# ALUMINIUM VS STEEL – ASSOCIATED WITH THE CURRENT SOLUTION IN IDEA STATICA CONNECTION

# 1
# CODE FACTORS

# CODE-FACTORS JUSTIFICATION

- Partial factors for ULS check of materials, bolts, and welds are identical between codes – compatibility guaranteed

## Aluminium EN 1999-1-1

**6.1.3 Partial safety factors**

(1) The partial factors $\gamma_M$ as defined in 2.4.3 should be applied to the various characteristic values of resistance in this section as follows:

**Table 6.1 - Partial safety factors for ultimate limit states**

| | |
|---|---|
| resistance of cross-sections whatever the class is: | $\gamma_{M1}$ |
| resistance of members to instability assessed by member checks: | |
| resistance of cross-sections in tension to fracture: | $\gamma_{M2}$ |
| resistance of joints: | See Section 8 |

NOTE 1 Partial factors $\gamma_{Mi}$ may be defined in the National Annex. The following numerical values are recommended:

$\gamma_{M1} = 1{,}10$
$\gamma_{M2} = 1{,}25$

**A1 Table 8.1 - Recommended partial factors $\gamma_M$ for joints**

| | |
|---|---|
| Resistance of members and cross-sections | $\gamma_{M1}$ and $\gamma_{M2}$ see 6.1.3 |
| Resistance of bolt connections | $\gamma_{M2} = 1{,}25$ |
| Resistance of rivet connections | |
| Resistance of plates in bearing | |
| Resistance of pin connections | $\gamma_{Mp} = 1{,}25$ |
| Resistance of welded connections | $\gamma_{Mw} = 1{,}25$ |
| Slip resistance, see 8.5.9.3 | |
| - for serviceability limit states | $\gamma_{Ms,ser} = 1{,}1$ |
| - for ultimate limit states | $\gamma_{Ms,ult} = 1{,}25$ |
| Resistance of adhesive bonded connections | $\gamma_{Ma} \geq 3{,}0$ |
| Resistance of pins at serviceability limit state | $\gamma_{Mp,ser} = 1{,}0$ |

## Steel EN 1993-1-1, 1993-1-8

**6.1 General**

(1) The partial factors $\gamma_M$ as defined in 2.4.3 should be applied to the various characteristic values of resistance in this section as follows:

- resistance of cross-sections whatever the class is: $\gamma_{M0}$
- resistance of members to instability assessed by member checks: $\gamma_{M1}$
- resistance of cross-sections in tension to fracture: $\gamma_{M2}$
- resistance of joints: see EN 1993-1-8

**NOTE 1** For other recommended numerical values see EN 1993 Part 2 to Part 6. For structures not covered by EN 1993 Part 2 to Part 6 the National Annex may define the partial factors $\gamma_{Mi}$; it is recommended to take the partial factors $\gamma_{Mi}$ from EN 1993-2.

**NOTE 2B** Partial factors $\gamma_{Mi}$ for buildings may be defined in the National Annex. The following numerical values are recommended for buildings:

$\gamma_{M0} = 1{,}00$
$\gamma_{M1} = 1{,}00$
$\gamma_{M2} = 1{,}25$

**Table 2.1: Partial safety factors for joints**

| | |
|---|---|
| Resistance of members and cross-sections | $\gamma_{M0}$ , $\gamma_{M1}$ and $\gamma_{M2}$ see EN 1993-1-1 |
| Resistance of bolts | $\gamma_{M2}$ |
| Resistance of rivets | |
| Resistance of pins | |
| Resistance of welds | |
| Resistance of plates in bearing | |
| Slip resistance | |
| - at ultimate limit state (Category C) | $\gamma_{M3}$ |
| - at serviceability limit state (Category B) | $\gamma_{M3,ser}$ |
| Bearing resistance of an injection bolt | $\gamma_{M4}$ |
| Resistance of joints in hollow section lattice girder | $\gamma_{M5}$ |
| Resistance of pins at serviceability limit state | $\gamma_{M6,ser}$ |
| Preload of high strength bolts | $\gamma_{M7}$ |
| Resistance of concrete | $\gamma_c$ see EN 1992 |

**NOTE:** Numerical values for $\gamma_M$ may be defined in the National Annex. Recommended values are as follows: $\gamma_{M2} = 1{,}25$ $\gamma_{M3} = 1{,}25$ and $\gamma_{M3,ser} = 1{,}1$ ; $\gamma_{M4} = 1{,}0$ ; $\gamma_{M5} = 1{,}0$ ; $\gamma_{M6,ser} = 1{,}0$ ; $\gamma_{M7} = 1{,}1$ .

