TALAT
Training in Aluminium Application Technologies

Talat Lecture 2302

Design of Joints

APPENDIX

FIGURES AND TABLES FROM EUROCODE 9

16 pages

Table 3.4: Minimum guaranteed values of 0,2 % proof strength $f_{0,2}$ and ultimate strength f_u for Bolts, solid and hollow rivets

Material	Type of fastener	Alloy grade	Temper	$f_{0,2}$ 0,2% Proof strength N/mm²	f_u Ultimate strength N/mm²
Aluminium alloy	Solid Rivets	5056A	O	145	270
		5086	O	100	240
		6082	T4[1)]	-	200
			T6[1)]	-	295
	Hollow Rivets	5154A	O or F	-	215
	Bolts	6082	T6	260	310
		6061	T6	245	310
		2017A	T4	250	380
		7075	T6	440	510
Steel	Bolts	4.6		240	400
		5.6		300	500
		6.8		480	600
		8.8		640	800
		10.9		900	1000
Stainless Steel	Bolts	A4	A4-50	210	500
		A4	A4-70	450	700
		A4	A4-80	600	800

[1)] Cold driven

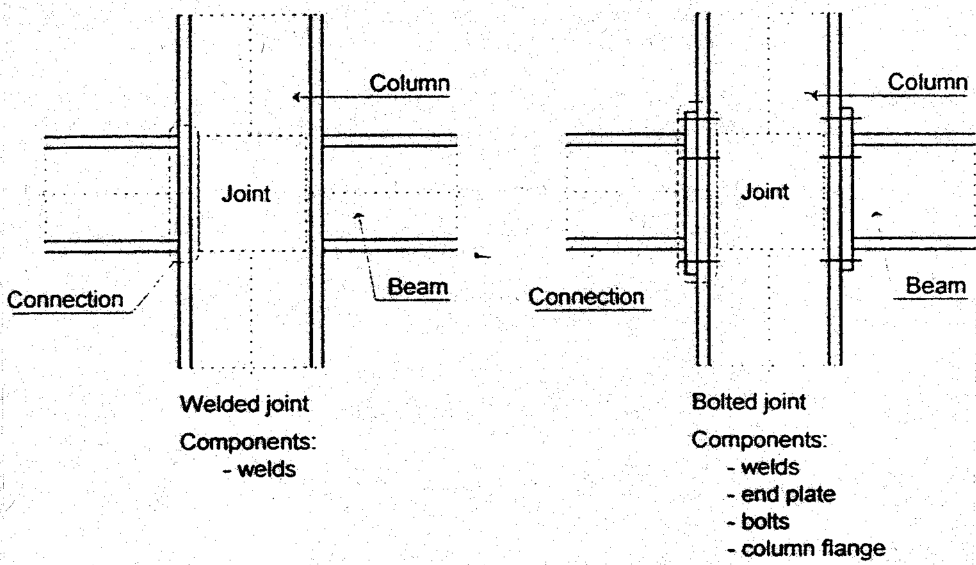


Figure 6.1: Definition of "connection" and "joint"

