Test Jig (2-5-A1/Figure 10 or 2-5-A1/Figure 11).
- 9 1 Face Bend and 1 Root Bend required.

FIGURE 15
Welder Qualification Test No. Q2

For material of unlimited thickness.

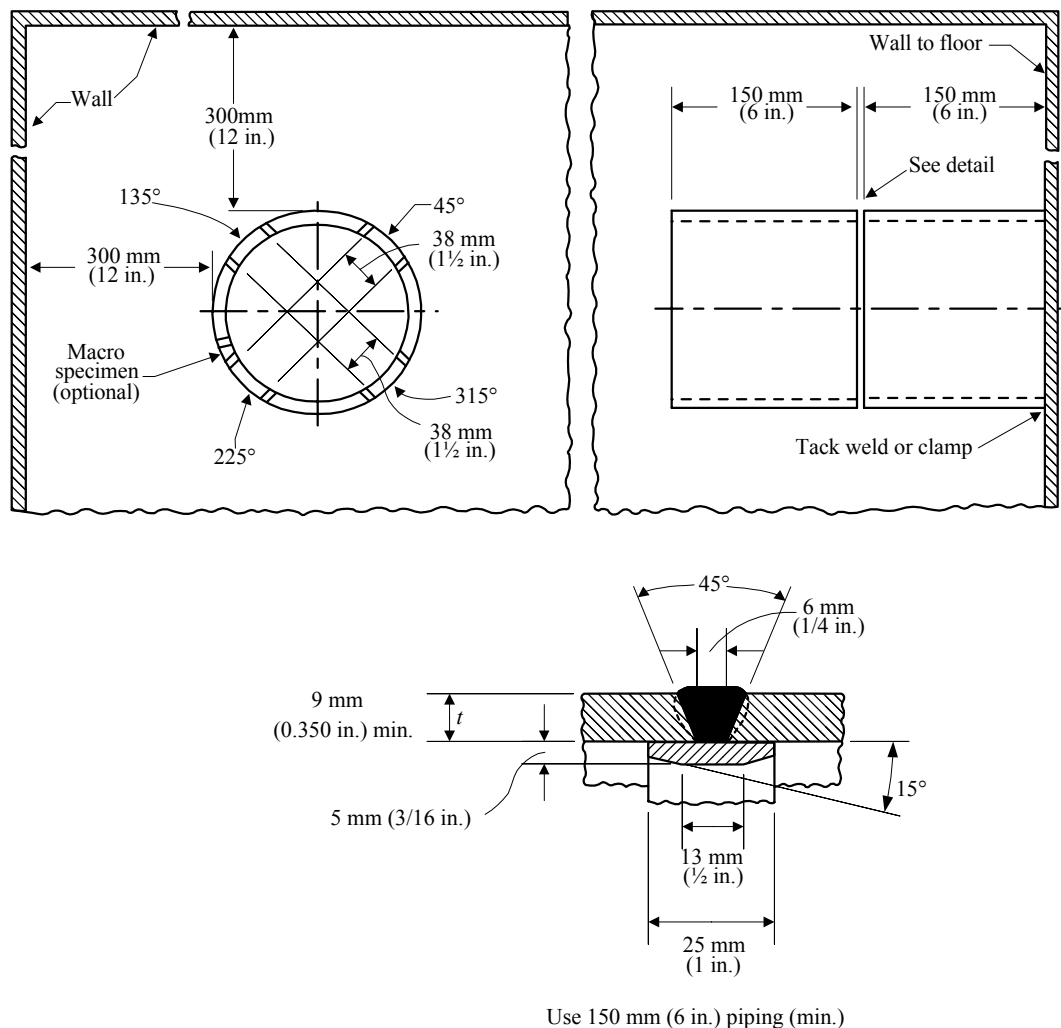


Notes:

- 1 When welding in the flat and vertical positions of welding, the groove angle is to be 25 degrees; when welding in the horizontal position, the groove angle is to be 35 degrees and the unbeveled plate is to be located on the top side of the joint.
- 2 Backing strap is to be contiguous with plates.
- 3 Each pass of the weld is to be made with the same size electrode that will be used in production and a maximum interpass temperature of 66°C (150°F).
- 4 Joints welded in the vertical position are to be welded upwards.
- 5 Welding is to be done from one side only.
- 6 Machine reinforcement and backing strap flush. Do not remove any undercutting.
- 7 All specimens are to be machined or sawed from plate.
- 8 Machining is to be done transverse to weld.
- 9 Break edges of specimens to a radius of $t/6$ maximum.
- 10 Bend Specimen in Guided Bend Test Jig (2-5-A1/Figure 10 or 2-5-A1/Figure 11).
- 11 2 Side Bends required for plate. 4 Side Bends required for pipe.

FIGURE 16
Welder Qualification Test No. Q4

For pipe 19.1 mm ($\frac{3}{4}$ in.) thick or less.



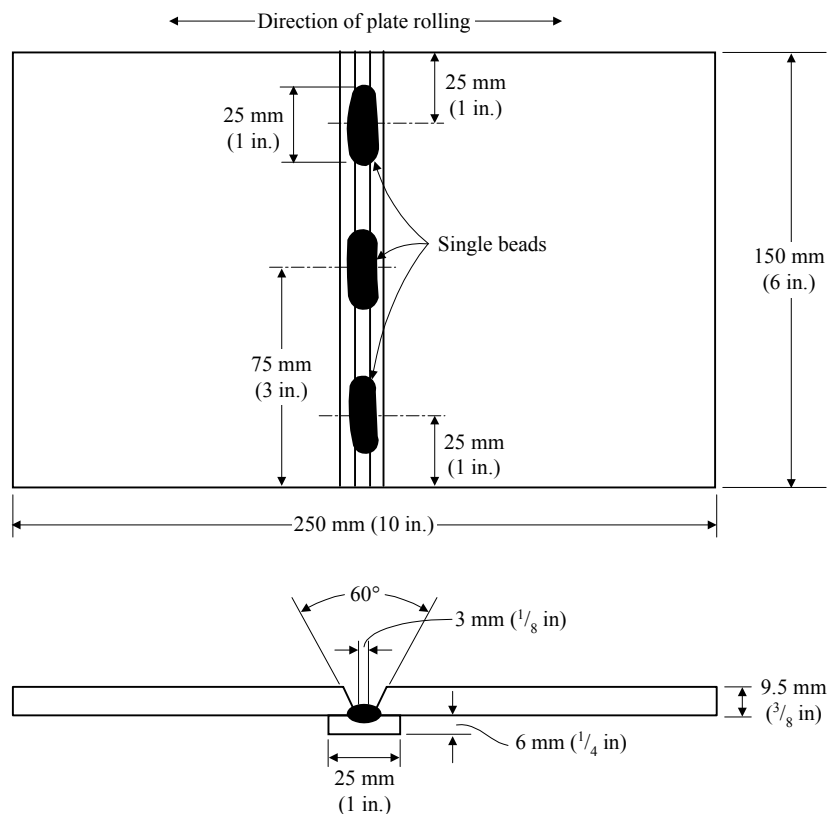
Use 150 mm (6 in.) piping (min.)

Notes:

- 1 Each pass of the weld is to be made with the same size electrode that will be used in production and a maximum interpass temperature of 66°C (150°F).
- 2 Machine reinforcement and backing strap flush. Do not remove any undercutting.
- 3 Machining is to be done transverse to weld.
- 4 All specimens are to be machined or sawed from piping.
- 5 Break edges of specimens to a radius of $t/6$ maximum.
- 6 Mark top and front of piping to insure proper location of specimens.
- 7 Remove face-bend specimens from 45 degree and 225 degree points, and root-bend specimens from 135 degree and 315 degree points as indicated.
- 8 Welding is to be done from one side only.
- 9 Bend Specimen in Guided Bend Test Jig (2-5-A1/Figure 10 or 2-5-A1/Figure 11).
- 10 2 Root Bends and 2 Face Bends required.
- 11 For thicknesses over 19.1 mm ($\frac{3}{4}$ in.), t is to be a minimum of $\frac{1}{2}$ of the thickness to be welded in production.
- 12 For GTA welding, no backing bar need be employed and root opening may be reduced to zero.

FIGURE 17
Welder Qualification Test No. Q5

For Tack Welders.



Notes:

- 1 Electrode diameter used is to be representative of that used for tack welding in production.
- 2 Backing strap is to be contiguous with plates.
- 3 Joints welded in the vertical position are to be welded upwards.
- 4 Specimen is to be bent in one piece with backing strap in place and face of weld in tension.
- 5 Weld fractures are to exhibit no unfused areas on backing strap or sides of groove throughout length of each tack.
- 6 For GTA welding, no backing bar need be employed and root opening may be reduced to zero.

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PART

2

CHAPTER

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PART

2

CHAPTER 6 Materials for Hull Construction – Fiber Reinforced Plastics (FRP)

SECTION 1 General

1 Resins

Resins for the basic laminate of this Guide, other than those utilized for gel coats, are to be unsaturated, general-purpose or fire retardant polyesters suitable for marine use, and are to be catalyzed in strict accordance with manufacturers' recommendations.

1.1 Polyester Resins

Isophthalic polyester or orthophthalic polyester may be used. The former is often used for gel coat and outer ply lamination; the latter is an effective laminating resin.

1.3 Vinylester and Epoxy Resins

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

1.5 Gel Coats

All gel coats are to be used in strict accordance with the manufacturers' recommendations. Where a gel coat is not used, details of the proposed water barrier are to be submitted for consideration.

1.7 Curing Systems

For polyester and vinylester resins the level of catalyst and accelerator are to be as recommended by the manufacturer to ensure full polymerisation of the resin. In general, the rate of gelation is to be controlled by the amount of catalyst accelerator added to the resin. The amount of catalyst is not to be less than 1% of the base resin, by weight.

1.9 Phenolic Resins

Phenolic resins having superior properties for fire resistance may not be 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 manufacturers recommendation.

1.11 Resin Properties

The properties of a resin are to be for the final form of the resin actually used in production with all additives and fillers included. The amount of silicon dioxide or other material added to provide thixotrophy is to be the minimum necessary to resist flowing or draining. The following liquid and cured condition properties of resins are to be provided, for the gel coat resin and laminating resin, and if different, for the skin coat:

- Liquid Properties (at 25°C)
 - Monomer Content %
 - Viscosity – Brookfield (Spindle No. & RPM) CPS
 - Thixotropic Index, Minimum
 - Specific Gravity
 - Flash Point, Closed Cup
 - Fillers (type and amount)
- Cure Characteristics (at 25°C)
 - Gel Time, Minutes (indicate initiator (catalyst) and activator (promoter) and %)
 - Gel to Peak, Minutes
 - Peak Exotherm
- Cured Properties for Resin Clear Casting
 - Barcol Hardness
 - Heat Deflection Temperature
 - Tensile Strength and Tensile Modulus
 - Tensile Elongation at Break, %
 - Flexural Strength & Modulus
 - Volume Shrinkage
 - Water Absorption
- Chemical analysis and shelf life.

For polyester resins the tensile elongation at break is generally not to be less than 1.0% for laminating resins and is to be generally not less than 2.0% for gel coat resins. Elongation of other resins will be specifically considered.

1.13 Additives

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

1.15 Fillers

All 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. 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. Pigments, thixotropes and fire retardant additives are to be considered as fillers in the calculation of total filler content. 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. Details of all fillers are to be submitted.

3 Reinforcing Materials

Fiber reinforcement includes E glass fiber, S or R glass, carbon and aramid (Kevlar) fibers. The use of hybrid reinforcing materials is also acceptable. 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.

5 Core Materials

Expected shear strengths of core materials are shown in 2-6-1/Table 1. Core materials other than those shown will be subject to special consideration. 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, as required in Section 2-6-5. Construction methods and procedures for core materials are to be in strict accordance with core manufacturer's recommendations.

5.1 PVC Foam Cores

Foam cores are to be of the closed cell types and impervious to water, fuel, and oils. Foam cores are to be compatible with the resin system and have good aging ability. Foam cores are to have good strength retention at 60°C (140°F). If the foam core is manufactured into formable sheets of small blocks, the open weave backing material and adhesive are to be compatible and soluble, with the laminating resin. 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 entrapped residual gaseous blowing agents from the cells of the foam core.

5.3 Balsa Wood

Balsa wood is to be end grained. Balsa wood is to be treated chemically against fungal and insect attack and kiln dried shortly after felling, and is to be sterilized and homogenized. Balsa wood is to have an average moisture content of 12%. If the balsa wood is 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.