# 2

# MATERIAL & MATERIAL PROPERTIES

# MATERIAL SPECIFICATION

- Eurocode 9 allows only specific aluminium alloys for structural use. These follow strict requirements for mechanical properties, tempers, availability in structural product forms, and weldability. The most commonly used alloys fall into the 5xxx and 6xxx series, plus selected cast alloys.

- Top 3 for general structural design

  1. EN AW-6082 T6 (primary extrusion alloy for load-bearing members)
  2. EN AW-6061 (alternative high-strength extrusion alloy)
  3. EN AW-5083 (primary plate alloy for welded structures)

- Additional widely used

  - EN AW-6060 / 6063 for complex, non-primary structural extrusion shapes
  - EN AW-5754 / 5454 for plates and shell structures
  - EN AC-43000 / 44200 for cast connectors

# MATERIAL PROPERTIES

- Material properties for user-defined material in IDEA StatiCa. Prime setup for valid structural simulation and outputs.

| | Carbon steel | Aluminium alloy | Stainless steel |
|---|---|---|---|
| Grade | S275 | EN AW 6061 T4 | EN 1.4401(316) |
| Material yield strength $\sigma_y$ or $\sigma_{0.2}$ ($N/mm^2$) | 275 | 110 | 220 |
| Young's modulus E ($N/mm^2$) | 210000 | 70000 | 200000 |
| Strain at fracture $A_o$ (%) | 24 | 12 | 45 |
| Density $\rho$ ($kg/m^3$) | 7850 | 2700 | 8000 |
| Thermal expansion coefficient $\alpha$ ($K^{-1}$) | $12\times10^{-6}$ | $23.2\times10^{-6}$ | $16\times10^{-6}$ |
| Thermal conductivity k (W/mK) | 54 | 250 | 16 |
| Total amount of material recycled (%) | 60[a] | 70[a] | 70[a] |

# MATERIALS

- The temper and thickness are altering the yield strength and ultimate strength $f_{0,fu}$
- Another property is observed for the HAZ (heat-affected zone) area due to welding. The material strength is softened/reduced due to material degradation.

| Alloy EN-AW | Temper [1] | Thick-ness mm [1] | $f_o$ [1] | $f_u$ | $A_{50}$ [1) 6)] | $f_{o,haz}$ [2] | $f_{u,haz}$ [2] | HAZ-factor [2] | | BC 4) | $n_p$ 1), 5) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | N/mm² | | % | N/mm² | | $\rho_{o,haz}$ [1] | $\rho_{u,haz}$ | | |
| 6082 | T4 / T451 | ≤ 12,5 | 110 | 205 | 12 | 100 | 160 | 0,91 | 0,78 | B | 8 |
| | T61/T6151 | ≤12,5 | 205 | 280 | 10 | 125 | 185 | 0,61 | 0,66 | A | 15 |
| | T6151 | 12,5<t≤100 | 200 | 275 | 12 [3)] | | | 0,63 | 0,67 | A | 14 |
| | T6/T651 | ≤ 6 | 260 | 310 | 6 | | | 0,48 | 0,60 | A | 25 |
| | | 6<t≤12,5 | 255 | 300 | 9 | | | 0,49 | 0,62 | A | 27 |
| | T651 | 12,5<t≤100 | 240 | 295 | 7 [3)] | | | 0,52 | 0,63 | A | 21 |

| Property | Non-heat-treatable alloys (e.g., 5083) | Heat-treatable alloys (e.g., 6061-T6) |
|---|---|---|
| Elastic modulus (E) | unchanged | unchanged |
| Strength loss in HAZ | 20–50% | 40–60% |
| Cause of strength loss | annealing removes strain hardening | dissolution/overaging of precipitates |
| Naturally recoverable? | ❌ no (strain hardening does not return) | ❌ no (cannot naturally regain T6/T651) |
| Recoverable by heat treatment? | ❌ not fully (only cold working helps) | ✓ yes, but only full solution treat + quench + age |
| Recoverable by natural aging? | minimal | minimal (10–20% at best) |

