

## 12 ALUMINIUM CONNECTIONS

In the past decades, a large number of studies have been carried out to enlarge our knowledge on the behaviour of aluminium structures. One of the main research areas was on connections between aluminium structural members (bolted, welded and adhesive bonded connections) [Bulson, 1992]. All the results of these research efforts have been incorporated into Eurocode 9 [ENV 1999-1-1, 1999], which includes specifications and rules for the design of aluminium structures. In the design of mechanical fasteners the limited ductility of basic material needs to be taken into account. For friction grip bolted joints the transfer of forces is affected by the relaxation of the aluminium. Bolts of austenitic steel are used to avoid the risks of corrosion.

As far as the welding of aluminium structural members is concerned, welded connections have been widely established and developed and is an important joining method [Dwight, 1999]. The welds do not limit ductility of the connection, this being a great advantage compared to bolted and riveted connections [Mazzolani, 1995]. The design of welded connections is based on a method and assumptions similar to the ones used for steel structures with necessary modifications. The instructions for welding provided in Eurocode 9 [ENV 1999-1-1, 1999] can be used when the following requirements are satisfied:

- The structures are loaded with predominantly static loads,
- The welding process MIG (Metal Inert Gas) can be used for all thickness, while TIG (Tungsten Inert Gas) is being used only for material thickness up to  $t = 6 \text{ mm}$  and for repair, and
- The welding consumables should correspond to the aluminium alloy of the connecting members. The choice of filler metal has a significant influence on the strength of the weld metal, being usually lower strength than the strength of the basic material, see Table 12.1.

Table 12.1 Characteristic strength values of the weld metal  $f_w$  [MPa]

Filler metal	Alloy							
	3103	5052	5083	5454	6060	6061	6082	7020
5356	-	170	240	220	160	190	210	260
4043A	95	-	-	-	150	170	190	210

According to Chapter 6.6.1, a higher partial safety factor of  $\gamma_M = 1,65$  (instead  $\gamma_M = 1,25$ ) should be used, if a lower quality level of welding has been specified by the designer for partial or non-strength members. Special care must be taken where aluminium structural connections are subjected to frequently fluctuating service loads leading to fracture due to fatigue. The basis for the design of such aluminium connections with respect to the limit state of fatigue induced fracture is presented in the ENV 1999-2.

### Q&A 12.1 Resistance of Fillet Welds

In the calculation of a fillet weld, what stresses need to be checked so that the demands of Eurocode 9 are satisfied?

The approach that has to be followed is similar to the one presented in Chapter 3. The stresses in a fillet weld, see Figure 12.1, can be decomposed into stress components in the most critical section at the weld throat.

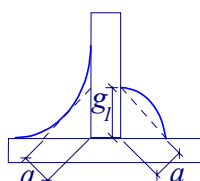


Figure 12.1 Thickness of the fillet weld throat, effective thickness

The stress components are the following, see Figure 12.12:

- $\sigma_{\perp}$  the normal stress perpendicular to the critical plane of the throat,
- $\sigma_{//}$  the normal stress parallel to the axis of the weld, it should be neglected for design resistance of the fillet weld,
- $\tau_{\perp}$  the shear stress (in the critical plane of the throat) perpendicular to the weld axis,
- $\tau_{//}$  the shear stress (in the critical plane of the throat) parallel to the weld axis.

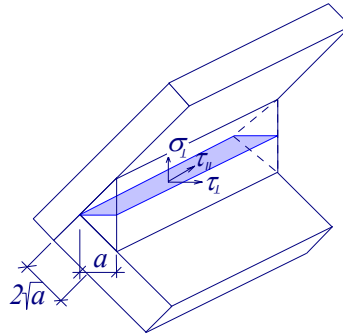


Figure 12.2 Stress components in a fillet weld

The resistance of the fillet weld is sufficient if both the following conditions are satisfied:

$$\sqrt{\sigma_{\perp}^2 + 3(\tau_{\perp} + \tau_{//})^2} \leq \frac{f_w}{\gamma_{Mw}} \quad (12.1)$$

and

$$\sigma_{\perp} \leq \frac{f_w}{\gamma_{Mw}} \quad (12.2)$$

### Q&A 12.2 Effective Width and Throat Thickness of Fillet Welds

What are the geometrical restrictions, concerning effective width and the throat thickness, when using fillet welding?

