SECTION 3 WELDING AND OTHER CONNECTIONS MEANS FOR ALUMINIUM ALLOYS

1 General

1.1 Application

1.1.1 The requirements of this Section apply for the preparation, execution and inspection of welded connections or riveting connections in aluminium hull structures of yachts.

They are to be complemented by the criteria given [2]. These criteria being given as recommendations, minor departures may be accepted by the Society, on a case by case basis.

The general requirements relevant to fabrication by welding and qualification of welding procedures are given in the Rule Note NR216 Materials and Welding, Chapter 5.

1.1.2 The requirements of this Section apply also for heterogeneous connection of aluminium alloy members to steel members, by riveting, bi-mettalic transition joints, or other means.

1.1.3 Weld connections are to be executed according to the approved plans. Any detail not specifically represented in the plans is, if any, to comply with the applicable requirements.

1.1.4 It is understood that welding of the various types of aluminium alloys is to be carried out by means of welding procedures approved for the purpose, even though an explicit indication to this effect may not appear on the approved plans.

1.1.5 The quality standard adopted by the shipyard is to be submitted to the Society and applies to all constructions unless otherwise specified on a case by case basis.

1.2 Welding filler products

1.2.1 The choice of welding filler metal is to be made taking into account the welding procedure, the assembly and the grade of aluminium alloy corresponding to the parent metal.

1.2.2 Welding filler products are generally to be approved by the Society.

1.2.3 The filler products used are to be mentioned in the welding booklet or the welding specification of the construction concerned.

2 Welding - type of connections and preparation

2.1 General

2.1.1 The types and dimensions of the welds, their preparation and performing conditions, their field of use are dealt with hereafter.

2.1.2 Other types and dimensions may be considered, subject to the review by the Society.

2.1.3 Assembly conditions, other than those provided for hereafter, are to be agreed upon with the Surveyor.

2.1.4 The method used to prepare the parts to be welded is left to the discretion of each shipbuilder, according to its own technology and experience.

It is reviewed during the qualification of welding procedure as defined in the Rule Note NR 216 Materials and Welding.

2.1.5 The Surveyor is to be provided with the following information:

- location of prefabrication joints welded at workshop
- location of joints carried out on the building slip for assembly of the prefabricated panels
- welding sequences
- sequence of assembly of prefabricated panels
- general information on the welding operations.

2.1.6 The welding procedure, filler products and the design of joints are to be described in a welding booklet.

Moreover, the welding booklet is to indicate, for each type of joint, the preparations and various welding parameters.

The welding booklet is to define, for each type of assembly, the nature and the extent of the inspections proposed and, in particular, of the non-destructive testing (dye-penetrant tests and, if needed, radiographic inspection).

2.1.7 The welding booklet is to be submitted for review by the Society Surveyor.

2.2 Butt weld

2.2.1 As a rule, butt welding is to be used for plate and section butts; it is mandatory for heavily stressed butts such as those of the bottom, keel, side shell, sheerstrake and strength deck plating, and bulkheads (in particular bulkheads located in areas where vibrations occur).

2.2.2 Permissible root gap j is to be defined during qualification tests of welding procedures and indicated in the welding booklet.

2.2.3 In the case of assembly of two plates of different thicknesses, the thickest plate is to be tapered with a maximum slope of 1/4, where:

for $e_1 \leq 10$ mm and $e_2 - e_1 \geq 3$ mm

for $e_1 > 10$ mm and $e_2 - e_1 \geq 4$ mm

where:

e_1 : Thickness of the thinnest plate, in mm

e_2 : Thickness of the thickest plate, in mm.

On the thickest plate, tapering can be carried out on one face or on both faces, as shown in Fig 1 and Fig 2.

2.2.4 In the case of unsupported butt welds, a backweld is recommended for thicknesses greater than or equal to 4 mm.

Figure 1 : Tapering on one face

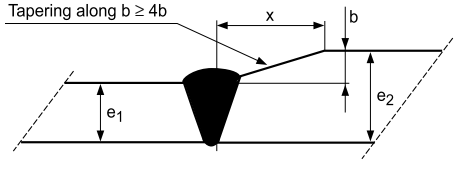
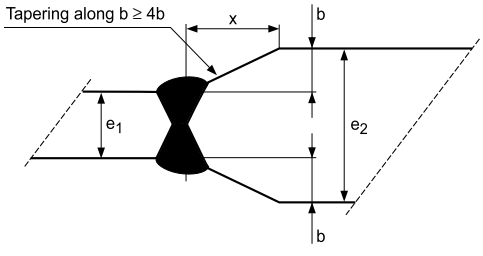