| Term | Meaning | Structural Impact |
|---|---|---|
| Alloy | Chemical composition | Strength, corrosion, weldability |
| Temper | Mechanical processing state | Actual design strength, ductility |
| Ageing | Strength increase via precipitates | Controls HAZ softening in welds |
| Wrought | Mechanically worked metal | Reliable structural profiles |
| Cast | Melted + poured in mould | Use only for connectors, not members |

- **Steel's microstructure is thermally reversible; aluminium's is not**

# IF THE TEMPERATURE RAISING UP

- The material stiffness is degrading under the increased temperature.
- But if the temperature comes back to standard temperature, the modulus of elasticity has some recovery memory and comes back to 69 – 71000 MPa
- Strength in HAZ will drop about 40-60 % and will not recover due to precipitates dissolve
- Tabs – are coming from EN 1999-1-2

**Table 2 — Modulus of elasticity of aluminium alloys at elevated temperature for a two hour thermal exposure period, $E_{al,\theta}$**

| Aluminium alloy temperature, $\theta$ (°C) | Modulus of elasticity, $E_{al,\theta}$ (N/mm²) |
|---|---|
| 20 | 70 000 |
| 50 | 69 300 |
| 100 | 67 900 |
| 150 | 65 100 |
| 200 | 60 200 |
| 250 | 54 600 |
| 300 | 47 600 |
| 350 | 37 800 |
| 400 | 28 000 |
| 550 | 0 |

(5) The 0,2 proof strength ratios $k_{0,\theta}$ and the ratio $E_{al,\theta}/E_{al}$ for aluminium alloys at elevated temperature $\theta_{al}$/°C are shown in Figure 2a and 2b for up to 2 hours thermal exposure period.

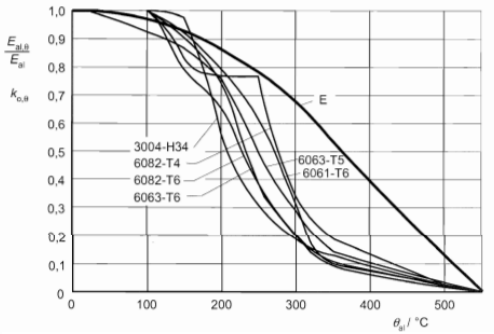



**Table 1a — 0,2% proof strength ratios $k_{0,\theta}$ for aluminium alloys at elevated temperature for up to 2 hours thermal exposure period**

| Alloy | Temper | Aluminium alloy temperature °C | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | 20 | 100 | 150 | 200 | 250 | 300 | 350 | 550 |
| EN AW-3004 | H34 | 1,00 | 1,00 | 0,98 | 0,57 | 0,31 | 0,19 | 0,13 | 0 |
| EN AW-5005 | O | 1,00 | 1,00 | 1,00 | 1,00 | 0,82 | 0,58 | 0,39 | 0 |
| EN AW-5005 | H14[1)] | 1,00 | 0,93 | 0,87 | 0,66 | 0,37 | 0,19 | 0,10 | 0 |
| EN AW-5052 | H34[2)] | 1,00 | 1,00 | 0,92 | 0,52 | 0,29 | 0,20 | 0,12 | 0 |
| EN AW-5083 | O | 1,00 | 1,00 | 0,98 | 0,90 | 0,75 | 0,40 | 0,22 | 0 |
| EN AW-5083 | H12[3)] | 1,00 | 1,00 | 0,80 | 0,60 | 0,31 | 0,16 | 0,10 | 0 |
| EN AW-5454 | O | 1,00 | 1,00 | 0,96 | 0,88 | 0,50 | 0,32 | 0,21 | 0 |
| EN AW-5454 | H34 | 1,00 | 1,00 | 0,85 | 0,58 | 0,34 | 0,24 | 0,15 | 0 |
| EN AW-6061 | T6 | 1,00 | 0,95 | 0,91 | 0,79 | 0,55 | 0,31 | 0,10 | 0 |
| EN AW-6063 | T5 | 1,00 | 0,92 | 0,87 | 0,76 | 0,49 | 0,29 | 0,14 | 0 |
| EN AW-6063 | T6[4)] | 1,00 | 0,91 | 0,84 | 0,71 | 0,38 | 0,19 | 0,09 | 0 |
| EN AW-6082 | T4[5)] | 1,00 | 1,00 | 0,84 | 0,77 | 0,77 | 0,34 | 0,19 | 0 |
| EN AW-6082 | T6 | 1,00 | 0,90 | 0,79 | 0,65 | 0,38 | 0,20 | 0,11 | 0 |