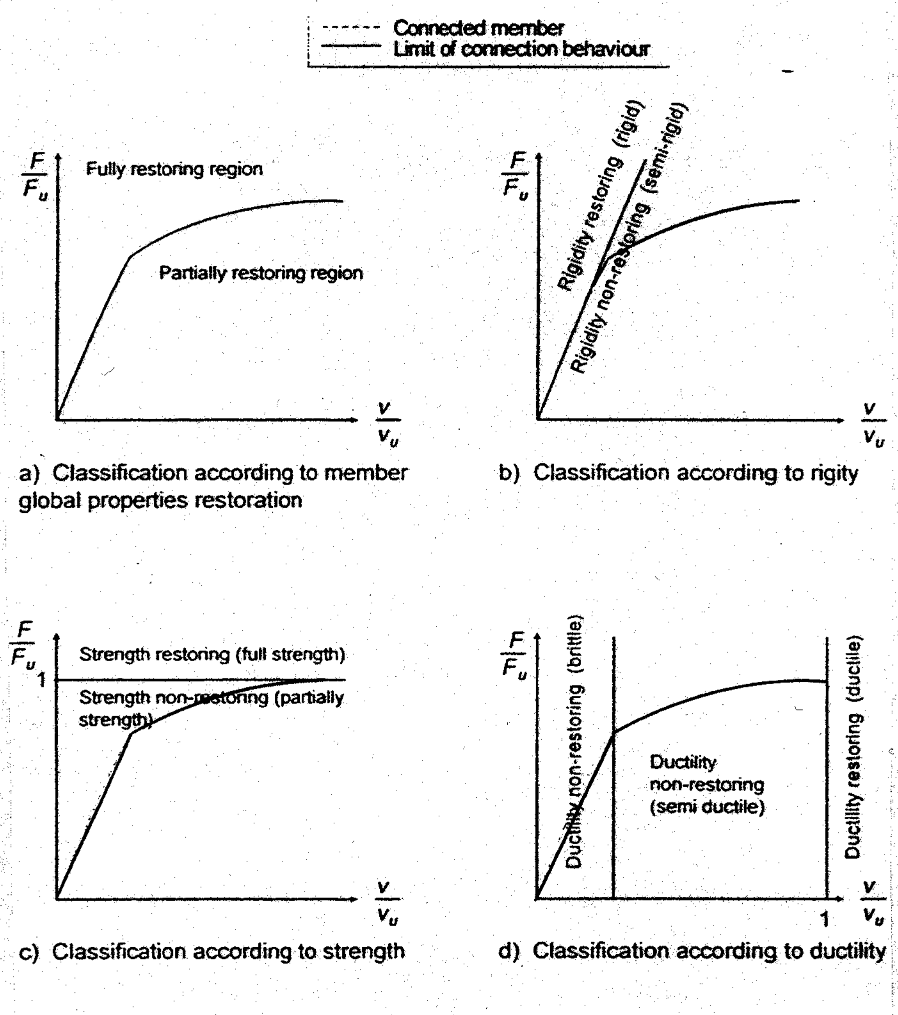


Figure 6.2 a) - d): Classification of connections

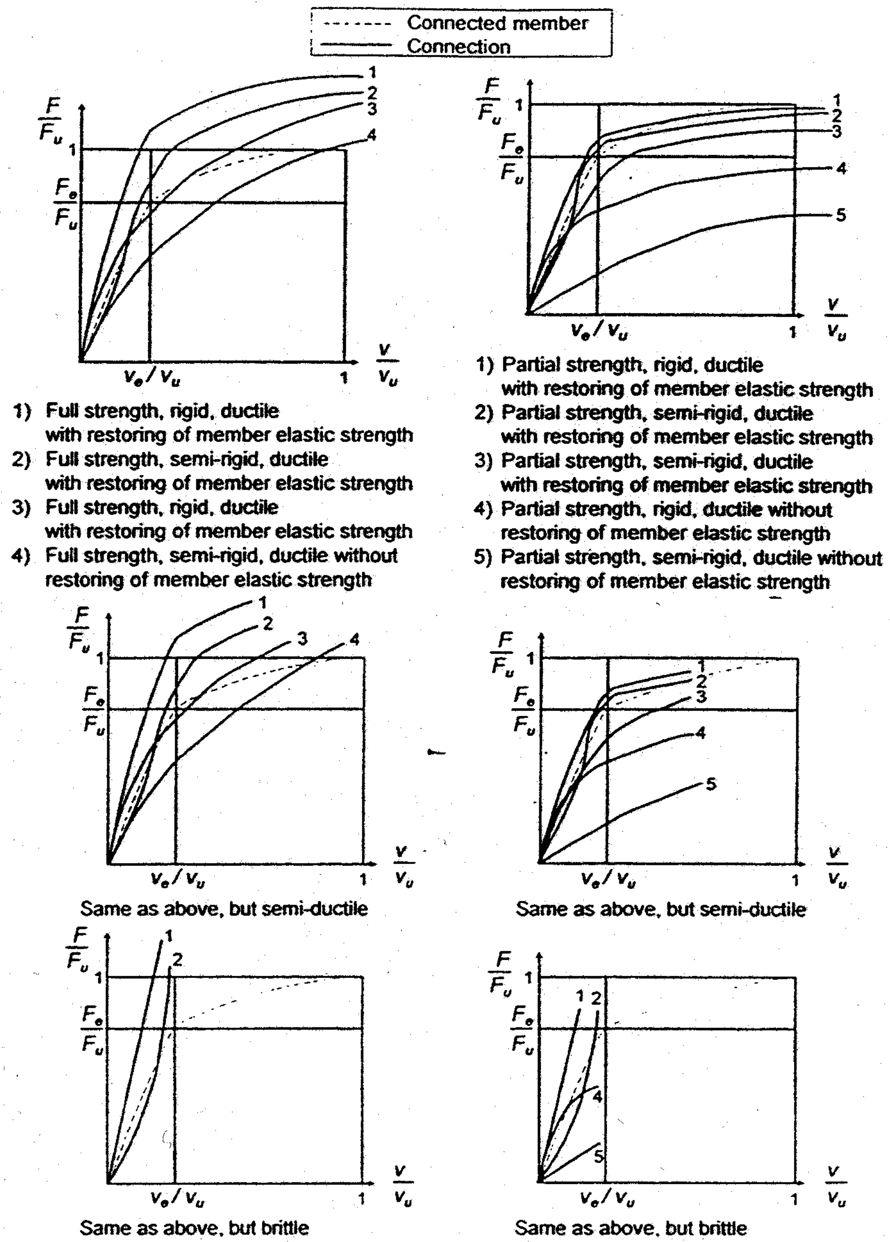


Figure 6.3: Main connection types

Table 6.1: General design requirements

Method of global analysis (see 5.2.1)	Type of connection which must be accounted for	Type of connection which may be ignored
ELASTIC	Semi-rigid connections (full or partial strength, ductile or non-ductile with or without restoring of member elastic strength) Partial strength connections (rigid or semi-rigid, ductile or non-ductile) without restoring of member elastic strength	Fully restoring connections Rigid connections (full or partial strength, ductile or non-ductile) with restoring of member elastic strength Partial strength connections (rigid, ductile or non-ductile) with restoring of member elastic strength
PLASTIC (rigid-plastic elastic-plastic ineline-plastic)	Partial strength connections (rigid or semi-rigid ductile or non-ductile) without restoring of member elastic strength	Fully restoring connections Partial strength, ductile connections (rigid or semi-rigid) with restoring of member elastic strength Full strength connections