Figure 2 : Tapering on both faces



2.3 Fillet weld in a lap joint

2.3.1 Fillet weld in a lap joint may be used only for members submitted to moderate stresses.

2.3.2 Rule throats of fillet welds are shown in Fig 3 and Fig 4.

The width b, in mm, of overlapping is not to be less than:

$b \geq 1,5 (e_1 + e_2) + 20$

2.3.3 The ends are to be watertight, as far as practicable.

2.3.4 The weld closest to the shoulder may be intermittent except in liquid compartments and exposed areas.

Figure 3 : Fillet weld in lap joint

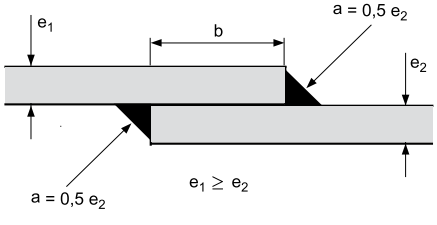
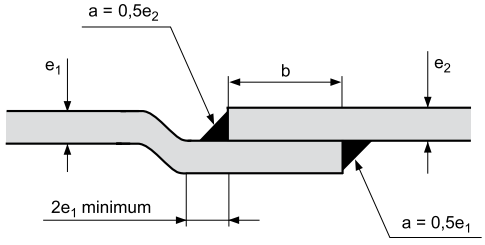


Figure 4 : Fillet weld in joggled lap joint



2.4 Butt welds on permanent backing

2.4.1 Butt weld on permanent backing may be accepted where a backing run is not feasible.

2.4.2 The type of bevel and the root gap between the members to be assembled are to be such as to ensure a proper penetration of the weld on its backing.

2.4.3 The gap, in mm, in the bottom of the groove, as shown in Fig 5, is not to exceed:

- for $e \leq 6$:

  $\alpha = 0^o$

  $j = e$

  $e_1 = e + 1 \leq 6$ mm

- for $6 < e \leq 20$:

  $\alpha = 20^o$

  $j = 6$ mm

  $e_1 = 6$ mm

- for $e > 20$:

  $\alpha = 15^o$

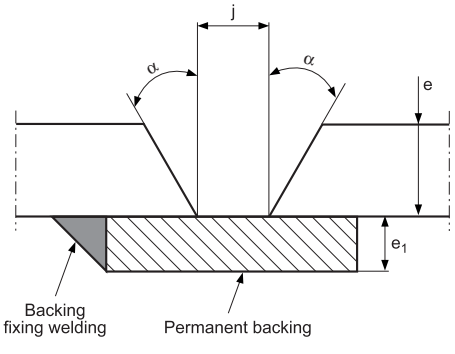
  $j = 10$ mm

  $e_1 = 10$ mm

2.4.4 The scantlings of permanent backing are to be determined in accordance with the importance of the welding of the parts assembled.

2.4.5 For extruded sections with an integrated melting bath for backing, preparation before welding is defined during the qualification of welding procedures.

Figure 5 : Butt weld on permanent backing



2.5 Butt welding on temporary backing

2.5.1 Preparation before welding of the butt welds carried out on temporary backing is to be defined during the qualification of welding procedures.

2.6 Slot welding

2.6.1 Slot welding may be used where fillet welding is not possible.

2.6.2 The shape is shown in Fig 6 and Fig 7, depending on the plate thickness.

2.6.3 Slot welding is not to be completely filled by the weld. As much distance as possible is to be allowed between the two fillet roots.

2.6.4 The distance L_b between extremities of two consecutive slot welds, as shown in Fig 8, is to be such that:

$10\ e \leq L_b \leq 200$

where e is the plate thickness, in mm.

The maximum distance L_b depends on the stresses of the members.