5.5 Core Bonding Materials

Core bonding materials are to be used in accordance with the manufacturer's instructions. The proposed core bonding to be used with the core material is to be indicated on the Material Data Sheet and the construction plans.

TABLE 1
Properties of Core Materials

<i>Material</i>	<i>Density</i>		<i>Minimum Shear Strength</i>		
	<i>kg/m³</i>	<i>lb/ft³</i>	<i>N/mm²</i>	<i>kgf/mm²</i>	<i>psi</i>
Balsa, end-grain	104	6.5	1.6 ⁽¹⁾	0.16 ⁽¹⁾	225 ⁽¹⁾
Balsa, end-grain	144	9	2.5 ⁽¹⁾	0.25 ⁽¹⁾	360 ⁽¹⁾
PVC, crosslinked	80	5	0.9	0.09	122
PVC, crosslinked	100	6.25	1.4	0.14	200
PVC, linear ⁽²⁾	80–96	5–6	1.2	0.12	170

Notes:

- 1 These values are for Ecuadorian balsa.
- 2 Caution is to be taken when linear PVC cores are used in areas that are susceptible to high temperatures because of their low heat distortion temperature.

7 Laminates

7.1 Basic Laminate

The basic laminate consists of an unsaturated general-purpose polyester resin and alternate plies of E-glass, fiberglass mat and fiberglass woven roving fabricated by the contact or hand lay-up process. The minimum glass content of this laminate is 35% by weight.

7.3 Uni-directional Laminates

Lay-up details showing the thickness and weight of the plies are to be indicated on the drawings.

A sufficient balance of properties in the warp and fill directions is to be maintained to prevent laminate failure in any direction. The ratios of the verified minimum laminate strengths in the fill direction to those in the warp direction are to be not less than the following:

<i>Member</i>	<i>Fill Strength/Warp Strength</i>
Panel, aspect ratio = 1.0	0.80
Panel, aspect ratio > 2.0	0.61
Stiffening member	0.25

For panels with aspect ratios between 1.0 and 2.0, the ratios are to be obtained by interpolation.

The values of E_F/F , E_T/T and E_C/C in the fill direction are not to exceed the same ratios in the warp direction.

7.5 Bi-Directional Laminates

Lay-up details showing the thickness and weight of the plies are to be indicated on the drawings.

7.7 Sandwich Laminates

All core material are to be effectively bonded to their laminated skins.

7.9 Mechanical Properties

The mechanical properties used in design for all laminates are to be verified by approved material tests. See Section 2-6-5.

2-6-1/Table 2 gives the average mechanical properties for various laminating materials. Thickness, strength, and stiffness vary from the type of construction (hand lay-up, vacuum bagging, RTM, or resin infusion) and the quality of the builder. These values are minimum for hand lay-up construction and are to be used for guidance only. For sandwich construction, the core to skin bond line is to be tested in tension (flatwise tension test, see 2-6-1/Table 1) to determine its integrity. The bondline is considered acceptable if failure occurs in the cored region of the sample or within the laminate skins. The properties to be used for a particular laminate are subject to verification by approved material tests as required in Section 2-6-5.

7.11 Nonstructural Plies

Gel coats and skin coats of either fiber mat or fiber cloth weighing less than 30 grams per square meter (0.1 ounce per square foot) are considered to be nonstructural. They are not to be included when assessing laminate strength and stiffness.

7.13 Laminate Thickness

The average thicknesses given below are provided only as guidance to the designer for mat and woven plies laid-up separately. Thickness indicated on the submitted plans for use with the guide are to be verified by the Surveyor and approved material tests.

The cured resin-and-mat plies may be taken to have average thickness equal to 0.25 millimeters per 100 grams of mat in each square meter (0.03 inches per ounce of mat in each square foot) of the basic laminate. The cured resin-and-woven roving plies may be taken to have an average thickness equal to 0.12 millimeters per 100 grams of woven roving in each square meter (0.0016 inches per ounce of woven roving in each square yard) of the basic laminate.

For mat and woven roving laminates differing in glass content from the basic laminate, the average cured laminate thickness, t , (excluding nonstructural plies) can be obtained from the following equation:

$$t = \frac{Wk}{c} \left(\frac{305}{f_g} - 269 \right) \quad \text{mm (in.)}$$

where

- k = 0.35 mm (0.0138 inches)
- f_g = the glass content, percentage by weight, of one ply of the mat and one ply of the woven-roving of the laminate to be used
- c = glass content per pair of composite fiberglass reinforcement of basic laminate,
= 1272 g/m² (4.17 oz/ft²)
- W = total weight of fiberglass reinforcement of the laminate in g/m² (oz/ft²), of the laminate thickness, t

7.15 Plywood and Timber Members

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.

TABLE 2
FRP Laminate Properties

SI Units:

	<i>Basic Laminate kgf/mm²</i>	<i>“S” Glass kgf/mm²</i>	<i>Kevlar kgf/mm²</i>	<i>Carbon kgf/mm²</i>
Flexural Strength, F	17.5	45.9	23.5	51
Flexural Modulus, E_f	773	1835	2236	4500
Tensile Strength, T	12.6	36.4	39.4	43.4
Tensile Modulus, E_t	703	1920	2314	4500
Compressive Strength, C	11.9	30.5	14.4	30
Compressive Modulus, E_c	703	1828	2285	4430

TABLE 2 (continued)
FRP Laminate Properties

MKS Units:

	<i>Basic Laminate N/mm²</i>	<i>“S” Glass N/mm²</i>	<i>Kevlar N/mm²</i>	<i>Carbon N/mm²</i>
Flexural Strength, F	172	450	230	500
Flexural Modulus, E_f	7580	18000	22000	43800
Tensile Strength, T	124	357	386	425
Tensile Modulus, E_t	6890	18800	22700	43800
Compressive Strength, C	117	299	142	284
Compressive Modulus, E_c	6890	18000	22500	43700

U.S. Customary Units:

	<i>Basic Laminate psi</i>	<i>“S” Glass psi</i>	<i>Kevlar psi</i>	<i>Carbon psi</i>
Flexural Strength, F	25000	65300	33400	72500
Flexural Modulus, E_f	1100000	2610000	3180000	6400000
Tensile Strength, T	18000	51800	56000	61700
Tensile Modulus, E_t	1000000	2730000	3290000	6400000
Compressive Strength, C	17000	43400	20500	41100
Compressive Modulus, E_c	1000000	2600000	3250000	6300000

9 Adhesives

9.1 General

Adhesives for structural applications are to be used in accordance with the manufacturer's recommendations. The details of all structural adhesives are to be specified on the Material Data Sheet and on the construction plans submitted. Details concerning the handling, mixing and application of adhesives are to form part of the Builders Process Instruction. 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 Process Description is to identify the level of training required for personnel involved in the application of structural adhesives.

9.3 Requirements for Structural Application

For adhesive materials to be acceptable for use in structural applications, they are to comply with the following requirements:

- i) The minimum shear strength of the adhesive is to be between 6.9 N/mm² (1000 psi) and 10 N/mm² (1500 psi). This shear strength is to be achieved in temperatures ranging from ambient to 49°C (120°F). The testing is to be performed to ASTM D1002 or ASTM D3165 using FRP substrates. All failures of test samples are to be either cohesive or fiber tear.
- ii) The adhesive is to be tested in fatigue using ASTM D3166 (note: the test substrates may be metallic). The test is to be conducted at 50% of the ultimate tensile strength and is to last for a minimum of one million cycles at 30 Hz.

- iii)* The process for the application of the adhesive is to be submitted for review and is to include the maximum bondline thickness, non-destructive testing methods, and maximum creep.
- iv)* The elastic modulus of the adhesive is to be considerably less than that of the FRP skin to which it is being adhered
- v)* The strain of failure ratio of the adhesive is to be much larger than the surrounding structure.
- vi)* The mechanical properties of the adhesive are achieved rapidly, such that the use of screws or bolts will not be necessary to hold the substrates together while the adhesive cures.
- vii)* The adhesive is to be compatible with the lamination resin.

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PART

2

CHAPTER 6 Materials for Hull Construction – Fiber Reinforced Plastics (FRP)

SECTION 2 Fabrication

1 General

The use of fabricating procedures differing from those given below will be specially considered.

3 Fabrication Procedures

3.1 General

The laminate is to be lay-up by one of the following methods:

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

3.3 Laminate Layup

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 (2 in.). Unless otherwise specifically approved, no laps in the various plies of a laminate are to be closer than 100 mm (4 in.) 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 uni-directional laminates.

3.5 Sandwich Panel Layup

Sandwich panels may be laminated with cores that either 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 are capable of carrying shear loads, (e.g. 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 with 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 layup. For foam cores the resin is to be applied and sufficiently rolled to ensure that all voids are filled, and the coat of resin for wood cores should be substantial enough to seal the grain of the wood.

3.7 Secondary Bonds

In general, secondary bonds should only be used when a primary bond cannot be achieved. Where ever 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's recommendations should be adhered to:

- i) The area is to be clean and free from all foreign particles such as wax, grease, dirt, and dust.
- ii) 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 layup 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.

Where methods other than conventional secondary bonding are proposed, the shipyard is to demonstrate that the proposed method is equivalent in strength to a conventional secondary bond.

PART

2

CHAPTER 6 Materials for Hull Construction – Fiber Reinforced Plastics (FRP)

SECTION 3 Building Process Description

1 General

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.

- i) Description of construction facilities, including environmental control and material storage and handling.
- ii) Specifications for resins, reinforcing products, and core materials including the manufacturer's recommendations.
- iii) Layup procedures, including type, orientation of reinforcements, sequence, resin mixing methods, and resin pot-life limits.
- iv) Secondary bonding procedures.
- v) Inspection and quality-control systems
- vi) Laminate properties derived from destructive qualification testing including sample check sheets, forms, and guides.

3 Building Facilities

3.1 Material Storage Premises

The premises are to be equipped and arranged so that the material manufacturer's recommendations for storage and handling can be followed:

3.1.1

Premises are to be enclosed, protected from the sun, clean, dry, ventilated as necessary, and sufficiently free of dust so that materials are not contaminated or degraded. Materials are to remain sealed in storage as recommended by the manufacturer.

3.1.2

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.

3.1.3

Resins, catalysts, hardeners and accelerators are to be stored in a well-ventilated space at temperatures recommended by the manufacturer. 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. Resin tanks are to be arranged so that they can be stirred at the frequency and time recommended by the manufacturer.

3.1.4

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.

3.1.5

Material 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 manufacturing facility in accordance with fire and insurance codes.

3.3 Mold Construction

Molds are to be constructed to the following criteria:

3.3.1

Molds are to be constructed of a suitable material and are to be adequately stiffened to maintain their overall shape and fairness of form.

3.3.2

The materials used in the construction of molds are not to affect the resin cure.

3.3.3

The finish on a mold is to be such that the moldings produced are suitable for the purpose intended. The resultant aesthetic appearance of the molding, is not part of ABS Survey and approval.

3.3.4

Where multiple section molds are used, the sections are to be carefully aligned to the attending Surveyor's satisfaction prior to molding. Mismatch between mold sections is to be avoided.

3.3.5

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

3.3.6

Prior to use, all molds are to be conditioned to the workshop temperature.

3.3.7

Lifting arrangements are to be designed such that moldings are subjected to minimal distortion and unnecessary stressing. Moldings are to be adequately supported to avoid distortion during final cure.

3.5 Laminating Premises

Premises are to be arranged and equipped so that the material manufacturer's recommendations and builder's standards for handling, laminating and curing can be followed:

3.5.1

Premises are to be fully enclosed, dry, clean, shaded from the sun, and adequately ventilated to remove fumes, overspray, and dust from the molds 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.

3.5.2

Temperature is to be maintained adequately constant at a temperature between 16°C and 32°C (60°F and 90°F). The humidity is to be kept adequately constant to prevent condensation and is not to exceed 80%. Where spray molding is taking place, the humidity is not to be less than 40%. Temperature and humidity are to be within limits recommended by the manufacturer of the materials. Departures from the foregoing will be considered provided the temperatures and humidity are within the limits recommended by the manufacturer and are reviewed by the Bureau prior to laminating.

3.5.3

The laminating temperature in the premises is to be attained at least 24 hours before commencement of lamination, and is to be maintainable regardless of the outdoor temperature.

3.5.4

Sufficient temperature and humidity monitoring equipment is to be provided and detailed records are to be kept in accordance with the Quality Assurance system.

3.5.5

Laminating areas are to be remote from operations creating dust.

3.5.6

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.

3.5.7

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.