HARDENING (rigid-hardening elastic-hardening generically inelastic)	Partially restoring connections	Fully restoring connections

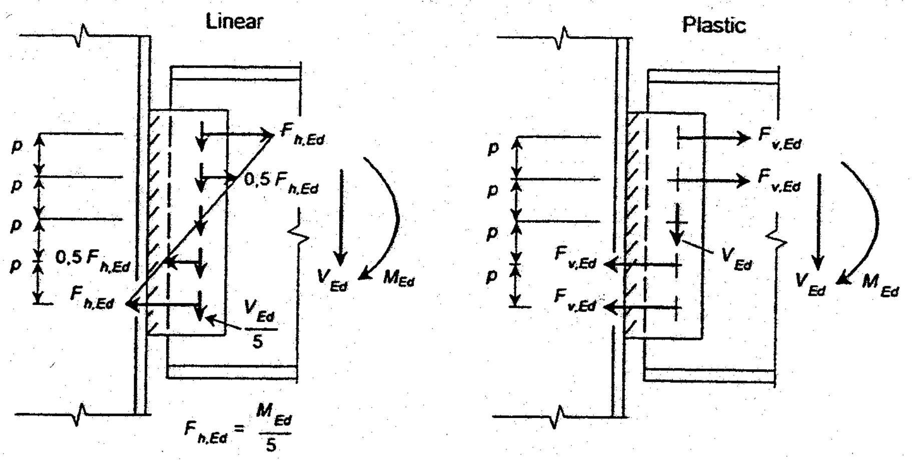
Table 6.6: Slip factor of treated friction surfaces

Total joint thickness mm	Slip factor μ
$12 \leq \Sigma t < 18$	0,27
$18 \leq \Sigma t < 24$	0,33
$24 \leq \Sigma t < 30$	0,37
$30 \leq \Sigma t$	0,40

Table 6.3: Categories of bolted connection

Shear connections		
Category	Criteria	Remarks
A bearing type	$F_{v,Ed} \leq F_{v,Rd}$ $F_{v,Ed} \leq F_{b,Rd}$	No preloading required. All grades from 4.6 to 10.9.
B slip resistant at serviceability	$F_{v,Ed,ser} \leq F_{s,Rd,ser}$ $F_{v,Ed} \leq F_{s,Rd}$ $F_{v,Ed} \leq F_{b,Rd}$	Preloaded high strength bolts. No slip at the serviceability limit state.
C slip resistant at ultimate	$F_{v,Ed} \leq F_{s,Rd}$ $F_{v,Ed} \leq F_{b,Rd}$	Preloaded high strength bolts. No slip at the ultimate limit state.
Tension connections		
Category	Criterion	Remarks
D non-preloaded	$F_{t,Ed} \leq F_{t,Rd}$	No preloading required. All grades from 4.6 to 10.9.
E preloaded	$F_{t,Ed} \leq F_{t,Rd}$	Preloaded high strength bolts.