2.6.5 The width of the opening is to be such as to allow easy fillet weld along its perimeter.

2.6.6 Slot welds are to be, as far as practicable, parallel to the direction of main stresses.

Figure 6 : Slot welding for e ≤ 12 mm

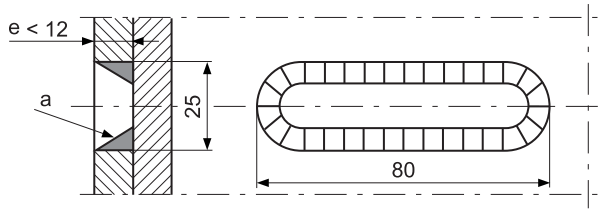


Figure 7 : Slot welding for e > 12 mm

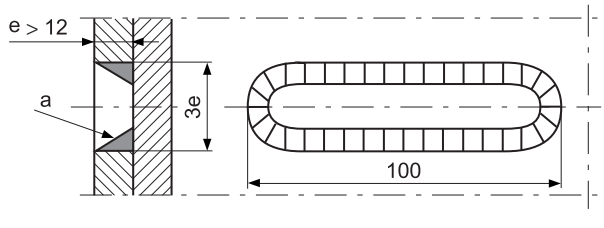


Figure 8 : Distance between slot welds

2.7 Plug welding

2.7.1 Plug weld is to be used exceptionally as a substitute to slot welding.

2.7.2 Plug welding is to be completely filled by the welding.

2.7.3 Weld preparation and execution procedures are to be submitted for the review by the Surveyor.

2.8 Fillet weld

2.8.1 The scantlings of fillet weld assemblies for hull members are given in Tab 1. The scantlings may be increased for particular loading conditions.

Where the members to be assembled have different thicknesses, their connection is to be specially considered by the Society.

The minimum throat thickness t_T of a double continuous fillet weld, in mm, is to be obtained from the following formula:

$t_T = w_F t$

where:

w_F : Welding factor, defined in Tab 1 for the various hull structural connections

t : Actual thickness, in mm, of the thinner plate of the assembly

Throat t_T is not to be greater than 1,5 t.

As a rule, the throat thickness of fillet welds is not to be less than 4 mm.

In the case of automatic welding with deep penetration, or in case of TIG welding, a reduction in the throat may be accepted subject to qualification of the welding procedure.

2.8.2 The clearance j is to be as follows:

$j \leq 1$ mm for $e \leq 8$ mm

$j \leq 2$ mm for $e > 8$ mm

For greater clearances, the throat thickness is to be increased by half the clearance j, as shown in Fig 9.

2.8.3 Where the thickness exceeds 8 mm, a preparation may be recommended, as shown in Fig 10 and Fig 11.

In any case, a blocking device of 3 mm minimum is to be provided.