The effective width of the fillet weld should be at least eight times the throat thickness  $a$ . The maximum length is limited by  $100 a$ . When the length is larger, effective length of the weld  $L_{w,eff}$  is used instead, which can be calculated as

$$L_{w,eff} = \left( 1,2 - 0,2 \frac{L_w}{100 a} \right) L_w \quad (12.3)$$

This reduction is used only in cases when stress in the welds of overlapping connection is not uniformly distributed, but reaches higher values at its ends, see Figure 12.3a. Uniform stress distribution can be achieved by proper shape of the connected parts, see Figure 12.3b.



a) non-uniform stress distribution      b) modification for uniform stress distribution

Figure 12.3 Stress distribution in welded overlapping joints with fillet welds

Throat thicknesses of double sided fillet weld loaded perpendicularly to the weld axis, see Figure 12.4, should satisfy the following condition

$$a > 0,7 \frac{t \sigma \gamma_{Mw}}{f_w}, \quad (12.4)$$

where

$$\sigma = \frac{F_{Sd}}{t L} \quad (12.5)$$

and  $F_{Sd}$  is applied force,  $t$  thickness of the connected element and  $L_w$  length of the weld.

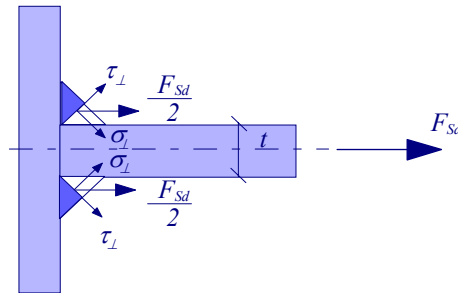


Figure 12.4 Double fillet welded joint loaded perpendicularly to the weld axis

Throat thickness of the weld loaded parallel to the axis, see Figure 12.5, should be bigger than

$$a > 0,85 \frac{t \tau \gamma_{Mw}}{f_w}, \quad (12.6)$$

where

$$\tau = \frac{F_{Sd}}{t L_w}. \quad (12.7)$$

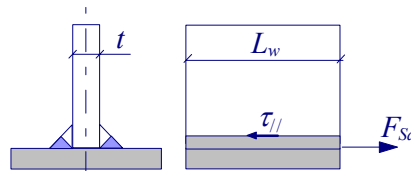


Figure 12.5 Double fillet welded joint loaded parallel to the weld axis

### Q&A 12.3 Butt welds in aluminium joints

What information does Eurocode 9 provide with respect to the characteristics of partially penetrated butt welds between the aluminium elements?

When butt welds are used for connecting aluminium elements, full penetration butt welds should be used. Partial penetration butt welds should be used only in cases, when verified by testing that no serious weld defects are apparent. In other cases partial penetration butt welds shall be only applied with a higher partial safety factor  $\gamma_M$  because of the high susceptibility for weld defects.

The effective thickness of full penetration butt weld is taken as the thickness of the connected elements. When elements with different thickness are welded, the smaller shall be taken into account as weld thickness. For partial penetration butt welds an effective throat thickness should be applied, see Figure 12.6. The effective length should be taken as the total length of the weld when run-on and run-off plates are used. Otherwise the total length should be reduced by twice the thickness  $a$ .



Figure 12.6 Effective throat thickness of partial penetration butt weld

The stresses in butt welds should satisfy the following criteria:

The normal stress, tension or compression, perpendicular to the weld axis

$$\sigma_{\perp} \leq \frac{f_w}{\gamma_{Mw}}, \quad (12.8)$$

shear stress parallel to the weld axis

$$\tau \leq 0,6 \frac{f_w}{\gamma_{Mw}}, \quad (12.9)$$

and combination of normal and shear stresses

$$\sqrt{\sigma_{\perp}^2 + 3 \tau^2} \leq \frac{f_w}{\gamma_{Mw}}. \quad (12.10)$$