Key: $F_{v,Ed}$ design shear force per bolt for the ultimate limit state
$F_{v,Rd}$ design shear resistance per bolt
$F_{s,Rd}$ design slip resistance per bolt at the ultimate limit state
$F_{v,Ed,ser}$ design shear force per bolt for the serviceability limit state
$F_{s,Rd,ser}$ design slip resistance per bolt at the serviceability limit state
$F_{b,Rd}$ design bearing resistance per bolt
$F_{t,Ed}$ design tensile force per bolt for the ultimate limit state
$F_{t,Rd}$ design tension resistance per bolt



(a) Distribution proportional to distance from centre of rotation

(b) Possible plastic distribution with one fastener resisting V_{Ed} and 4 resisting M_E

$$F_{v,Ed} = \sqrt{\left(\frac{M_{Ed}}{5p}\right) + \left(\frac{V_{Ed}}{5}\right)} \quad (6.11)$$

$$F_{v,Ed} = \frac{M_{Ed}}{6p} \quad (6.12)$$

Figure 6.9: Distribution of loads between fasteners
a) elastic load distribution
b) plastic load distribution

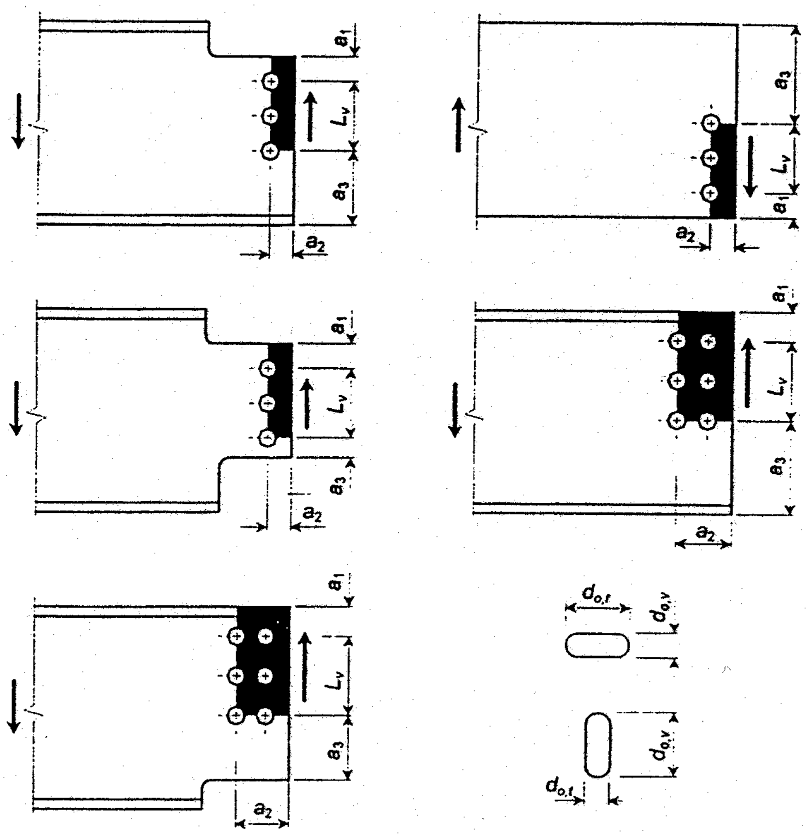


Figure 6.7: Block shear - effective shear area

Table 6.4: Design resistance for bolts

Shear resistance per shear plane:

- for strength grades lower than 10.9

$$F_{v,Rd} = \frac{0{,}6\, f_{ub}\, A}{\gamma_{Mb}} \qquad (6.13)$$

- for strength grades 10.9, stainless steel bolts and aluminium bolts

$$F_{v,Rd} = \frac{0{,}5\, f_{ub}\, A}{\gamma_{Mb}} \qquad (6.14)$$

A = A_S, if the shear plane passes through the threaded portion of the bolt
A = A, if the shear plane passes through the unthreaded portion of the bolt
f_{ub} = characteristic ultimate tensile strength of the bolt material