Figure 9 : Clearance

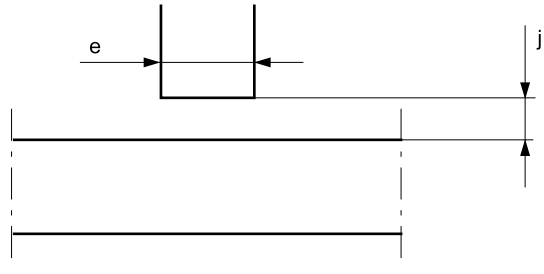


Figure 10 : Clearance and preparation

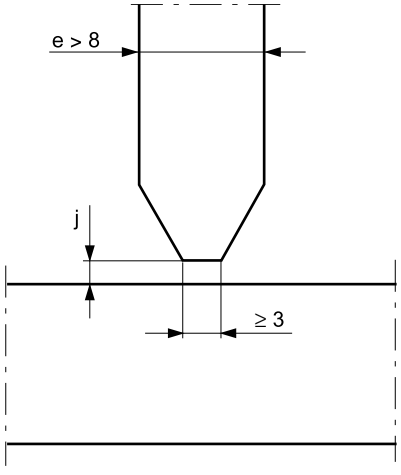


Figure 11 : Clearance and preparation

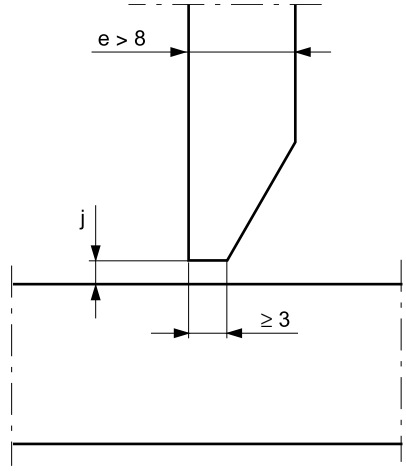


Table 1 : Welding factors w_F for the various hull structural connections

Hull area	Connection			w_F **(1)**
	of	to		
General, unless otherwise specified in the table	watertight plates	boundaries		0,35
	webs of ordinary stiffeners	plating		0,13
Bottom and double bottom	longitudinal ordinary stiffeners	bottom and inner bottom plating		0,13
	centre girder	keel plate		0,25
		inner bottom plating		0,20
	side girders	bottom and inner bottom plating		0,13
		floors (interrupted girders)		0,20
	floors	bottom and inner bottom plating	in general	0,13
			at ends (20% of span) for longitudinally framed double bottom	0,25
		inner bottom plating in way of brackets of primary supporting members		0,25
		girders (interrupted floors)		0,20
	partial side girders	floors		0,25
Side	ordinary stiffeners	side plating		0,13
Deck	ordinary stiffeners	deck plating		0,13
	strength deck	side plating		Partial penetration welding
	non-watertight decks	side plating		0,20
Bulkheads	ordinary stiffeners	bulkhead plating	in general(3)	0,13
			at ends (25% of span), where no end brackets are fitted	0,35
	tank bulkhead structures	tank bottom	plating and ordinary stiffeners (plane bulkheads)	0,45
		boundaries other than tank bottom		0,35
	watertight bulkhead structures	boundaries		0,35
	transverse bulkheads between floats of catamarans	boundaries		0,35

Hull area	Connection			w_F **(1)**
	of	to		
Structures located forward of 0,75 L from the AE	bottom longitudinal ordinary stiffeners	bottom plating		0,20
	floors and girders	bottom and inner bottom plating		0,25
	side frames	side plating		0,20
	side girders	side plating		0,25
After peak	internal structures	each other		0,20
	side ordinary stiffeners	side plating		0,20
	floors	bottom and inner bottom plating		0,20
Machinery space of motor yachts	girders	bottom and inner bottom plating	in way of main engine foundations	0,45
			in way of seating of auxiliary machinery	0,35
			elsewhere	0,20
	floors (except in way of main engine foundations)	bottom and inner bottom plating	in way of seating of auxiliary machinery	0,35
			elsewhere	0,20
	floors in way of main engine foundations	bottom plating		0,35
		foundation plates		0,45
	floors	centre girder	single bottom	0,45
			double bottom	0,25
Superstructures and deckhouses	external bulkheads	deck		0,35
	internal bulkheads	deck		0,13
	ordinary stiffeners	external and internal bulkhead plating		0,13
Pillars	pillars	deck	pillars in compression	0,35
			pillars in tension	Full penetration welding
Ventilators	coamings	deck		0,35
Rudders	horizontal and vertical webs directly connected to solid parts	each other		0,45
	other webs	each other		0,20
	webs	plating	in general	0,20
			top and bottom plates of rudder plating	0,35
		solid parts or rudder stock		According to Ch 10, Sec 2

(1) In connections for which $w_F \geq 0,35$, continuous fillet welding is to be adopted.

(2) Ends of ordinary stiffeners means the area extended 75 mm from the span ends. Where end brackets are fitted, ends means the area extended in way of brackets and at least 50 mm beyond the bracket toes.

(3) In tanks intended for the carriage of ballast or fresh water, continuous welding with $w_F = 0,35$ is to be adopted.

2.8.4 Efficient length, in mm, of the lines of welding is given by:

$d_e = d - 20$

where:

d : Actual length, in mm, of the line of welding.

2.8.5 The throat thickness t_{IT}, in mm, of intermittent welds is to be not less than:

$$t_{IT} = t_T \frac{p}{d_e}$$

without exceeding 1,5 e

where:

t_T : Throat, in mm, of the double continuous fillet weld, obtained from the Tab 1

p : Pitch, in mm, of the fillet welds positioned on the same side, measured as shown from Fig 13 to Fig 15 , according to the types of welds

d_e : Efficient length, in mm, of the fillet welds, defined in [2.8.4].

2.8.6 Staggered welds are to comply with the following requirements:

$d \geq 75$ mm

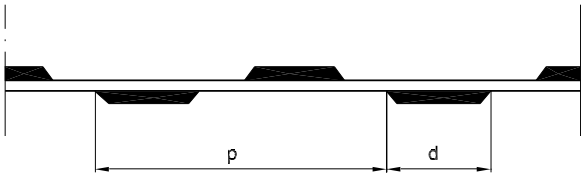
$p \leq 3\ d$

where:

p, d : As shown in Fig 12.

To reduce deformations, it is recommended to choose the values of d according to the thickness.