3.7 Equipment

All equipment is to be well maintained and operated to the specifications underlined by the equipment manufacturer's recommendations and the following guidelines:

3.7.1

Production equipment, hose connections, gauge faces, spray guns, meters and pumps are to be kept clean and properly serviced.

3.7.2

Floors and work tables are to be regularly cleaned and reasonably free of accumulation of resin and reinforcing materials.

3.7.3

Compressed air for air operated equipment is to be clean, dry and free from contaminants such as oil, moisture, or dirt. The system should include traps that are cleaned and serviced frequently.

3.7.4

The catalyst injection accelerator of spray gun is to introduce the catalyst into the resin or gel coat in a precise ratio and to result in a thoroughly homogeneous mixture. This accelerator is to be checked and calibrated frequently.

3.7.5

Chopper guns are to be maintained properly adjusted to ensure the desired fiber to resin ratio, fiber length and fiber distribution.

3.7.6

Resin delivery systems, both portable and fixed, are to be readily accessible for service and maintenance, including the cleaning of lines to prevent contamination.

3.7.7

For spray laminating, the weights of resin and reinforcement used is to be monitored continuously to check the glass/resin ratio. Samples are also to be taken on a regular basis to validate the calibration equipment.

3.7.8

All measuring 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.

5 Specifications and Data Sheets for Materials

Material specifications and data sheets are to be provided to the builders by the material manufacturers. In general, these data sheets are to include the cured mechanical properties of sample laminates as guidance to the designer. The material specification and data sheets are to also include information indicating the safe use and treatment of operators in the case of contamination.

5.1 Resins, Gel Coats, Catalysts, Accelerators, Hardeners, and Other Additives

The specifications are to indicate the contents of the resin and gel coats, type and amount of catalyst, accelerators, hardeners and other additives as well as recommendations for storage, handling and use.

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 unreinforced 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 manufacturer of the material. Batch data sheets are to be retained.

5.3 Reinforcing Materials

For reinforcing material 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.

5.5 Core Materials

Core material specifications are to indicate the material specification number, material type, density, and recommendations for storage, handling and use.

7 Receiving Materials

7.1 Resins, Gel Coats, Catalysts, Accelerators, Hardeners, and Other Additives

The builder is to have a range of acceptance criteria for properties. The builder is to sample and test each batch to verify properties. Cured samples should be retained for future reference in the event of subsequent problems such as rapid yellowing, sun blistering, and print through. All incoming raw materials are to be tested and inspected on receipt. Following testing, the drums or containers are to be labeled “Approved” or “Rejected.” “Rejected” material is to be returned to manufacturer immediately. See Section 2-6-5.

7.3 Reinforcing Materials

Testing on incoming materials should include a weight check and a visual inspection of a sample of the material for its physical condition. Batch data sheets are to be retained.

7.5 Core Materials

Check tests on density and moisture content for core materials are required. Batch data sheets are to be retained.

9 Laminating Procedure

This laminating procedure is for a standard hand layup technique. Different laminating techniques will be specially considered.

9.1 Start-up

Before laminating, the following items are to be checked and complied with:

9.1.1

Clean, dry, contaminant free air is delivered to equipment.

9.1.2

All materials are at laminating premise temperature.

9.1.3

Resins and gel coats are to be agitated to ensure a uniform mix. Manufacturer’s recommendations are to be adhered to, do not over agitate. Curing agents, fillers and pigments are to be added in strict accordance with the resin manufacturer’s recommendations.

9.1.4

The condition of the resin, gel coat and catalyst delivery system is to be checked to ensure proper pump operations, tips are clean, clear and in good condition, seals and lines are free of leaks, and that the filters are clean.

9.1.5

The equipment is to be calibrated in accordance with the equipment manufacturer’s instructions. Set delivery rates, ratios and mix to the material manufacturer’s instructions. Check the gel and cure times to verify calibration.

9.1.6

Record temperature, flow rates and catalyst ratios and maintain.

9.1.7

Catalyst amount is to be determined in accordance with the manufacturer's instructions.

9.1.8

Inspect the mold to ensure that there is adequate mold release agent, that the surface is dry and clean, and that the mold temperature is the same as the laminating premise temperature.

9.3 Application of Gel Coat

9.3.1

Apply the catalyzed gel coat, typically using multiple uniform passes of 6 to 8 mils to build up a uniform wet thickness of 25 to 30 mils. Recommended time between passes is 15 to 30 seconds; consult the manufacturer for optimum time, and for optimum gel coat thickness.

9.3.2

Commence lamination of skin coat as soon as adequate film cure has occurred in accordance with gel coat manufacturer's specification.

9.5 Lamination of Skin Coat

9.5.1

Exposed surface of gel coat is to be kept clean, free of dust and contaminants.

9.5.2

Wet film of catalyzed resin is applied by pouring, brushing or spraying to the entire gel coat surface. Apply at least 300 g/m² (1 oz./ft²) chopped strand or other skin coat as indicated on the approved plans, into wet resin and apply sufficient additional resin to complete wet-out of glass, i.e. resin encirclement of each individual fiber or complete impregnation of the mat, roving or cloth.

9.5.3

Roll-out skin coat to ensure saturation of fibers and elimination of air and voids in the skin coat. The consolidation is to be done with gentle rolling and with care not to damage the gel coat.

9.7 Main Lamination – Single Skin

9.7.1

Laminating is to be carried out by skilled workers trained and qualified to the level required by the Quality Control Plan.

9.7.2

Carry out lay-up in accordance with the lay-up schedule on the approved plans giving particular attention to type of reinforcing ply and their orientation.

9.7.3

Wet film of catalyzed resin is applied by pouring, brushing or spraying to the entire skin coated surface. Apply next reinforcing ply as required, and apply it to sufficient resin to completely saturate the glass fibers. Carefully roll-out the laminate to remove air pockets and void spaces.

9.7.4

Continue as indicated in the lay-up schedule. Time between plies is to be in accordance with the material manufacturer's recommendations.

9.7.5

The approved laminate schedule is to be carefully followed with respect to the particular ply type, weight and orientation. Ply overlaps along edges and at ends and ply staggering are to be in accordance with the approved plan.

9.7.6

During lay-up, guidance on gel time is to be strictly followed, with regard to laminating premise temperature and the amount of catalyst. The gelation time is to be suitable for the proposed application such that full wet-out of the reinforcement can be obtained without unnecessary drainage on vertical surfaces or excessive loss of the monomer.

9.7.7

The degree of laminate cure is established by the Barcol Hardness Test. The hardness meter is to be regularly checked for calibration during use. A value of 40 or more indicates a satisfactory degree of cure for polyester resin. Lesser values may be used for vinylester and epoxy resins. These are to be in accordance with the manufacturer's recommendations.

9.7.8

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 adverse effect on the mechanical properties of the cured laminate.

9.7.9

Laminating is to be carried out in a sequence and documented in the quality control procedure for the particular resin system. Similarly, the time lapse between the forming and bonding of structural members is to be kept within the limits recommended by the resin manufacturer. Where this is not practicable, the surface of the laminate is to be prepared to improve the bond in accordance with the resin manufacturer's instructions.

9.7.10

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.

9.7.11

The exposed edges of all openings cut in single skin laminate panels are to be suitably sealed. Where such edges are in wet spaces or under water, the edges of such openings are to have rounded edges and are to be sealed by two plies of 450 g/m² (1.5 oz/ft²) chopped strand mat (or equivalent) reinforcement.

9.9 Main Lamination – Sandwich Laminate

9.9.1

For sandwich laminates, where applicable, single skin requirements are to be adhered to.

9.9.2

The ply before the core is to be chopped strand mat. Mat is to be thoroughly wet-out with a generous application of resin. Alternatively, core manufacturer's putty or compound may be used. Core is to be laid-up in strict accordance with the core manufacturer's instructions and approved plans. A generous coat of resin or putty, etc. is to be applied to the core and subsequent ply, generally chopped strand mat, applied and thoroughly wet-out and rolled out. The core is to be vacuum bagged to the skins. Where it is not practicable, alternative lamination will be considered.

9.9.3

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

9.9.4

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, additional building up of the surface or contouring of the core is required.

9.9.5

Where other than epoxy resins are being used, the reinforcement against either side of the core is to be of the chopped strand mat type. No additional flow coating is to be applied to the foam core prior to laminating.

9.9.6

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 bond process. The primer is to seal the panels, including all surfaces between the blocks of contoured material, without completely filling the surface cells.

9.9.7

Where panels of rigid core materials are to be used, the vacuum bagging techniques are 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.

9.9.8

Thermoforming of core material is to be carried out with the core manufacturer's recommendations. Maximum temperature limits are to be observed.

9.9.9

Where panels of controllable 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 molding. 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 depths of the core between the blocks. It is recommended that grid scored panels using a carrier scrim cloth are adopted.

9.9.10

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.

9.9.11

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.

9.9.12

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.

9.9.13

Exposed edges of openings cut in sandwich panels are to be suitably sealed. The cut edges are, in general, to be sealed with a weight of reinforcement not less than required for the outer skin of the sandwich. Where other than an epoxy resin system is used, the first layer of such reinforcement is to be chopped strand mat with a weight not exceeding 450 g/m² (1.5 oz/ft²).

9.9.14

Scored core material should be avoided whenever possible. However, when necessary, only single cut core material should be used in all external panels. When scored core material is used, the scores are to be properly filled with the bedding putty. The layer of bedding putty between the core material and the FRP skins should be between 0.5 mm and 2 mm (0.02 in. and 0.08 in.) thick.

9.11 Release and Curing

9.11.1

After completion of the lay-up, the molding is to be left in the mold for a period to allow the resin to cure before being removed. This period is not to be less than 12 hours or that recommended by the resin manufacturer.

9.11.2

Care is to be exercised during removal from the mold to ensure that the hull, deck and other large assemblies are adequately braced and supported to avoid damage and to maintain the form of the molding.

9.11.3

Where female molds are adopted, all primary stiffening and transverse bulkheads are to be installed prior to the removal from the mold unless agreed otherwise.

9.11.4

Moldings 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 moldings to be protected against adverse weather conditions.

9.11.5

Moldings are, in general, to be stabilized in the molding 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.

9.13 Secondary Bonding

9.13.1

Laminating is to proceed as a continuous process, as far as practicable, with the minimum of delay between successive plies. Where a secondary bond is to be made, it is to be carried out with the resin manufacturer's recommendation, details of which are to be incorporated into the builder's quality assurance plan.

9.13.2

Internal stiffening members, internal structural bulkheads, etc. are generally secondary bonded to the hull. Secondary bonding is the application of a resin wet ply to an already fully cured surface.

9.13.3

The cured surface is to be sanded and thoroughly cleaned and dry. A generous coat of resin is to be applied to the cured surface and the first ply laid-on and further resin applied. The first ply is generally chopped strand mat. An alternative method is to use a peel ply on the cured laminate, which is to be removed and the laminate is to be lightly abraded prior to the secondary bond.

9.13.4

The overlap of the resin wet plies to the cured laminate are to be in accordance with the approved plans.

11 Inspection

11.1 General

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:

- i) Check the mold to ensure it is clean and releasing agent is properly applied.
- ii) Gel coat, check thickness, uniformity and application and cure before applying laminating resin first layer of reinforcement.
- iii) Check resin formulation and mixing. Check and record amounts of base resin, catalysts, hardeners, accelerators, additives and fillers.
- iv) Check that reinforcements are uniformly pregmated and well wet-out, and that lay-up is in accordance with approved drawings and the approved standards of overlaps are complied with. All variation in materials should be brought to the attention of the appropriate ABS Technical Department.
- v) Check and record resin/fiber ratios.
- vi) Check that curing is occurring as specified. Immediate remedial action is to be taken when improper curing or blistering is noted.
- vii) Visual overall inspection of completed lay-up for defects that can be corrected before release from the mold. The laminated parts are to be free of open voids, pits, cracks or protruding fibers.
- viii) Check and record hardness of cured hull prior to release from mold.
- ix) The ambient temperature, humidity, and gel time is to be monitored and recorded.

11.3 Voids

Excessive void content can reduce the overall strength of the laminate, and therefore the laminate is to be inspected for the following:

- i) There are to be no voids extending through more than one ply of laminate.
- ii) There are to be no voids larger than 12 mm (0.50 in) in their greatest dimension.
- iii) There are to be no voids larger than 3 mm (0.125 in) on each ply in any 150 mm × 150 mm (6 in × 6 in) area, with a maximum of six (6) total voids in this area.
- iv) There are to be no more than three (3) voids larger than 3 mm (0.125 in) on each ply in any 300 mm × 300 mm (12 in × 12 in) area, with a maximum of twenty (20) total voids in this area.