Bearing resistance:

$$F_{b,Rd} = \frac{2{,}5\, \alpha f_u\, d\, t}{\gamma_{Mb}} \qquad (6.15)$$

where α is the smallest of:

$$\frac{e_1}{3d_0};\ \frac{p_1}{3d_0} - \frac{1}{4};\ \frac{f_{ub}}{f_u}\ or\ 1{,}0: \qquad (6.16)$$

f_u is the characteristic ultimate strenght of the material of the connected parts

Tension resistance

$$F_{t,Rd} = \frac{0{,}9\, f_{ub}\, A_S}{\gamma_{Mb}} \quad \text{for steel bolts} \qquad (6.17)$$

$$F_{t,Rd} = \frac{0{,}6\, f_{ub}\, A_S}{\gamma_{Mb}} \quad \text{for aluminium bolts} \qquad (6.18)$$

A is the shank cross sectional area of bolt
A_S is the stress area of bolt
d is the bolt diameter
d_0 is the hole diameter
e_1, p_1 see figure 6.4

Table 6.5 Design resistance for aluminium rivets

Shear resistance per shear plane: $F_{v,Rd} = \dfrac{0{,}6 f_{ur} A}{\gamma_{Mr}}$	(6.22)
Bearing resistance: $F_{b,Rd} = \dfrac{2{,}5\ \alpha f_u d_0 t}{\gamma_{Mr}}$	(6.23)
where α is the smallest of: $\dfrac{e_1}{3d_0};\ \dfrac{p_1}{3d_0} - \dfrac{1}{4};\ \dfrac{f_{ur}}{f_u}$ or 1,0	(6.24)
f_u is characteristic ultimate strengths of the material of the connected parts	
Tension resistance: Not recommended.	
A is the area of the rivet hole d_0 is the diameter of the rivet hole f_{ur} is the specified ultimate strength of the rivet e_1, p_1 see figure 6.4	

Table 6.2: Reduction factors β_2 and β_3

Pitch p_1	$\leq 2{,}5\ d_0$	$\geq 5{,}0\ d_0$
β_2 for 2 bolts	0,4	0,7
β_3 for 3 bolts or more	0,5	0,7

Table 6.7: Design resistances for pin connections

Criterion	Resistance
Shear of the pin	$F_{v,Rd} = 0{,}6\ A\ f_{up}/\gamma_{Mp}$
Bending of the pin	$M_{Rd} = 0{,}8\ W_{el}\ f_{up}/\gamma_{Mp}$
Combined shear and bending of the pin	$[M_{Ed}/M_{Rd}]^2 + [F_{v,Ed}/F_{v,Rd}]^2 \leq 1{,}0$
Bearing of the plate and the pin	$F_{b,Rd} = 1{,}5\ t\ d\ f_0/\gamma_{Mp}$

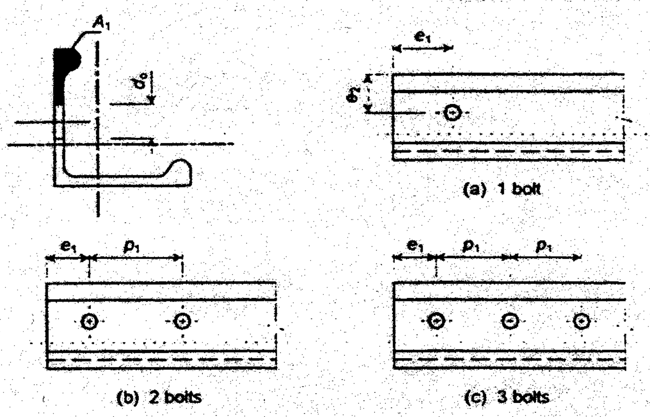


Figure 6.8: Connections of angles with bulbs (covers also angles without bulbs)

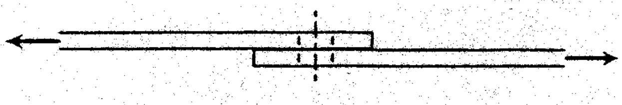
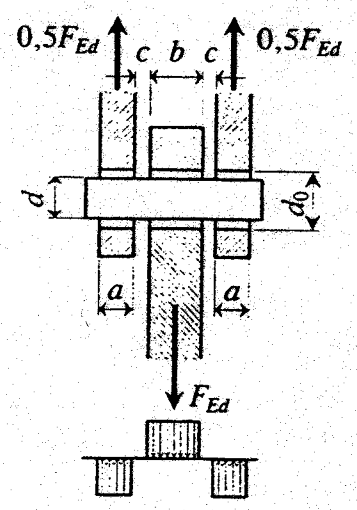