Figure 12 : Staggered welds



For members subjected to dynamic loads, staggered welds with overlap may be accepted, subject to the following requirements:

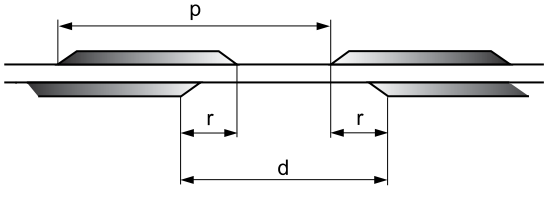
$d \geq 75$ mm

$r \geq 20$ mm

where:

d, r : As shown in Fig 13.

Figure 13 : Staggered weld subjected to dynamic loads



2.8.7 Chain welds are to comply with the following requirements:

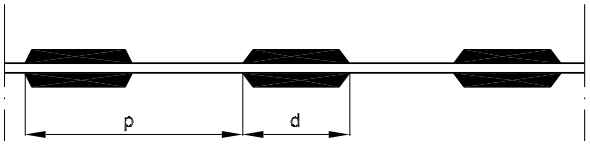
$d \geq 75$ mm

$p - d \leq 200$ mm

where:

p, d : As shown in Fig 14.

Figure 14 : Chain weld



2.8.8 In way of cut-outs for the passage of stiffeners, the throat thickness of the continuous fillet welds located between cut-outs is to not be less than:

$$t_{IT} \geq t_T \frac{p}{d_e}$$

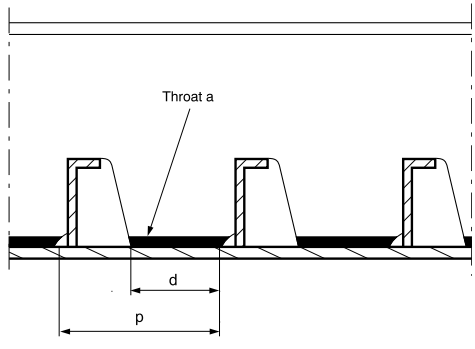
where:

d_e : Efficient length, defined in [2.8.4]

p, d : As shown in Fig 15.

In the case of connections ensuring the continuity of the strength members on each side of a continuous member, the throat thickness is to be determined with respect to the thinnest intermittent member.

Figure 15 : Fillet weld in way of cut-outs



2.8.9 Throat thickness of welds connecting ordinary stiffeners with primary supporting members

The throat thickness of fillet welds connecting ordinary stiffeners and collar plates, if any, to the web of primary supporting members is to be not less than $0{,}35t_W$, where t_W is the web thickness, in mm.

In general, the resistant weld section A_W, in cm^2, connecting the ordinary stiffeners to the web of primary members, is to be not less than:

$$A_W = \varphi \cdot p \cdot s \cdot \ell \cdot \left(1 - \frac{s}{2 \cdot \ell}\right) K \cdot 10^{-3}$$

where:

φ : coefficient as indicated in Tab 2

p : design pressure, in kN/m^2, acting on the secondary stiffeners, as defined in Ch 7, Sec 1 and Ch 7, Sec 2

s : spacing of ordinary stiffeners, in m

ℓ : span of ordinary stiffeners, in m

K : greatest material factor of ordinary stiffener and primary member, as defined in Ch 4, Sec 3, [3].

Table 2 : Coefficient φ

Case	Weld	φ
1	Parallel to the reaction exerted on primary member	200
2	Perpendicular to the reaction exerted on primary member	160

2.9 Particular conditions applying to bilge keels

2.9.1 Connection of the bilge keel to the intermediate flat is to be made by continuous welds, with a throat not less than or equal to the one of the continuous welds connecting the intermediate flat to the bilge.

Butt welds of the shell plating, intermediate flat and bilge keel are to be suitably staggered.

To avoid shell plating being damaged, butt welds of the intermediate flat are to be made on a backing.

Butt welds of the bilge keel are not to extend up to the intermediate flat but are to stop on a scallop. The weld is to be free from defects in way of the scallop and, where necessary, the defects are to be ground.

2.10 Welding - performing conditions

2.10.1 The items to be welded and the filler products are to be stored in a dry room sufficiently aired and free from condensation.

Welding operations in open air are to be avoided. It is recommended to carry out the welding of the greatest number possible of items under shelter.

2.10.2 Arc welding of aluminium alloys is to be carried out under an inert atmosphere, using either a refractory electrode (TIG process), or a consumable electrode (MIG process).