Note that interconnected voids are to be considered a single void, and spaces occupied by foreign matter in the laminate are to be considered as voids.

13 Faults

13.1 General

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.

13.3 Production Faults

Production faults are to be brought to the attention of the attending Surveyor and a rectification system is to be agreed upon.

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PART

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CHAPTER 6 Materials for Hull Construction – Fiber Reinforced Plastics (FRP)

SECTION 4 Quality Control

1 Application

A quality assurance system is to be set up in association with the building process description. The objective of the system is to measure and record compliance with approved plans and the building process description. Quality control records are to be carefully kept, and are to be available at all times for review and routine verification by the Surveyor to the Bureau. Compliance with the quality assurance system is required, in general, for craft that are obtaining ABS classification.

3 Definitions

3.1 Hull Construction

Hull construction consists of construction of the hull, deck, deckhouse and all other structure that affects the structural, weathertight and watertight integrity of the craft. Included are windows, doors, hatches, rudders, skegs and keels.

3.3 Quality Assurance Standard

The quality assurance requirements of ABS for the hull construction of small craft.

3.5 Quality Assurance

All activities and procedures concerned with the attaining of quality, including records and documents to verify attainment.

3.7 Quality Assurance System

The organization indicating responsibilities, activities, resources and events that provide the procedures from which data and records originate to verify the builder's capability to comply with quality requirements. It includes the building process description.

3.9 Building Process Description

A description of the building process, covering building facilities, material receiving procedures, laminating process, inspection and testing. Monitoring and recording of the building process description implements quality control.

3.11 Quality Control

The operational means and functions used to measure and regulate the quality of construction to the required standards.

3.13 Inspection

The process of measuring, examining, testing, and comparing an item with the approved plans, approved building process and approved builder's standards.

3.15 Assessment

The initial inspection of the quality system at the builder's facilities to verify that all requirements are met and that the facilities are in accordance with the approved building process description and quality control procedures.

3.17 Audit

Verification that the building process and quality control process continue to be as effectively maintained as they were at the initial assessment.

3.19 System Monitoring

The checking by ABS Surveyors on a regular basis the processes, activities and necessary documentation to verify that the builder's quality system continues to be effectively carried out in accordance with the ABS quality assurance standard.

5 Design

5.1 Plan Review

The plans showing scantlings and arrangements and details of materials, building process description and quality assurance manual, as listed below, are to be submitted for review prior to start of production. All review amendments are to be included on the working plans.

5.3 Revisions

Any revisions made after approval are to be submitted to the attending Surveyor, who, at his discretion, may agree to the revision or require the plans to be resubmitted for approval. Where the Surveyor agrees to the revision, he is to provide the Technical Office responsible for plan approval with the details.

7 Building Process Description – Quality Control

A building process description is to be submitted for review. It is to cover in detail the building facilities, receipt of materials process, manufacture, inspection and testing. The relevant stages in the building process description are to be monitored and recorded as given in the quality assurance manual. It is to be agreed upon at which stages the Surveyor will carry out quality control monitoring and direct inspection. Direct inspection will include, but will not be limited to, final inspection on completion of construction.

9 Certification of Quality Assurance

At the request of the builder, ABS will carry out plan approval of the craft to be constructed and review of the Building Process Description and Quality Assurance Manual. On satisfactory completion of this and subsequent inspection by an ABS Surveyor to verify the building process and quality assurance system are in accordance with the reviewed documents, a Quality Assurance Certificate will be issued.

The certificate is valid for one year and will be reissued each year subject to a satisfactory audit.

All information and data submitted by a builder for approval or review under the ABS Quality Assurance program will be treated with strictest confidence and will not be shown to or discussed with any third party without the written consent of the builder.

Builders receiving ABS Quality Assurance Certificates will be published by ABS, together with information on whether the craft are receiving classification or type approval.

11 Documentation of Quality Assurance System

The builder is to establish, document, and maintain an effective quality assurance system to ensure and verify that the material, processes and procedures used comply with the applicable requirements.

This documentation is to be in the form of a quality assurance manual that provides the policies, and fully details procedures adopted to comply with the applicable requirements.

13 Personnel

A representative of the builder will be named to have the necessary authority and responsibility to ensure the requirements of this standard are complied with. Unless specifically approved otherwise, the quality assurance representative is to have no other duties or functions. This representative is to have the authority to stop production in the event of a serious quality problem.

The builder is to have an adequately staffed quality control group, whose duties are carried out free of production priorities. This group will generally be supervised by the builder's quality assurance representative.

Other staff whose duties affect quality, including production management, are to have specified responsibility and authority to identify, control and assess quality. In process, inspections may be done by production staff provided it is checked by the builder's quality control group representative on staff.

15 Internal Audit

Internal audits of the quality assurance system in all production areas and other areas concerned with product quality, as given in this standard, are to be carried out under the supervision of the builder's quality assurance representative. The audits are to be at an agreed frequency and the results are to be evaluated at a management review meeting, attended by the builder's quality assurance representative and the production and testing management.

17 Documentation

The approved quality assurance manual, building process description, approved plans, material specifications, material bunch data sheets, completed quality control forms, material sample and test results are to be prepared and maintained readily available for inspection by the Surveyor.

19 Purchase

19.1

Materials and components incorporated into the hull construction that affect quality are to be obtained from recognized manufacturers and suppliers. Recognition may be on the following:

- i)* Documented records of previous satisfaction in supply.
- ii)* Approval by a recognized independent organization to a suitable quality assurance standard.
- iii)* Batch sample inspection and testing against batch data sheets and approval by ABS.
- iv)* Satisfactory assessment and evaluation of the manufacturer's/supplier's capability or quality assurance system at the manufacturer's/supplier's plant by the builder's quality assurance representative.

19.3

Records of manufacturers and suppliers are to be kept to monitor their performance. Those with a poor record are to be considered for replacement.

19.5

Purchase requisitions are to contain all of the necessary technical specification details.

19.7

Purchase orders are to be precise and clear, giving revision status of all referenced documents, standards, etc. and are to include any requirements for certification. Purchase orders are to be reviewed for accuracy prior to issue.

21 Material Receipt, Inspection and Storage

21.1

The material is to be kept separate prior to receiving inspection.

21.3

All materials are to be confirmed as identifiable to a purchase order, and that they are in a satisfactory condition, having no damage or contamination. Data batch sheets are to be provided with each delivery, and where required, certificates of conformity. Batch sample test may be required.

21.5

The temperature, humidity and cleanliness of the storage spaces for resin system materials, fiber reinforcing materials and core materials are to be monitored and recorded at a suitable frequency.

21.7

Materials with a limited shelf life are to be used before the expiration date and in full compliance with the manufacturer's recommendations.

21.9

Where the ambient temperature of the production area differs from that of the storage area, and the material performance is affected by this temperature difference, the material is to be placed in the production area in time to allow the necessary temperature change to occur before the material is used.

21.11

All material is to be fully identifiable in storage and is to be maintained from issue to use in production.

21.13

All material known or thought to be non-conforming is to be segregated from acceptable material.

23 Production

23.1

The necessary plans and other instructions are to be available to the manufacturing staff in all work areas. Instructions are to include control of equipment and method of working.

23.3

All material, parts, hulls and decks during construction are to be specifically identified and are to be traceable to the applicable plans, work instructions, etc.

23.5

Work during the manufacturing stages is to be carried out strictly in accordance with the applicable building process description and monitored and recorded on documents that are part of the building process description. The builder's staff member responsible for each stage is to sign to accept responsibility as soon as the stage is satisfactorily completed.

23.7

Production areas are to have the means of controlling the ambient temperature and humidity. The respective values are to be monitored and recorded at regular intervals. The working areas are also to be kept adequately clean and dust free.

23.9

Materials are to be taken from the stores in sufficient quantities so that they can be processed without delay. Materials waiting to be used are to be kept in conditions that will not lead to contamination, such as moisture absorption or deterioration.

23.11

The production staff is to have ready access to instructions on mold preparation, resin mixing, laminating, curing and release processes.

23.13

The time of application of gel coat, laminating and other time sensitive processes is to be monitored and recorded.

23.15

All equipment and tools in the laminating process such as gel coat and resin application systems, catalyst mixing systems, spray lay-up equipment, compressed air systems, etc. are to be maintained, serviced, and calibrated at suitable intervals to ensure that they are in good working order.

23.17

The list of personnel trained in the laminating processes is to be readily available.

25 Production Inspections and Tests

Inspection and tests are to be carried out at the appropriate stages of manufacture in accordance with the building process description. The acceptance/rejection criteria are also to be in accordance with the building process description. Inspections and tests are to be carried out and recorded by authorized personnel and each inspection and test is to be signed for when satisfactorily completed. Subject to prior agreement, certain inspections may be carried out by production personnel provided there is a system for monitoring by the quality control staff.

27 Final Inspection

Final inspection of each completed hull is to be carried out by the quality control staff. It is to include verification that the construction processes and inspections have been completed satisfactorily, documented and that no outstanding non-conforming items remain.

29 Non-conforming Materials and Components

29.1

All materials and components considered to be non-conforming are to be clearly labeled as such and kept separated from accepted materials.

29.3

There is to be a system of recording a non-conformance, for documenting the authorized corrective measures and for confirmation, where applicable, that the non-conformance has been eliminated by corrective measures.

31 Corrective Action

31.1

Guarantee claims and other customer complaints are to be recorded together with the agreed method of rectification.

31.3

Records of guarantee claims and customer complaints, cases of non-conformance and inspection test results are to be analyzed at suitable intervals to detect trends and introduce corrective measures to reduce the probability of any recurrence.

31.5

Corrective actions are to be kept under surveillance until their effectiveness and suitability are proven satisfactory by experience.

33 Calibration and Maintenance of Equipment

33.1

Production and inspection equipment is to be calibrated and maintained to ensure the procedures and criteria for workmanship and inspection can be carried out with the necessary precision and quality. Whenever available, the manufacturers' calibrations are to be used.

33.3

A list of all such equipment is to be maintained with each item specifically identified and its required calibration/maintenance marked on the item.

33.5

The calibration/maintenance interval and the method and accuracy of the calibration/maintenance of each type of equipment is to be established.

33.7

Records of the calibration/maintenance process are to be maintained and are to include details of any adjustment or repairs.

33.9

Calibration is to be carried out against master instruments of known accuracy based on national or international standards or in accordance with the manufacturer's instructions.

33.11

The interval, method and results of calibration/maintenance are to be reviewed at internal audits.

35 Training

The necessary basic training, qualifications or experience for, as a minimum, the quality assurance, inspection and test personnel, and those performing the laminating and forming processes, calibration, maintenance and internal or external auditing/assessing, are to be prescribed by the builder.

37 Records

37.1

The builder is to develop and maintain records that show achievement of the required quality and the effective operation of the quality system. The following categories of documents as a minimum are to be retained as records after their use:

37.1.1

Superseded versions of the quality assurance manual, documented procedures, generally applicable work instructions and workmanship standards, internally produced standards, accept/reject criteria and representative samples, procedure approval tests and lists of recognized suppliers.

37.1.2

Working drawings and their revision history, copies of purchase orders, records of incoming, in-process and final inspections and tests, certificates of conformity for the raw materials used, records of temperature and humidity, completed non-conformance reports, guarantee claims, customer complaints, training records, internal audit reports, corrective action analysis and minutes of management review meetings.

37.3

All records are to be kept for a defined period of time. Product related records are to be kept for a statutory period of time.

37.5

All records are to be efficiently collated, held in secure storage and systematically identified and indexed to enable retrieval.

PART

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CHAPTER

6 Materials for Hull Construction – Fiber Reinforced Plastics (FRP)

SECTION

5 Testing

1 Gel Time

The builder is to establish and implement a resin gel-time control system for the gel-time desired in production. This gel time is to be within the gel-time upper and lower limits recommended by the resin manufacturer. Resin mixes are to be monitored and recorded to assure proper gel times. During layup the temperature and humidity in the laminating area is to be recorded at regular intervals. The catalyst and gel time are to be adjusted to suit any changing conditions.

3 Barcol Hardness

Prior to removal from the mold, the laminate is to be checked with a Barcol hardness tester at a suitable number of locations to determine the degree of cure. The Barcol hardness number of the cured laminate measured on the surface without the gel coat, is to be not less than 40. When using a Barcol hardness tester the minimum thickness is $\frac{1}{32}$ inch, and the following should be applied:

- i) For a Barcol reading between 0–30: 25 readings, discard high and low and average the rest.
- ii) For a Barcol reading between 30–40: 12 readings, discard high and low and average the rest.
- iii) Barcol hardness tester cannot generally be used with epoxy.