Table 12.2 Values of HAZ softening factor  $\rho_{haz}$

Alloy series	Condition	$\rho_{haz}$ (MIG welding)	$\rho_{haz}$ (TIG welding)	Note
Extrusions, sheets, plates, drawn tubes and forgings				
Any	O F	1,00	1,00	
6xxx	T4	1,00	-	
	T5	0,65	0,60	
	T6	0,65	0,50	
7xxx	T6	0,80	0,60	applied when tensile stress acts transversely to the axis of butt or fillet
		1,00	0,80	applied for all other conditions
Sheets, plates, and forgings				
5xxx	H22	0,86	0,86	
	H24	0,80	0,80	
3xxx	H14 H16 H18	0,60	0,60	
1xxx	H14	0,60	0,60	

### Q&A 12.4 Heat Affected Zones

How does the development of high temperatures in the vicinity adjacent to the welds affect the design of aluminium welded connections?

Structural aluminium is weakened in the heat affected zones (HAZs) adjacent to welds. The affected region extends immediately around the weld, beyond which the strength properties rapidly recover their full values. Eurocode 9 Clause 6.6.2 deals specifically with heat-affected zones (HAZ), which need to be taken into account for the following classes of alloys:

- Heat-treatable alloys in any heat-treated condition above T4 (6xxx and 7xxx series)
- Non-heat-treatable alloys in any work-hardened condition (3xxx and 5xxx series)

In alloys in O or T4-condition, or when material is in the F-condition and design strength is based on O-condition properties, there is no weakening in the vicinity of welds [Dwight, 1999]. Here the

severity and extent of HAZ are different for TIG and MIG welding. For TIG welding, a larger HAZ area and more severe softening due to higher heat-input is considered [Mazzolani, 1985].

The two main aspects of HAZ softening are its severity and its extent. The characteristic strengths  $f_o, f_a, f_v$  in the HAZ are calculated in a way determined in the Eurocode 9 for the parent metal and reducing them by softening factor  $\rho_{haz}$ . The other method is reducing the area over which the stress acts, see Figure 12.7. Thus the design resistance of a simple rectangular section affected by HAZ softening can be expressed as

$$F_{Rd} = \frac{A(f_a \rho_{haz})}{\gamma_{Mw}} = \frac{A f_{a,haz}}{\gamma_{Mw}}, \quad (12.11a)$$

or

$$F_{Rd} = \frac{(\rho_{haz} A) f_a}{\gamma_{Mw}}. \quad (12.11b)$$

The values of  $\rho_{haz}$  are provided in Table 12.2.

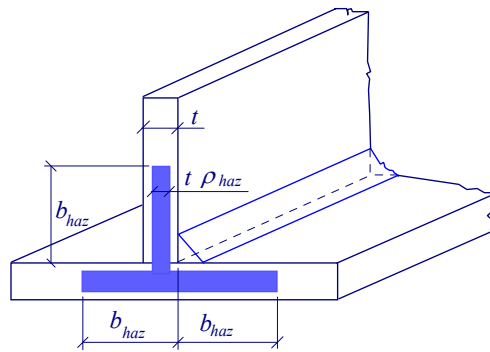


Figure 12.7 Heat affected zones at fillet weld

These values are valid from the following time after welding, providing the material has been held at a temperature not less than 10°C:

- 6xxx series alloys- 3 days,
- 7xxx series alloys- 30 days.

Table 12.3 Extent of HAZ for MIG and TIG welding

Thickness $t$	$b_{haz}$ (MIG welding)	$b_{haz}$ (TIG welding)
$0 < t \leq 6 \text{ mm}$	20 mm	30 mm
$6 < t \leq 12 \text{ mm}$	30 mm	-
$12 < t \leq 25 \text{ mm}$	35 mm	-
$t > 25 \text{ mm}$	40 mm	-

If the material is held at a temperature lower than 10°C after welding, the recovery time will be prolonged. Advice should be sought from the manufacturer. The heat affected zone is assumed to extend over a distance  $b_{haz}$  in any direction from the weld, see Figure 12.8 and Table 12.3. If the distance from the weld to the edge of the element is smaller than three times  $b_{haz}$ , then the HAZ extends to the full width of the element. The measurement of  $b_{haz}$  is taken as follows:

- transversely from the centre line of an in-line fillet weld,
- transversely from the point of intersection of the welded surfaces at fillet welds,
- transversely from the point of intersection of the welded surfaces at butt welds used in corner, tee or cruciform joints,
- in any radial direction from the end of the weld.