Automatic or semi-automatic weld may be used for prefabricated panels and on building slip for the connection of blocks.

2.10.3 The metal is to be properly degreased prior to welding, by means of a solvent which is inert for the metal and legally acceptable.

Before welding, a mechanical cleaning of the edges to be welded is also to be carried out, by means of brushing (stainless steel brush) or scraping. Chemical pickling may also be used.

2.10.4 Preparation of edges and adjusting are to comply with the tolerances indicated in the welding booklet.

2.10.5 If sections are butt welded, the weld is to extend over the full section.

Chamfers may be needed, in particular for bulb sections. If both sections have different heights, the strength continuity is to be restored.

2.10.6 It is recommended to start and end welded joints on appendices tack welded onto the ends. Restarting a discontinued weld, the end of the joint is to be carefully ground.

Overlapping of lines of welding over some 20 mm is necessary.

2.10.7 Whenever the thickness allows it, i.e. for thicknesses exceeding or equal to 4 mm, butt weld of hull plating or resistant members is to be carried out in two opposed runs minimum, in order to eliminate transverse flaws.

2.10.8 For welding of thicknesses greater than 8 mm, an efficient heating of plates to be connected is to be carried out, in order to prevent risks of condensation (pre-heating at about 70°C).

2.10.9 The provisions taken for the layout of joints, the adjustment of elements, the nature and execution order of welds, are to be such that they minimize the deformations.

3 Workmanship

3.1 Welding procedures and consumables

3.1.1 The various welding procedures and consumables are to be used within the limits of their approval and in accordance with the conditions of use specified in the respective approval documents.

3.2 Welding operations

3.2.1 Weather protection

Adequate protection from the weather is to be provided to parts being welded; in any event, such parts are to be dry.

In welding procedures using bare, cored or coated wires with gas shielding, the welding is to be carried out in weather protected conditions, so as to ensure that the gas outflow from the nozzle is not disturbed by winds and draughts.

3.2.2 Butt connection edge preparation

The edge preparation is to be of the required geometry and correctly performed. In particular, if edge preparation is carried out by flame, it is to be free from cracks or other detrimental notches.

3.2.3 Surface condition

The surfaces to be welded are to be free from moisture and other substances, such as mill scale, slag caused by oxygen cutting, grease or paint, which may produce defects in the welds.

Effective means of cleaning are to be adopted particularly in connections with special welding procedures; flame or mechanical cleaning may be required.

The presence of a shop primer may be accepted, provided it has been approved by the Society.

Shop primers are to be approved by the Society for a specific type and thickness according to the Rule Note NR216 Materials and Welding, Ch 5, Sec 3.

3.2.4 Assembling and gap

The setting appliances and system to be used for positioning are to ensure adequate tightening adjustment and an appropriate gap of the parts to be welded, while allowing maximum freedom for shrinkage to prevent cracks or other defects due to excessive restraint.

The gap between the edges is to comply with the required tolerances or, when not specified, it is to be in accordance with normal good practice.

3.2.5 Plate misalignment in butt connections

Misalignment d before butt welding of plates of the same thickness is not to exceed:

for e ≤ 10 mm: d ≤ 1 mm

for 10 mm < e ≤ 20 mm: d ≤ 2 mm

for e > 20 mm: d ≤ 3 mm.

3.2.6 Misalignment in cruciform connections

In the case of cruciform joint as shown in Fig 16, misalignment d is not to be greater than:

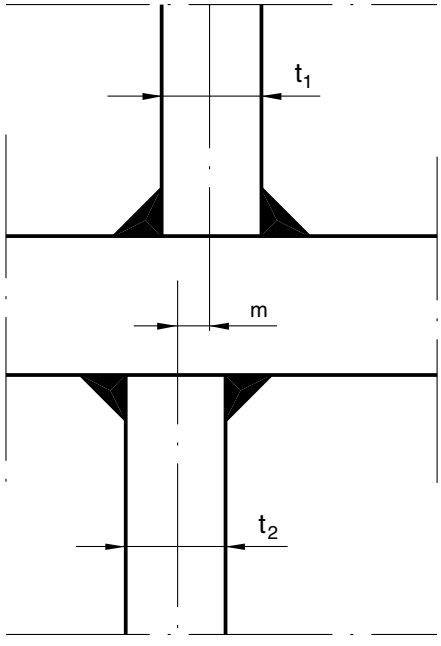
$d \leq e / 2$

where:

e : Thickness of the thickest plate (e_1 or e_2).