5 Burnout and Thickness

The builder is to conduct and record the results of a predetermined, sufficient number of tests for glass/fiber content and thickness checks on cutouts or plugs that have been removed from laminates to make way for through-hull and through-deck fittings. The plugs are to be identified by their location in hull. Each burnout test for glass reinforced laminates is to be made on a sample that is at least 25 mm (1 in.) in diameter. A record is to be made of the cured laminate thickness and the glass content by weight. Fiber content measurement for carbon and aramid (kevlar) fiber reinforced laminates are to be carried out by acid tests.

Additionally, a visual inspection of the residue may be required to determine the types and the number of layers of reinforcement used in the laminate.

The cured laminate thickness, in general, is not to differ more than 15% from the thickness indicated on the approved plans.

7 Void Content

Where the extent of voids in the laminate has been deemed suspect by the attending Surveyor, the void content of the laminate is to be tested in accordance with ASTM D2734.

The void content is not to exceed 4%. Where the void content is in excess of 2%, additional testing may be required.

9 Laminate Properties

Determination of laminate properties (specific gravity, glass content, tensile strength and modulus, flexural strength and modulus, shear strength, and, where glass content is 40% or more, interlaminar shear strength) is to be made on the basis of destructive qualification tests of panels assembled by the fabricator under environmental conditions and using resin formulations and process techniques simulating the conditions, formulations, and techniques to be used in actual production.

The fabricator is to lay up the test panels at an angle of about 45°. All panels are to be tested in the as-cured condition. All test results are to be reported. Bureau review of laminate design will be predicated on the quality of laminate produced by the fabricator. Laminate properties derived from qualification testing of sample panels, which are to be witnessed as necessary by the Surveyor are to be included in the process description.

Test panels may be either layed up as a qualification test sample at the time of craft lay-up, or may be taken from hull cut-outs or hull laminate extension tabs.

The tests associated with the laminate properties are shown in 2-6-5/Table 1.

TABLE 1
Tests for Physical Properties of FRP Laminates

<i>Type of Laminate</i>	<i>Properties</i>	<i>Test</i>
Single Skin	Flexural Strength and Modulus	ASTM D790 or D790M or ISO 178
Single Skin	Shear Strength, perpendicular and parallel to Warp	ASTM D732 85
Single Skin and Sandwich	Glass Content and Ply-by-Ply Analysis	ASTM D2584 or ISO 1172
Single Skin and Sandwich – Both Skins	Compressive Strength and Modulus	ASTM D695 or D695M or ISO 604
Single Skin and Sandwich – Both Skins	Tensile Strength and Modulus	ASTM D3039 or D638 or D638M or ISO 3268
Single Skin and Sandwich – Both Skins	Interlaminar Shear Strength	ASTM D3846
Sandwich – Core to Skin Bondline	Flatwise Tensile Test	ASTM C297
Sandwich – Core Material	Shear Strength and Modulus	ASTM C273

11 Test Results

One complete copy of the laboratory test report is to be forwarded promptly to the ABS Technical Office doing hull plan approval. Where test results are less than the laminate design properties, this is to be drawn to the attention of the Technical Office. One copy of all test results is to be filed in the classification survey report or hull certification report.

In the case of advanced composites, one copy of all test results is to be forwarded to the ABS Technical Office plan approval staff.

PART

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CHAPTER

6 Materials for Hull Construction – Fiber Reinforced Plastics (FRP)

SECTION

6 Repair

1 General

This Section specifies the requirements for repairs of defects during construction. These details are also applicable for repair of damaged laminates due to collisions, allisions, or other extreme forces.

All repair work relies on the use of proper secondary bonding technique (see 2-6-3/9.13). Therefore, additional replacement material is required to achieve the original strength of the laminate. Details of the area to be repaired, the materials to be used (resins, reinforcing materials, cores, etc.), and the repair process is to be submitted for review. Damage to the gel-coat and/or skin coat are not part of ABS survey unless they have an adverse effect on the laminate structural layers.

3 Materials

3.1 Resins

In general isophthalic polyester, vinyl ester, or epoxy resins are to be used for all repairs. Special consideration will be given for the use of other resins provided they are used in accordance with the manufacturer's recommendations. In all cases the shipyard is to demonstrate, to the satisfaction of the attending Surveyor, that the resin is capable of bonding to the cured laminate of the craft being repaired.

3.3 Fiber Reinforcements

The original primary fiber reinforcement is to be used in repair whenever practical. Where alternative reinforcements are used, they are to be similar in type and weight to those being replaced. Dissimilar fiber types are not to be used in a repair unless they were part of the original laminate.

5 Repair Procedures – Single Skin Laminate

5.1 Damage Assessment

Damages can be found either by visual inspection, probing, or hammer sounding of the structure. Damage can be found from indicators such as the following:

- i) Cracked or chipped paint or abrasion of the surface
- ii) Distortion of a structure or support member
- iii) Unusual build-up or presence of moisture, oil, or rust
- iv) Structure that appears blistered or bubbled and feels soft to the touch
- v) Surface and penetrating cracks, open fractures, and exposed fibers
- vi) Gouges
- vii) Debonding of joints

For the proper inspection of suspect areas, the removal of insulation, outfitting, or equipment may be required. The extent of damage is to be clearly indicated on the hull and is to be agreed upon by all parties prior to removal.

Where water is found in the laminate or core, the area is to be rinsed by fresh water and be allowed to dry for a minimum of 48 hours. Work is not to be performed on the laminate until the moisture is 0.5% by weight or less.

5.3 Removal of Damaged Laminate

5.3.1 Damage Partially Through the Thickness

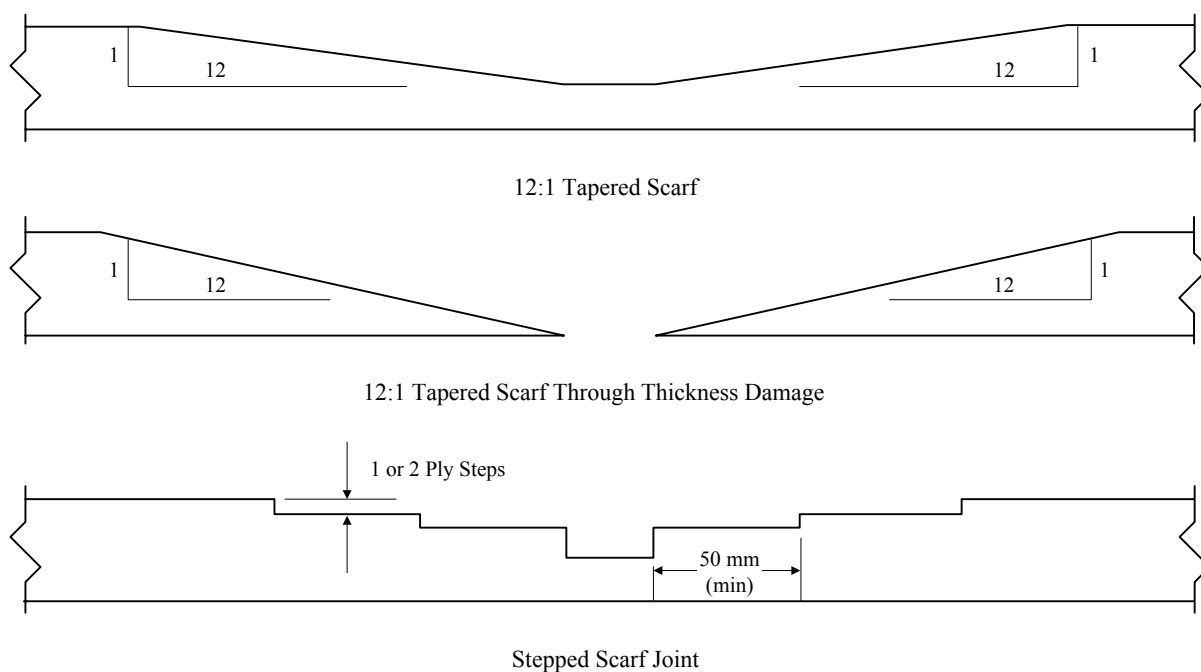
For damage extending partially through the thickness of a laminate, the damaged laminate can be removed using a course grit grinder. The damaged area is then to be shaped for repair using a fine grit grinder. See 2-6-6/Figure 1a or b for preparation details.

5.3.2 Damage Through the Thickness

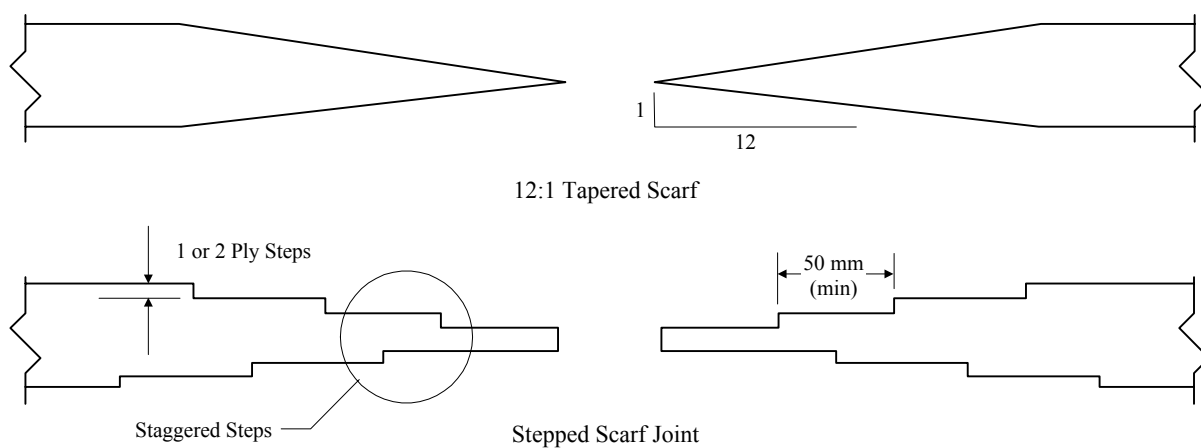
For damage that extend through the thickness of the laminate, the damaged area can be cut away. The laminating surfaces are to be prepared as indicated in 2-6-6/5.3.1 and 2-6-6/Figure 1a or 1b.