1) The values may be applied also for temper H24/H34/H12/H32
2) The values may be applied also for temper H12/H22/H32
3) The values may be applied also for temper H22/H32
4) The values may be applied also for EN AW-6060 T6 and T66
5) The values do not include an increase in strength due to aging effects. It is recommended to ignore such effects.

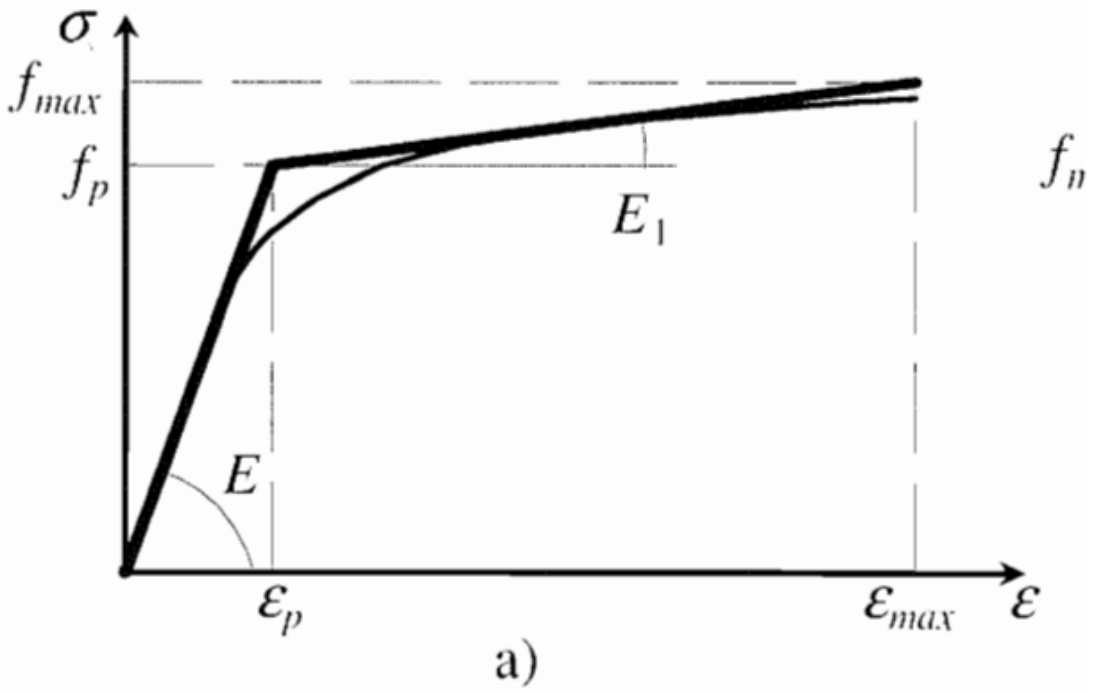
(3) The 0,2% proof strength of aluminium alloys at elevated temperature, not covered in Table 1a, but listed in Table 3.2a and 3.2b of EN 1999-1-1, should be documented by testing or the lower limit values of the 0,2% proof strength ratios given in Table 1b may be used.