Misalignment d may be limited even more in the case of highly stressed cruciform joints.

Figure 16 : Cruciform connection



3.2.7 Welding sequences

Welding sequences and direction of welding are to be determined so as to minimise deformations and prevent defects in the welded connection.

All main connections are generally to be completed before the ship is afloat.

Departures from the above provision may be accepted by the Society on a case by case basis, taking into account any detailed information on the size and position of welds and the stresses of the zones concerned, both during ship launching and with the ship afloat.

3.2.8 Interpass cleaning

After each run, the slag is to be removed by means of a metal brush and the grease is to be removed by appropriate cleaning ; the same precaution is to be taken when an interrupted weld is resumed or two welds are to be connected.

4 Riveting

4.1 General

4.1.1 This sub-article defines the conditions of riveting of hulls and structures made of aluminium alloy.

4.2 Choice of rivets

4.2.1 For the riveting of series 5000 Aluminium-Magnesium alloys, the grade of the rivet is to have magnesium content not exceeding 3,5%.

4.3 Shape of aluminium-alloy rivets

4.3.1 Diameters of rivets, diameters of hole perforations, manufacturing tolerances and shape of the heads are given in Tab 2 and Tab 3 and in Fig 17 and Fig 18. The diameters of rivets are given versus the thickness of the thinner member.