Figure 6.13: Single lap joint with one bolt



$$M_{Ed} = \frac{F_{Ed}}{8}(2a + 4c + b)$$

Figure 6.14: Bending moment in a pin

Table 6.8: Characteristic strength values of weld metal f_w

Characteristic strength	Filler metal [1)]	Alloy								
		3103	5052	5083	5454	6060	6005A	6061	6082	7020
f_w [N/mm²]	5356	-	170	240	220	160	180	190	210	260
	4043A	95	-	-	-	150	160	170	190	210[1)]

NOTE 1: For extruded profiles and material thickness $5 < t \leq 25$ mm in alloy 6060-T5 the above values have to be reduced to 140 N/mm² (see table 3.2b).
NOTE 2: For alloy 5754 the values of alloy 5454 and for alloy 6063 the values of alloy 6060 can be used.
NOTE 3: If filler metals 5056A, 5556A, or 5183 are used then the values for 5356 have to be applied.
NOTE 4: If filler metals 4047A or 3103 are used then the values of 4043A have to be applied.
NOTE 5: For different combinations of alloys the lowest characteristic strength of the weld metal has to be used.
[1)] Only in special cases due to the low strength and elongation of the joint

Table 3.6: Selection of filler metals (see table 3.5 for alloy types)

Parent metal combination [1]							
1st Part	2nd Part						
	Al-Si castings	Al-Mg castings	3000 series alloys	Other 5000 series alloys	5083	6000 series alloys	7020
7020	NR[2]	Type 5 Type 5 Type 5	Type 5 Type 5 Type 4	Type 5 Type 5 Type 5	5556A Type 5 5556A	Type 5 Type 5 Type 4	5556A Type 5 Type 4[4]
6000 series alloys	Type 4 Type 4 Type 4	Type 5 Type 5 Type 5	Type 4 Type 4 Type 4	Type 5 Type 5 Type 5	Type 5 Type 5 Type 5	Type 5 Type 4 Type 4	
5083	NR[2]	Type 5 Type 5 Type 5	Type 5 Type 5 Type 5	Type 5 Type 5 Type 5	5556A Type 5 Type 5	-	
other 5000 series alloys	NR[2]	Type 5 Type 5 Type 5	Type 5 Type 5 Type 5	Type 5 [3] Type 5			
3000 series alloys	Type 4 Type 4 Type 4	Type 5 Type 5 Type 5	Type 3 Type 3 Type 3				
Al-Mg castings	NR[2]	Type 5 Type 5 Type 5					
Al-Si castings	Type 4 Type 4 Type 4						-

[1] Filler metals for parent metal combination to be welded are shown in one box, which is located at the intersection of the relevant parent metal row and column. In each box, the filler metal for the maximum weld strength is shown in the top line; in the case of 6000 series and 7020 alloys, this will be below the fully heat treated parent metal strength. The filler metal for maximum resistance to corrosion is shown in the middle line. The filler metal for freedom from persistant weld cracking is shown on the bottom line.

NR[2] = Not recommended. The welding of alloys containing approximately 2% or more of Mg with Al-Si filler metal, or vice-versa is not recommended because sufficient Mg_2Si precipitate is formed at the fusion boundaries to embrittle the weld. Where unavoidable see prEN 1011-4.

[3] The corrosion behaviour of weld metal is likely to be better if its alloy content is close to that of the parent metal and not markedly higher. Thus for service in potentially corrosive environments it is preferable to weld 5454 with 5454 filler metal. However, in some cases this may only be possible at the expense of weld soundness, so that a compromise will be necessary.

[4] Only in special cases due to the lower strength of the weld and elongation of the joint.

NOTE: See prEN 1011-4 table B.5 for a wider range of parent metals, filler metals and more details on their selection.