**Table 1b - Lower limits of the 0,2% proof strength ratios $k_{0,\theta}$ for aluminium alloys at elevated temperature for up to 2 hours thermal exposure period**

| | Aluminium alloy temperature °C | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 20 | 100 | 150 | 200 | 250 | 300 | 350 | 550 |
| Lower limit values | 1,00 | 0,90 | 0,75 | 0,50 | 0,23 | 0,11 | 0,06 | 0 |

# MATERIAL MODEL

- Material model for material nonlinear simulation is supported as the bilinear with hardening in the plasticity region
- It respects the diagram that is in IDEA StatiCa for steel design.
- The design depends on the class of the section and ductility
- Depending on the alloy, temper, and welding procedure, the ultimate strain is altering.
- Eps_max = 0.5*epsu
- The values are not explicitly exposed in the code




**E.3 Approximate evaluation of $\varepsilon_u$**

According to experimental data the values of $\varepsilon_u$ for the several alloys could be calculated using an analytical expression obtained by means of interpolation of available results. This expression, which provides an upper bound limit for the elongation at rupture, can be synthesised by the following expressions:

A1 $\varepsilon_u = 0{,}30 - 0{,}22\frac{f_o(\mathrm{N/mm^2})}{400}$ if $f_o < 400\,\mathrm{N/mm^2}$ (E.19) A1

A1 $\varepsilon_u = 0{,}08$ if $f_o \geq 400\,\mathrm{N/mm^2}$ (E.20) A1

NOTE This formulation can be used to quantify the stress-strain model beyond the elastic limit for plastic analysis purposes but it is not relevant for material ductility judgement.

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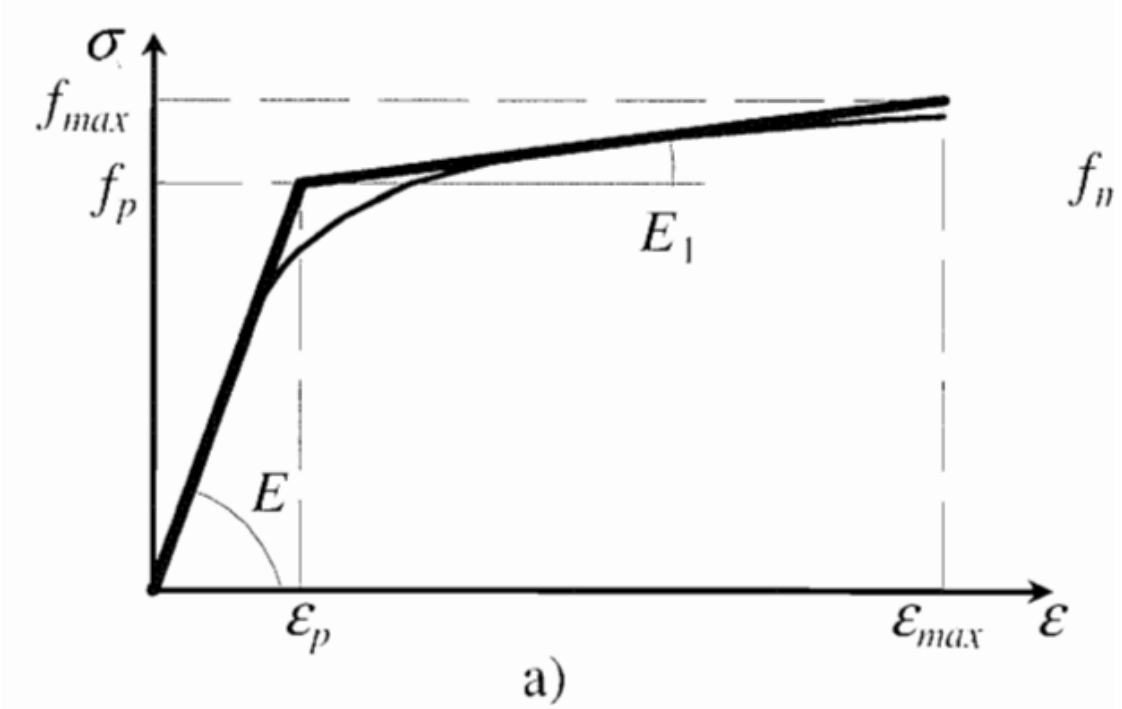
$$\varepsilon_u = 0{,}08 \quad \text{if } f_o \geq 400\ \mathrm{N/mm^2} \qquad \text{(E.20)}$$

NOTE This formulation can be used to quantify the stress-strain model beyond the elastic limit for plastic analysis purposes but it is not relevant for material ductility judgement.