FIGURE 1
Scarf Joint Preparation

a) SINGLE-SIDED SCARF



b) DOUBLE-SIDED SCARF



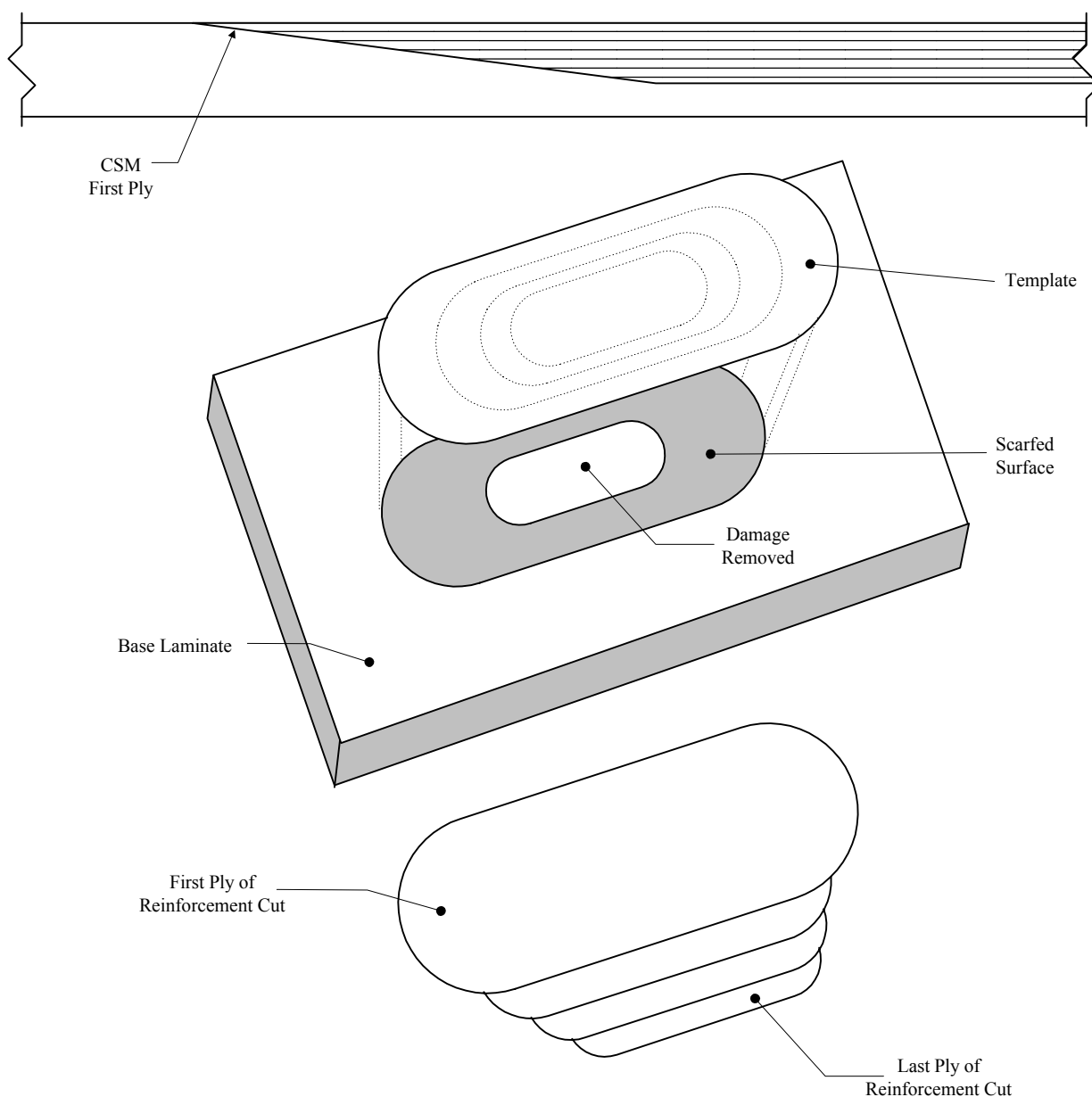
5.5 Laminating Procedures

5.5.1 General

All laminating procedures consist of using secondary bonding and the requirements in 2-6-3/9.13 are applicable. Generally, the lay-up is to have the smallest ply first with each successive ply being larger, as indicated in 2-6-6/Figure 2. Each of the successive plies are to be slightly oversized and trimmed as it is being laminated in place. Care is to be taken in using undersized plies as this may create a resin pocket along the bond line. The fiber orientation is to be maintained during lamination. Alternative methods for laminating will be subject to special consideration.

FIGURE 2
Repair Sequence

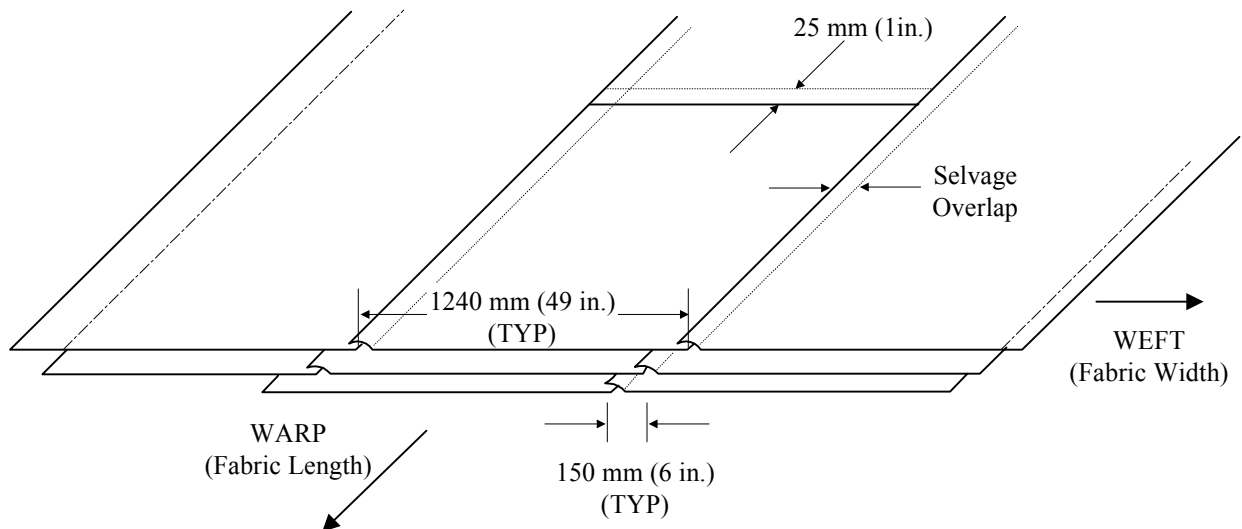
BUTTED LAY-UP



5.5.2 Overlap Requirements

Adjacent plies of reinforcement are to be over-lapped when fitted with a selvage edge. Other reinforcements may be butt jointed. Edge joints in successive layers are to offset 150 mm (6 in.) relative to the underlying ply. Lengthwise joints are also to be staggered 150 mm (6 in.). The ply overlap is to be a minimum of 25 mm (1 in.). See 2-6-6/Figure 3.

FIGURE 3
Ply Overlap Requirements



5.7 Laminating Process

In all cases the first ply applied to the existing surface is to be chopped strand mat. This layer is to cover the entire faying surface and is to be saturated in the laminating resin. The laminating procedures as outlined in 2-6-3/9.7 are to be followed. When lamination is required on an inclined or overhead surface, precautions are to be taken so that the wet reinforcements do not fall. Acceptable laminating repairs can be seen in 2-6-6/Figure 4 through 2-6-6/Figure 11.

FIGURE 4
Partially Through Thickness Defect Repair

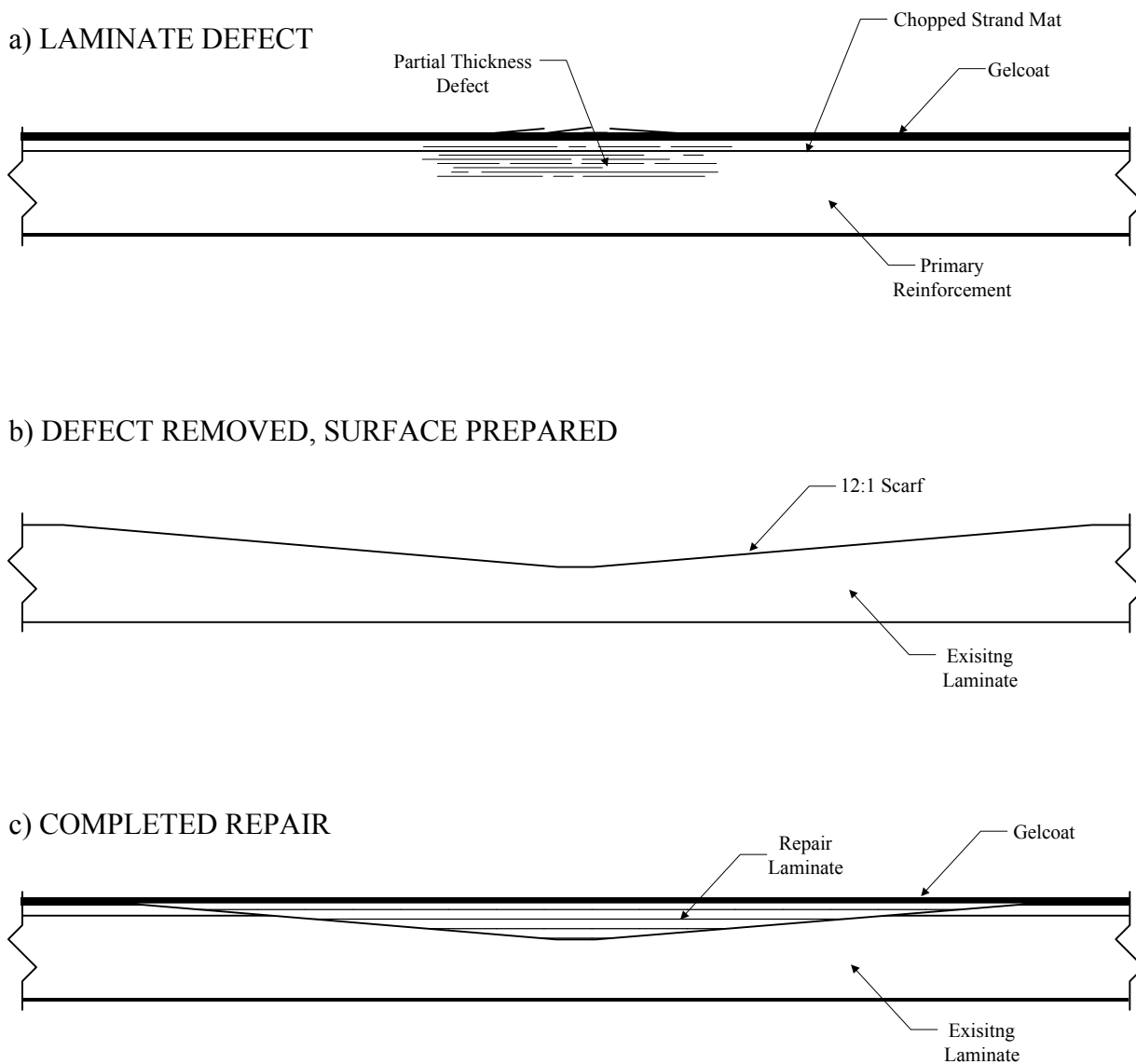
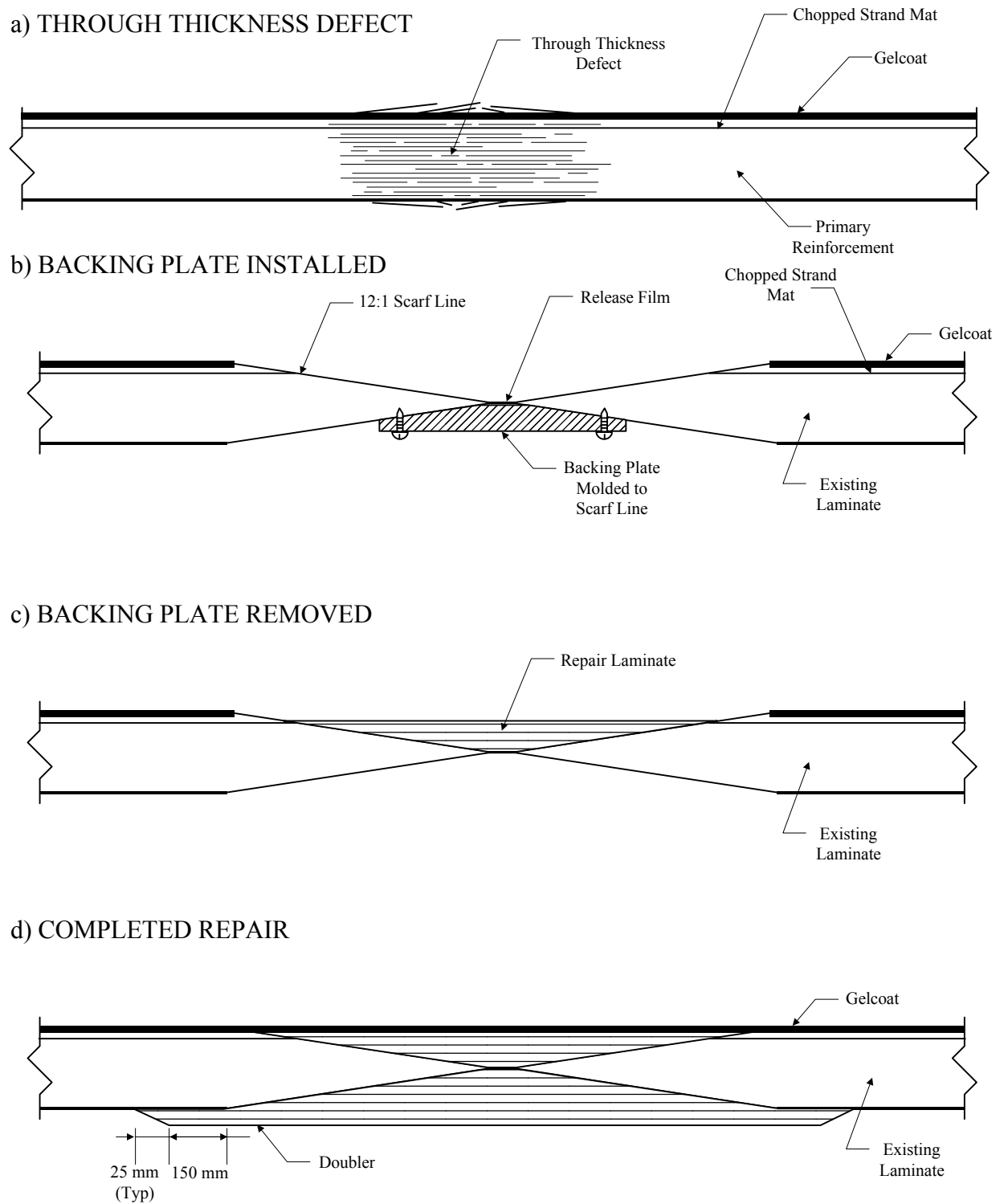
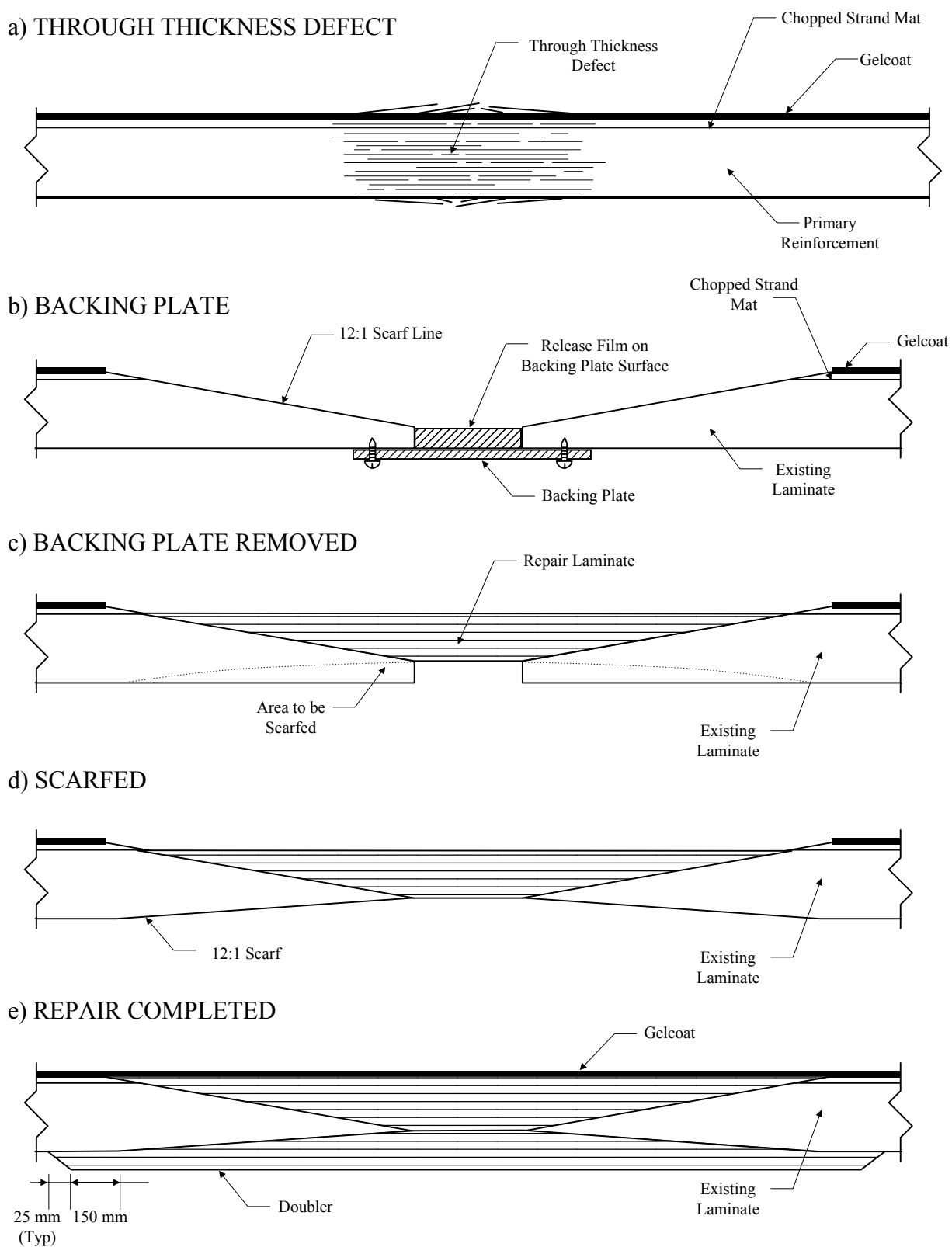