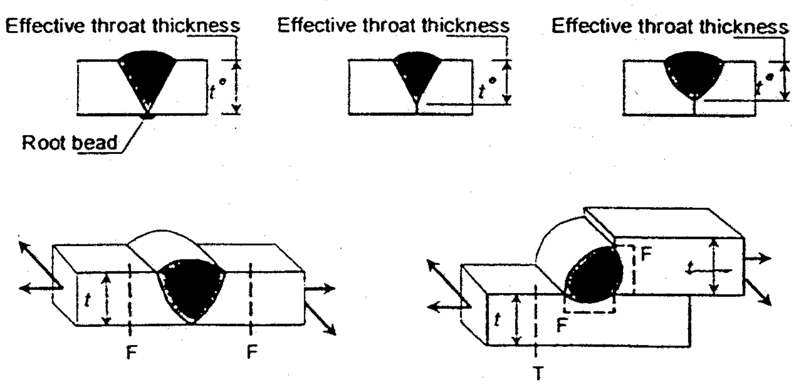


Figure 6.22: Failure planes HAZ adjacent to a weld; F = HAZ, fusion boundary; T = HAZ, toe of the weld, full cross section

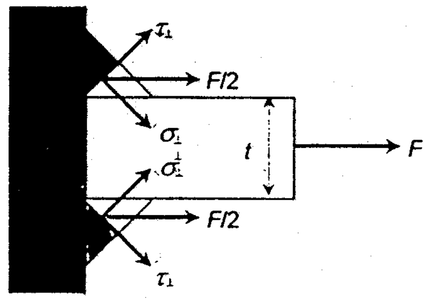


Figure 6.20: Double fillet welded joint loaded perpendicularly to the weld axis

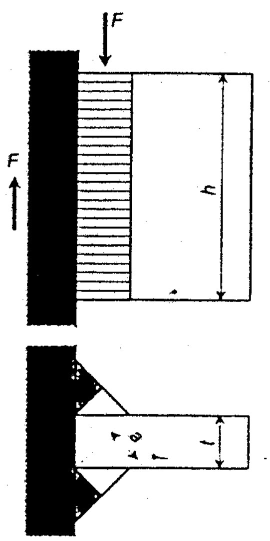


Figure 6.21: Double fillet welded joint loaded parallel to the weld axis

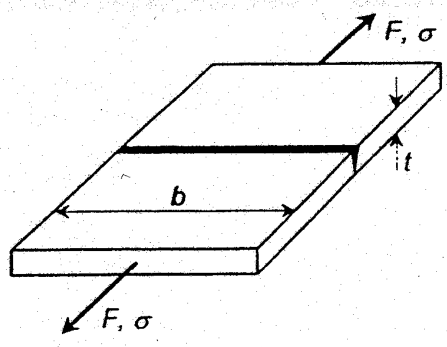


Figure 6.15: Butt weld, normal stresses

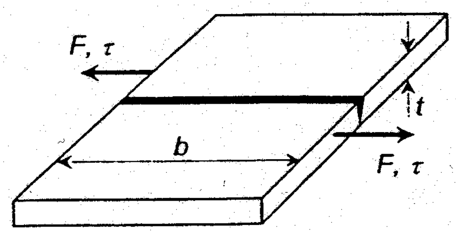


Figure 6.16: Butt weld, shear stresses

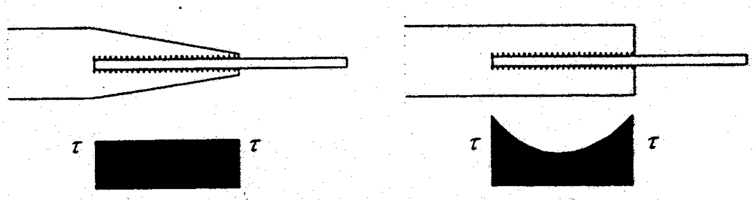


Figure 6.17: Stress Distributions in Lap Joints with Fillet Welds
a) Example of a uniform stress distribution
b) Example of a non uniform stress distribution

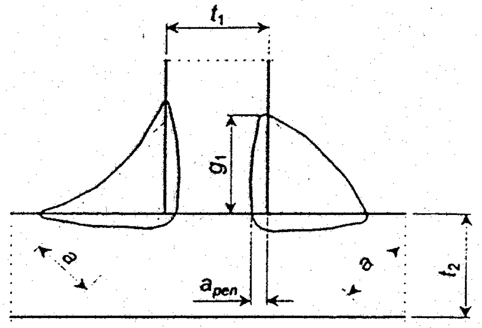


Figure 6.18: Effective throat thickness a; positive root penetration a_{pen}

Table 5.2: HAZ Softening Factor (ρ_{haz})