The HAZ boundaries should generally be taken as straight lines normal to the metal surface, particularly when welding thin materials. However, when surface welding is applied to thick material it is permissible to assume a curved boundary of radius  $b_{haz}$ .

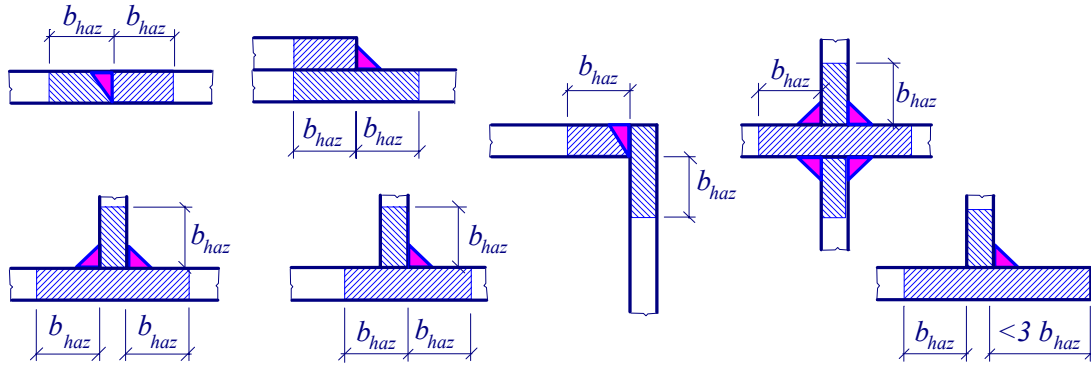


Figure 12.8 Heat affected zones at fillet weld

Characteristic strength of the heat affected zones is reduced to

$$f_{a,haz} = f_a \rho_{haz} \quad (12.12)$$

For the fully penetrated butt weld the strength in the heated affected zone is limited to

$$\sqrt{\sigma_{haz}^2 + 3 \tau_{haz}^2} \leq \frac{f_{a,haz}}{\gamma_{Mw}} \quad (12.13)$$

and for the partially penetrated butt weld, see Fig. 12.9, to

$$\sqrt{\sigma_{haz}^2 + 3 \tau_{haz}^2} \leq \frac{t_e}{t} \frac{f_{a,haz}}{\gamma_{Mw}} \quad (12.14)$$

For a fillet weld the strength in the heated affected zone at the toe of the weld is limited to

$$\sqrt{\sigma_{haz}^2 + 3 \tau_{haz}^2} \leq \frac{f_{a,haz}}{\gamma_{Mw}}, \quad (12.15)$$

respectively for fillet welds at the fusion boundary

$$\sqrt{\sigma_{haz}^2 + 3 \tau_{haz}^2} \leq \frac{g_l}{t} \frac{f_{a,haz}}{\gamma_{Mw}} \quad (12.16)$$

As a conclusion, it can be noted that the deformation capacity of a welded joint can be improved when the design strength of the welds is greater than that of the material in the HAZ.

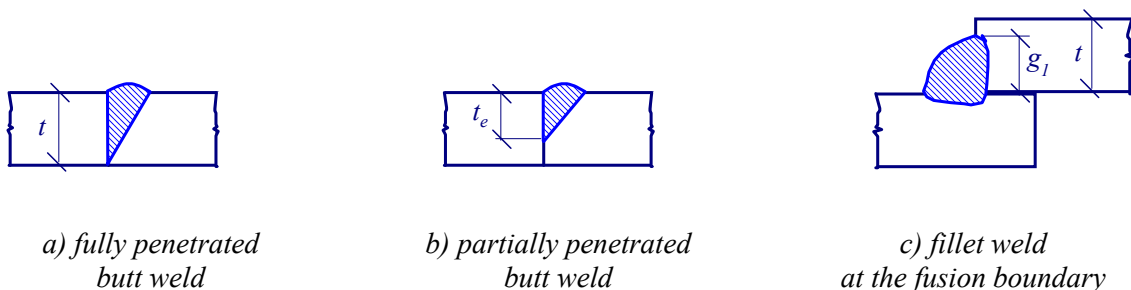


Figure 12.9 Penetration of welds