FIGURE 5
Double Sided Scarf Repair



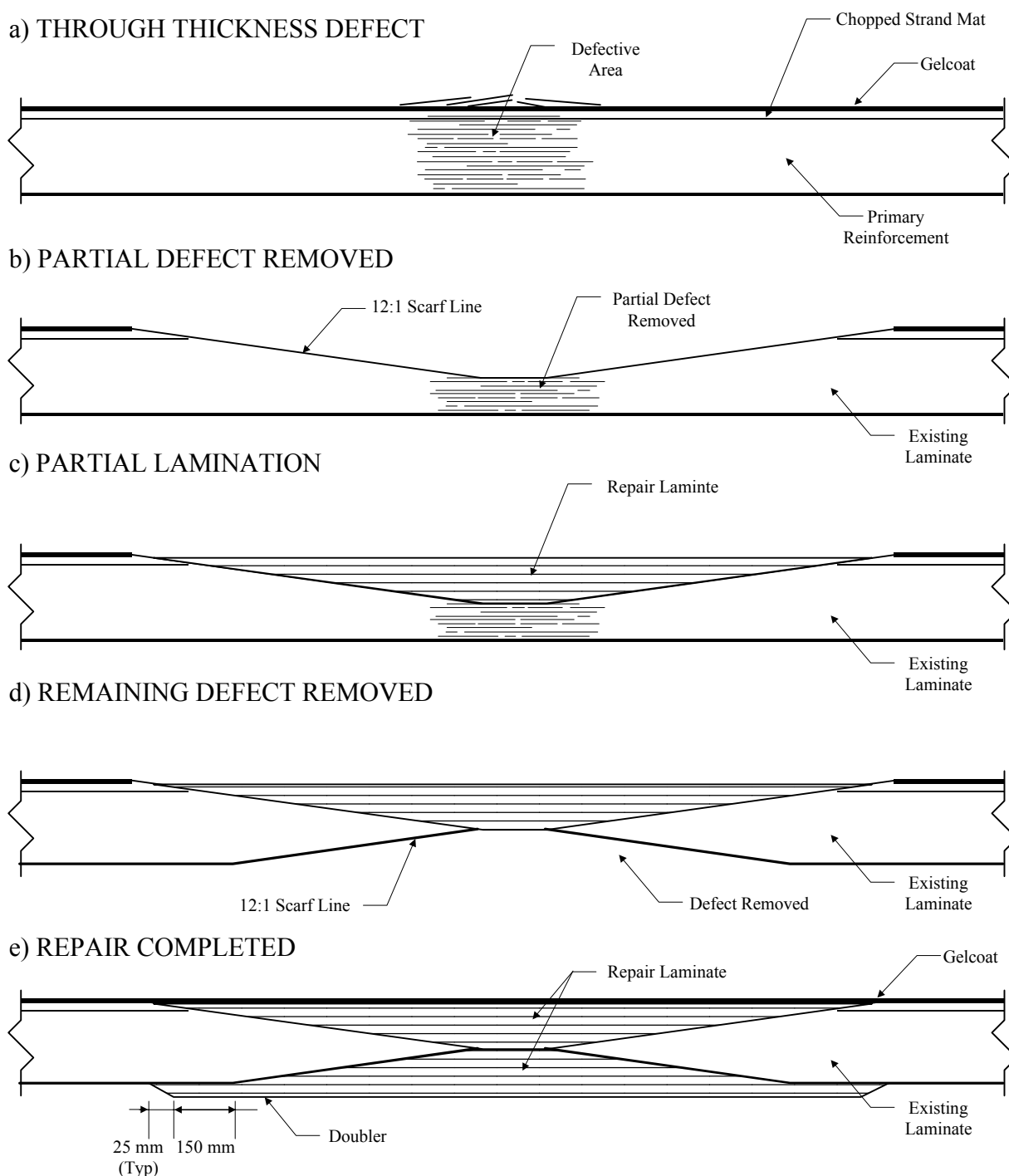
Note: Repair shown with additional plies onto non-molded side.

FIGURE 6
One Sided Scarf Repair – Backing Plate Installation



Note: Repair shown with additional plies onto non-molded side.

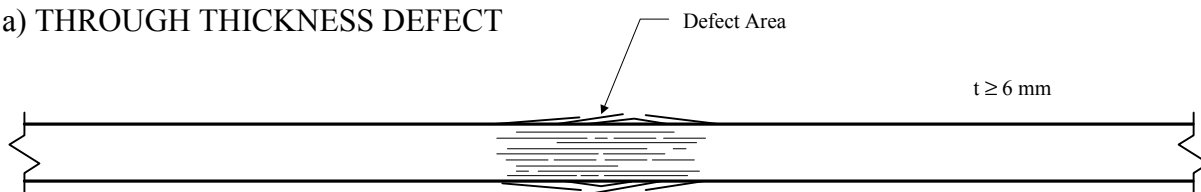
FIGURE 7
Repair Using Defective Section as Backing Plate



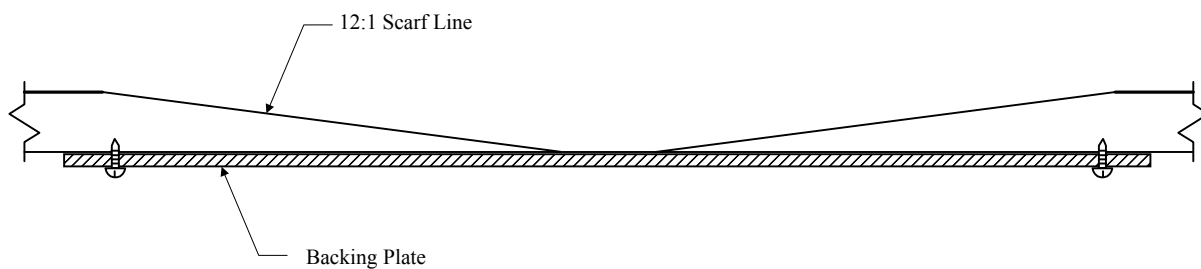
Note: Repair shown with additional plies onto non-molded side.

FIGURE 8
Single Sided Scarf Repair on Thin Laminate

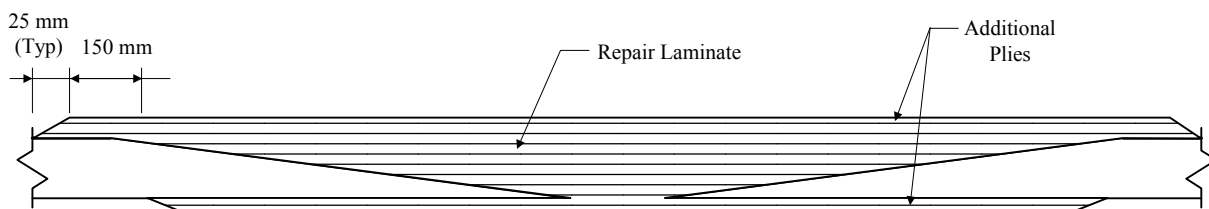
a) THROUGH THICKNESS DEFECT



b) BACKING PLATE INSTALLATION



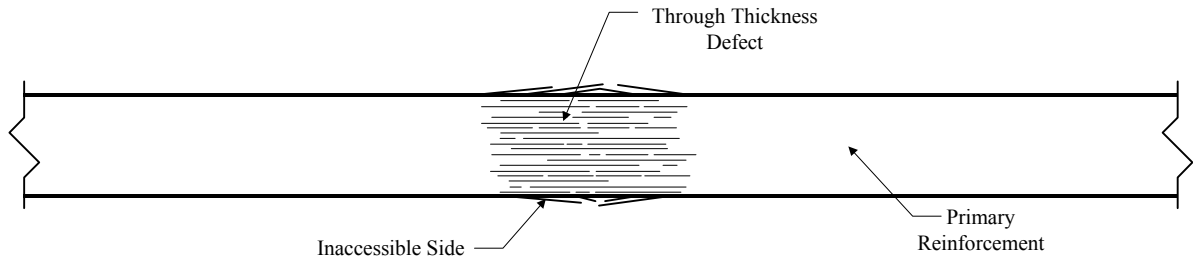
c) COMPLETED REPAIR



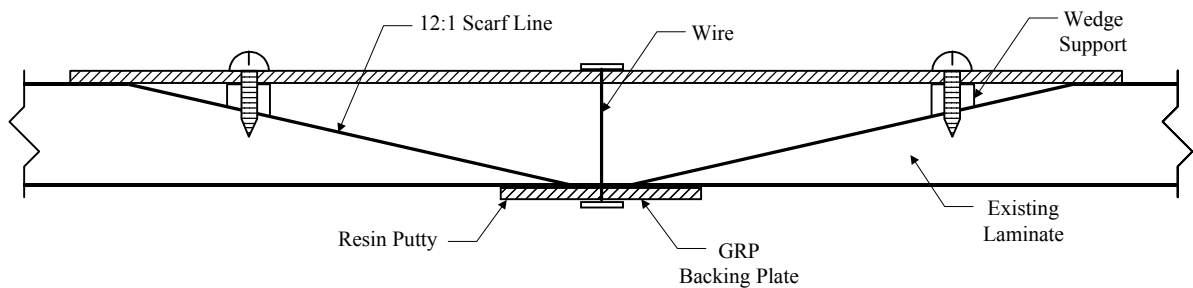
Note: Repair shown with additional plies onto non-molded side.