For all alloys supplied as extrusions, sheet, plate, drawn tubes and foreging in the O and F condition, ρ_{haz} = 1,0.			
Extrusions, sheet, plate, drawn tube and forging in 6xxx and 7xxx alloys in the T4, T5 and T6 condition:			
Alloy Series	Condition	ρ_{haz} (MIG welding)	ρ_{haz} (TIG welding)
6xxx	T4 T5 T6	1,0 0,65 0,65	– 0,60 0,50
7xxx	T6	0,80 [a)] 1,0 [b)]	0,60 [a)] 0,80 [b)]
Sheet, plate or forging in 5xxx, 3xxx and 1xxx alloys (in the work hardened (H) condition):			
Alloy Series	Condition	ρ_{haz} (MIG welding)	ρ_{haz} (TIG welding)
5xxx	H22 H24	0,86 0,80	0,86 0,80
3xxx	H14, 16, 18	0,60	0,60
1xxx	H14	0,60	0,60

[a, b)] For the definition of *a)* and *b)* see 5.5.2 (1)

Table 6.9: Characteristic shear strength values of adhesives

Adhesive types	$f_{v,adh}$ N/mm^2
1- component, heat cured, modified epoxide	35
2- components, cold cured, modified epoxide	25
2- components, cold cured, modified acrylic	20

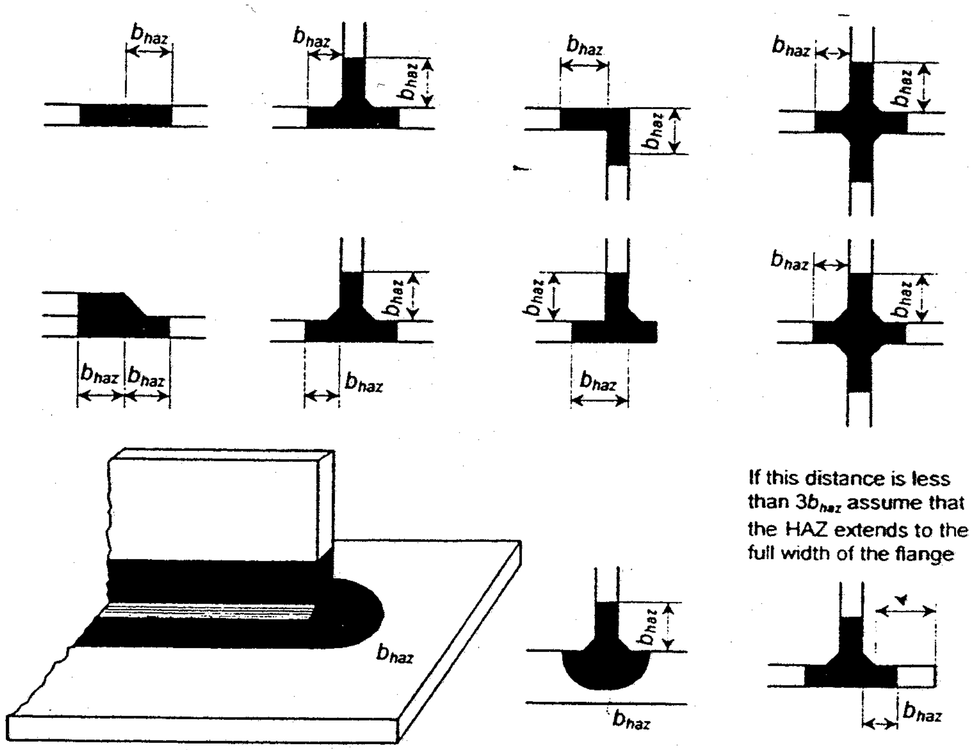


Figure 5.6: The extent of heat-affected zones (HAZ)

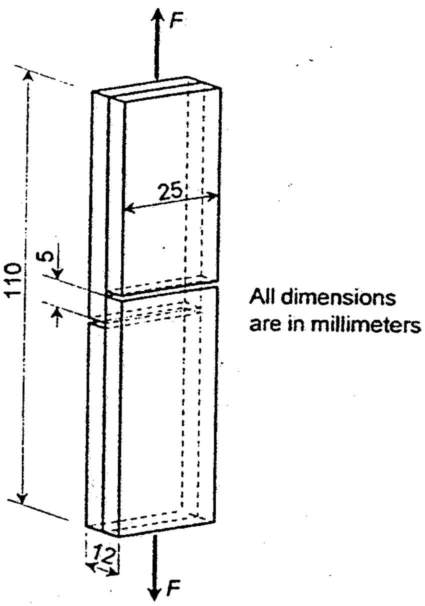


Figure 6.24: Thick adherend shear test specimen