4.3.2 Slight departure from the above dimensions may be accepted, to the satisfaction of the Surveyor.

Figure 17 : Manufactured heads

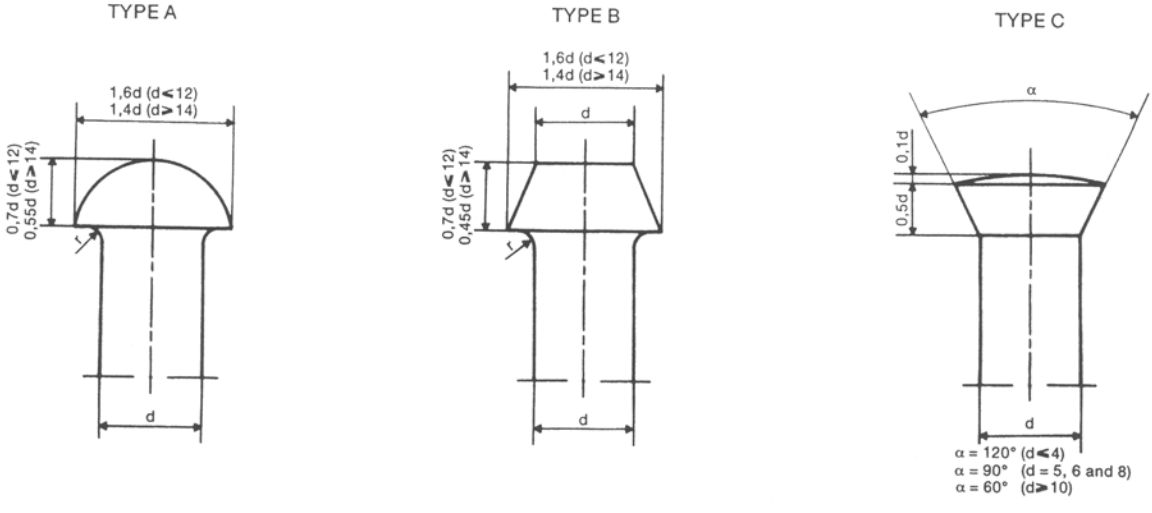


Figure 18 : Riveted heads

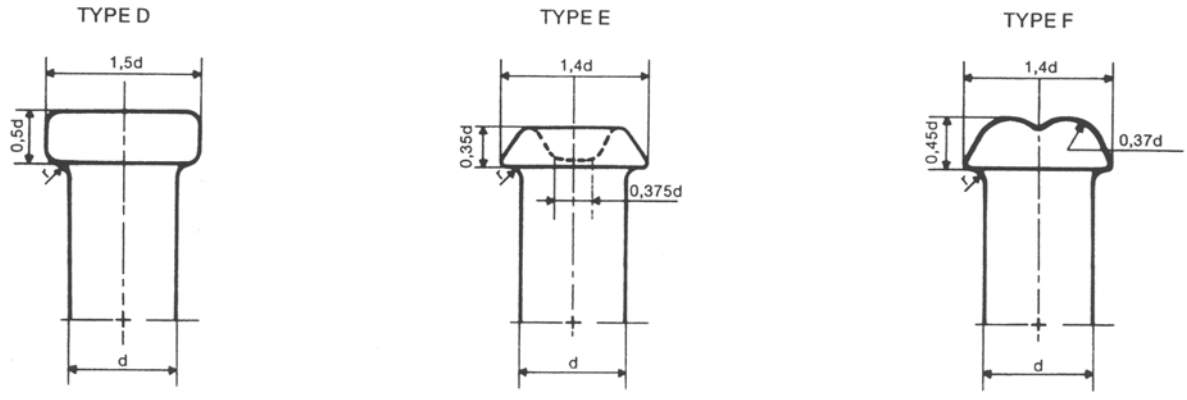


Table 3 : Rivets in aluminium alloy

Diameter of the rivets, in mm			Reaming of rivet holes, in mm		Thickness of plates and sections, in mm
nominal	minimum	maximum	minimum	maximum	
4	3,9	4,0	4,1	4,2	1,5 à 2
5	4,9	5,0	5,1	5,2	2 à 2,5
6	5,9	6,0	6,1	6,2	2,5 à 3
8	7,8	8,0	8,1	8,2	3 à 4
10	9,8	10,0	10,1	10,2	4 à 6
12	11,8	12,0	12,1	12,2	5 à 8
14	13,8	14,0	14,1	14,2	6 à 10
16	15,8	16,0	16,1	16,2	7 à 12
18	17,8	18,0	18,1	18,2	9 à 14
20	19,8	20,0	20,2	20,3	10 à 15
22	21,8	22,0	22,2	22,3	11 à 16
24	23,8	24,0	24,2	24,3	12 à 17
(1) Maximal diameter of rivet recommended for cold use.					

Table 4 : Rivets in aluminium alloy

Diameter d (in mm)	4 and 5	6	8 and 10	12	14	16 and over
Value of r (in mm)	0,2	0,3	0,4	0,5	0,6	0,05 d
Note 1: A manufactured head may be associated with different types of riveted heads. Type C rivets of diameter 10 mm or more may have flat points.						

4.3.3 For riveting of massive parts and accessories, the hole diameter may be increased by 2 mm.

4.4 Execution of riveting

4.4.1 The rivet holes are to be spaced regularly with a very low tolerance (0,1 to 0,2 mm). Holes are to be drilled.

4.4.2 The number of rows of rivets and the pitch depend on the relative strength required for the joint.

Pitch E is to be at least 2,5 d and at the most 6 d.

For riveting with several rows, the row spacing is to be, as a rule, equal to E for chain-riveting and to 0,75 E for staggered riveting.

4.4.3 Cold-riveting may be performed with well annealed rivets up to 14 mm in diameter for grade 5052 rivets. For larger diameters, hot-riveting is to be used (at $400^{o}C \pm 25^{o}C$). In some special cases, large diameter AlSiMg rivets may be used directly after hardening.

The holding dolly is to be heavier than that used for a steel rivet of the same diameter.

4.4.4 Any jointing system other than classical riveting (high performance fixation, etc.) is to be specially considered.

5 Heterogeneous assembly steel / aluminium alloy

5.1 General

5.1.1 This sub-article defines the conditions for heterogeneous assembly for hulls and structures made of aluminium alloys and steel.

5.2 Riveting of members in aluminium alloy onto steel members

5.2.1 Correct insulation between steel and aluminium is to be ensured by means of joints, washers and plastic or rubber tubes, or any other equivalent solution.

5.2.2 As far as practicable, the rivet is to be of the same composition as the aluminium alloy used for the structure.

5.2.3 Requirements of [4.2] apply. Diameters of rivets are given in Tab 3 according to the thickness of the member in aluminium alloy.

5.2.4 Requirements of [4.3] apply otherwise.

5.3 Jointing systems other than classical riveting

5.3.1 Any jointing system other than classical riveting (high performance fixation, etc.) may be used with the Society's agreement.

5.4 Transition joints by Aluminium/Steel cladded plates

5.4.1 The use of transition joints made of Aluminium/Steel cladded plates or profiles may be considered with the Society's agreement.

5.4.2 Transition joints are to be type-approved.

5.4.3 Qualification tests for welding procedures are to be carried out for each joint configuration.

5.4.4 A welding booklet giving, for each type of assembly, the preparations and various welding parameters is to be submitted for review.