FIGURE 9
Backing Plate Installation – Access from One Sided Repair

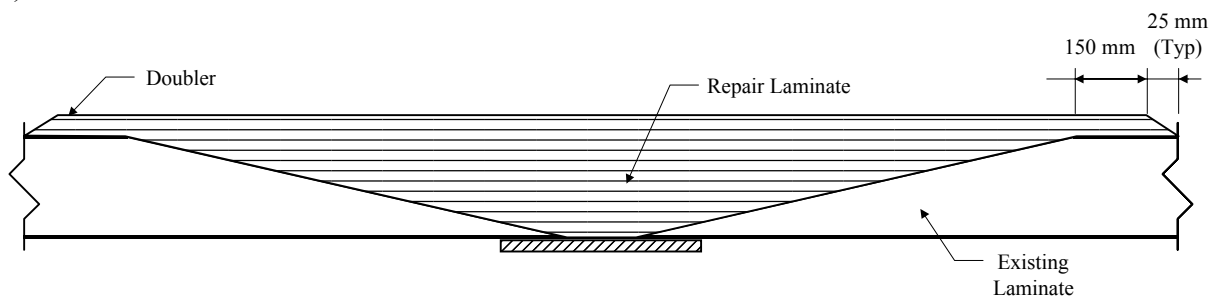
a) DEFECTIVE LAMINATE



b) BACKING PLATE INSTALLATION



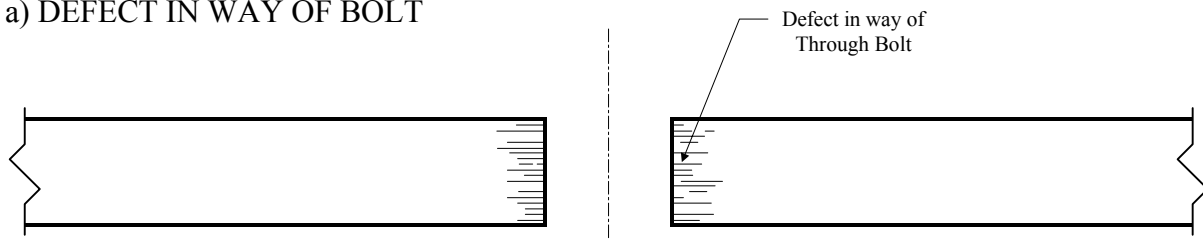
c) COMPLETED REPAIR



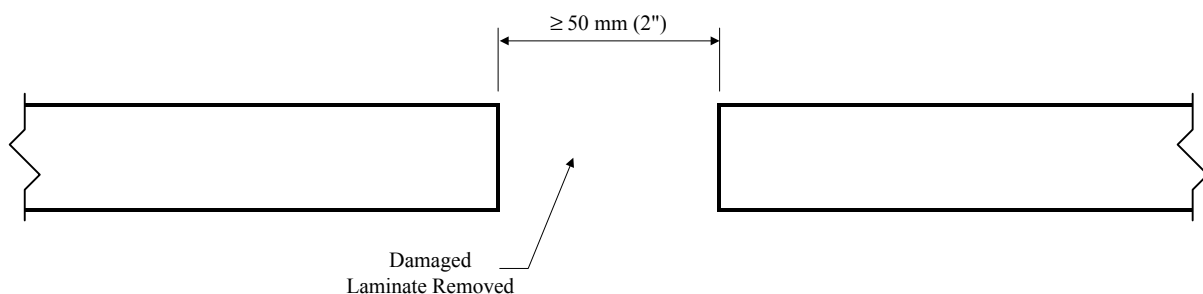
Note: Repair shown with additional plies onto non-molded side.

FIGURE 10
Repair in Way of Through Bolt Failure

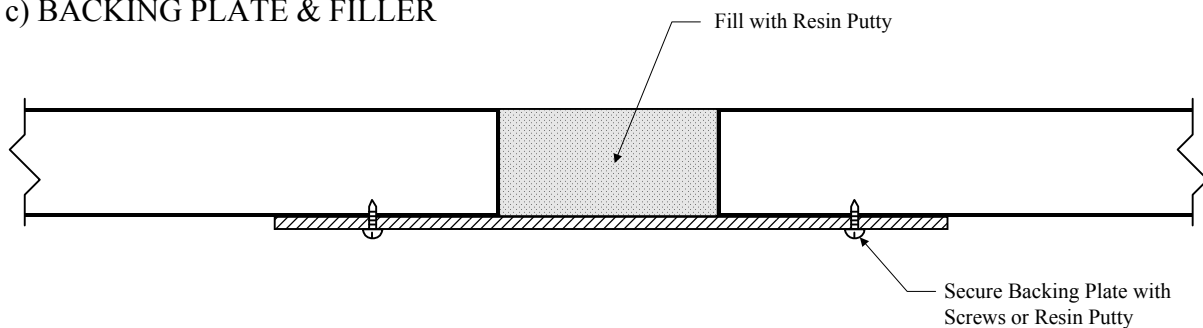
a) DEFECT IN WAY OF BOLT



b) LAMINATE REMOVAL



c) BACKING PLATE & FILLER



d) COMPLETED REPAIR

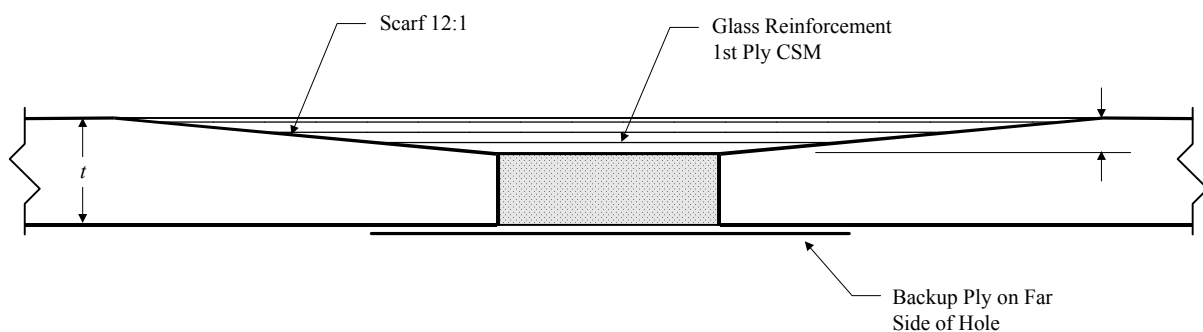
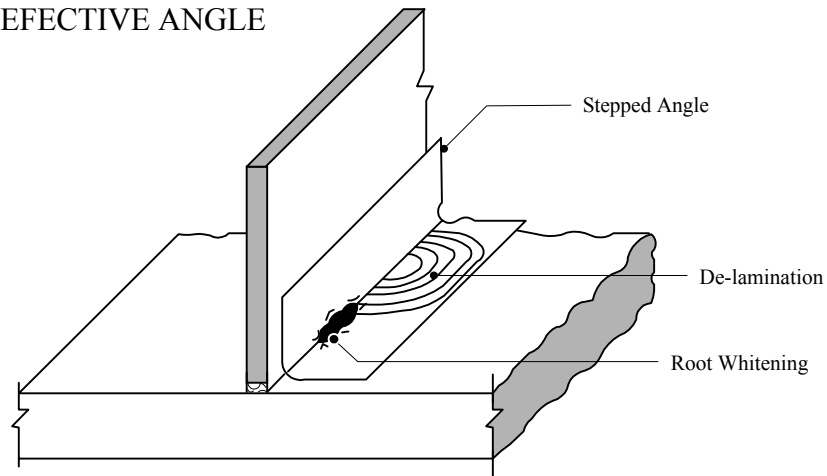
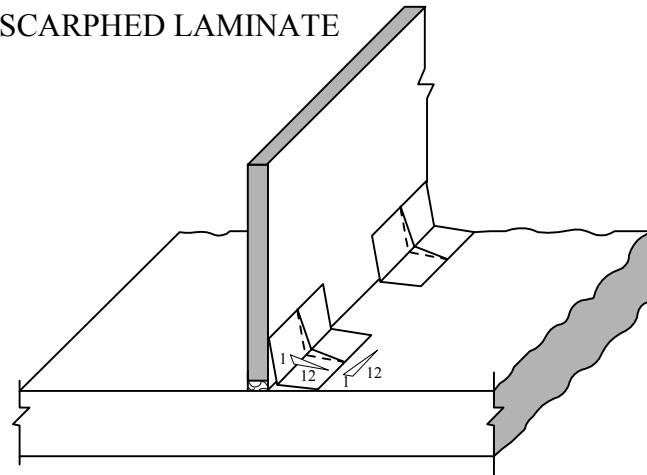


FIGURE 11
Stepped Angle Defect Repair

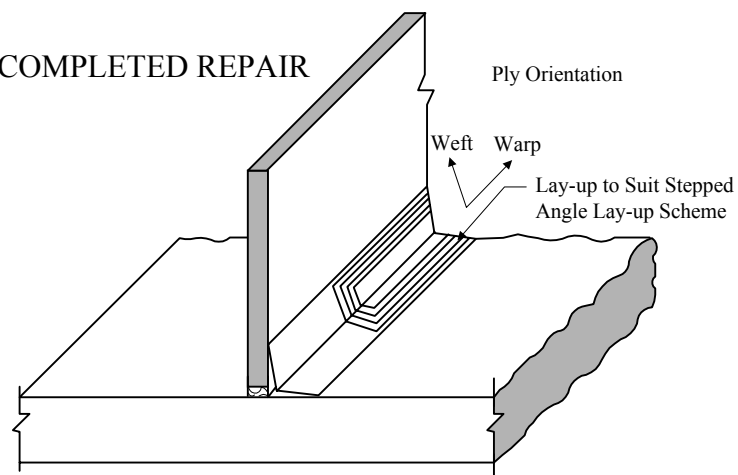
a) DEFECTIVE ANGLE



b) SCARPED LAMINATE



c) COMPLETED REPAIR



7 Repair Procedure – Sandwich Construction

7.1 Damage Assessment

The techniques outlined in 2-6-6/5.1 are to be applied to sandwich laminate. However, the extent of damage may extend far beyond the area of visible damage.

7.3 Removal of Damaged Laminate

The requirements in 2-6-6/5.3 are, in general, applicable to sandwich laminates. The cut back area will be increasingly larger proceeding from the outer skin to the inner skin.

7.5 Laminating Procedure and Process

In general, the skins of a sandwich laminate are to be as indicated in 2-6-6/5.5 and 2-6-6/5.7. The new core is to be similar in type and density to the core that is being replaced. The new core will need to be slightly thinner than the existing core to accommodate the additional repair laminate thickness. The laminating procedure outlined in 2-6-3/9.9 is to be followed.

9 Repair Acceptance

Prior to the acceptance and painting of the repair, the area is to be inspected for the following:

- i)* There are to be no open voids, pits, cracks, crazing, de-laminations, or embedded contaminants in the laminate.
- ii)* There is to be no evidence of resin discoloration or other evidence of extreme exotherm.
- iii)* There is to be no dry reinforcement as indicated by white laminate
- iv)* There are to be no wrinkles in the reinforcement and no voids greater than 12 mm ($\frac{1}{2}$ in)

The surface of the repair is to be smooth and conform to the surrounding surface contour. The degree of cure is to be within 10% of the required BARCOL hardness as indicated in 2-6-5/3.