- According to E.3 chapter, the approximate ultimate strain can be in the range (8-30) % based on the strength and alloy
- Eps_max = 0.5*epsu
- Plastic strain = Eps_max – elastic_strain
- Hardening modulus is dependent on:
  - E1(fu,fo,eps,eps_max)
  - This is different than for steel in IDEA !!!




$f_p$ = nominal value of $f_o$ (see Section 3)
$f_{max}$ = nominal value of $f_u$ (see Figure E.1a and Section 3) or $f_p$ (see Figure E.1b)
$\varepsilon_{max}$ = $0{,}5\ \varepsilon_u$
$\varepsilon_u$ = nominal value of ultimate strain (see E.3)
$\varepsilon_p$ = $f_o/E$
$E_1$ = $(f_u - f_o)/(0{,}5\ \varepsilon_u - \varepsilon_p)$

3

# HAZ – HEAT-AFFECTED ZONE

# HAZ – HEAT AFFECTED ZONE

- Aluminum loses strength when welded — unlike steel.
  - Heat destroys strengthening precipitates in heat-treatable alloys (6xxx)
  - HAZ strength may drop 40–60%
  - HAZ controls resistance in:
    - tension
    - compression
    - buckling
    - bending
    - fatigue
    - welded joints
  - This is why EN 1999:
    - explicitly defines HAZ values
    - provides formulas using HAZ modulus/thickness
    - requires designers to check HAZ every time a weld affects a cross-section
  - **Steel designers often underestimate this — one of the biggest mistakes when switching to aluminium design.**

  - **HAZ material properties have to be used in this regions**

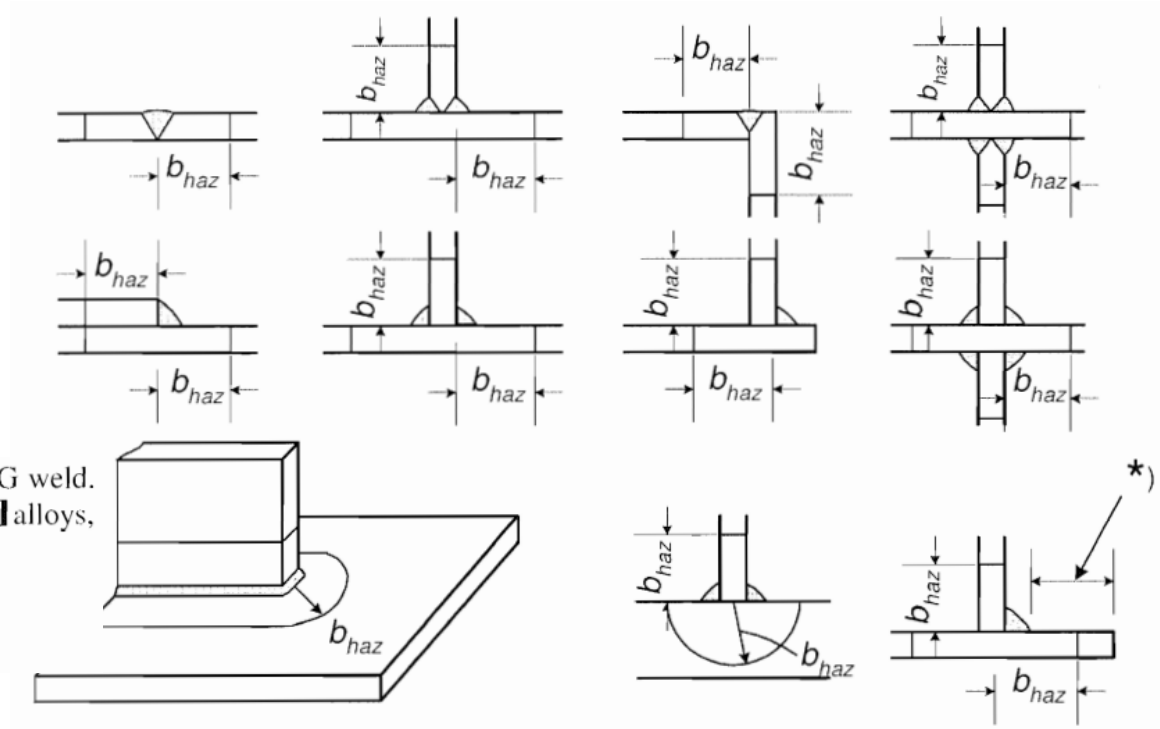
# HAZ – HEAT-AFFECTED ZONE

(3) For a MIG weld laid on unheated material, and with interpass cooling to 60°C or less when multi-pass welds are laid, values of $b_{haz}$ are as follows:

| | |
|---|---|
| $0 < t \leq 6$ mm: | $b_{haz} = 20$ mm |
| $6 < t \leq 12$ mm: | $b_{haz} = 30$ mm |
| $12 < t \leq 25$ mm: | $b_{haz} = 35$ mm |
| $t > 25$ mm: | $b_{haz} = 40$ mm |

(6) For a TIG weld the extent of the HAZ is greater because the heat input is greater than for a MIG weld. TIG welds for in-line butt or fillet welds in 6xxx, 7xxx A1 and work-hardened 3xxx and 5xxx series A1 alloys, have a value of $b_{haz}$ given by:

| | |
|---|---|
| $0 < t \leq 6$ mm: | $b_{haz} = 30$ mm |




- **Maybe the best options for users to define the HAZ properties for whole connection to avoid local model changes and complicated geometrical solutions.**
- **It will be conservative but most of the failure modes are happening in the HAZ where will be critical stress state**



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# 4

# CONNECTION DESIGN – STANDARD BOLTS

IDEA StatiCa®
Calculate yesterday's estimates

# DETAILING

- The detailing rules and criteria that are enabled to activate in IDEA StatiCa are consistent between EN 1993-1-8 and EN 1999-1-1.
- Left tab - Aluminium

**Table 3.3: Minimum and maximum spacing, end and edge distances**

| Distances and spacings, see Figure 3.1 | Minimum | Maximum[1) 2) 3)] | | |
|---|---|---|---|---|
| | | Structures made from steels conforming to EN 10025 except steels conforming to EN 10025-5 | | Structures made from steels conforming to EN 10025-5 |
| | | Steel exposed to the weather or other corrosive influences | Steel not exposed to the weather or other corrosive influences | Steel used unprotected |
| End distance $e_1$ | $1{,}2d_0$ | $4t + 40$ mm | | The larger of $8t$ or 125 mm |
| Edge distance $e_2$ | $1{,}2d_0$ | $4t + 40$ mm | | The larger of $8t$ or 125 mm |
| Distance $e_3$ in slotted holes | $1{,}5d_0$ [4)] | | | |
| Distance $e_4$ in slotted holes | $1{,}5d_0$ [4)] | | | |
| Spacing $p_1$ | $2{,}2d_0$ | The smaller of $14t$ or 200 mm | The smaller of $14t$ or 200 mm | The smaller of $14t_{min}$ or 175 mm |
| Spacing $p_{1,0}$ | | The smaller of $14t$ or 200 mm | | |
| Spacing $p_{1,i}$ | | The smaller of $28t$ or 400 mm | | |
| Spacing $p_2$ [5)] | $2{,}4d_0$ | The smaller of $14t$ or 200 mm | The smaller of $14t$ or 200 mm | The smaller of $14t_{min}$ or 175 mm |

1) Maximum values for spacings, edge and end distances are unlimited, except in the following cases:
- for compression members in order to avoid local buckling and to prevent corrosion in [AG] exposed members (the limiting values are given in the table) and; [AG]
- for exposed tension members [AG] to prevent corrosion (the limiting values are given in the table). [AG]

2) The local buckling resistance of the plate in compression between the fasteners should be calculated according to EN 1993-1-1 using $0{,}6\ p_1$ as buckling length. Local buckling between the fasteners need not to be checked if $p_1/t$ is smaller than $9\varepsilon$. The edge distance should not exceed the local buckling requirements for an outstand element in the compression members, see EN 1993-1-1. The end distance is not affected by this requirement.

3) $t$ is the thickness of the thinner outer connected part.

4) The dimensional limits for slotted holes are given in 1.2.7 Reference Standards: Group 7.

5) For staggered rows of fasteners a minimum line spacing of $p_2 = 1{,}2d_0$ may be used, provided that the minimum distance, L, between any two fasteners is greater or equal than $2{,}4d_0$, see Figure 3.1b).

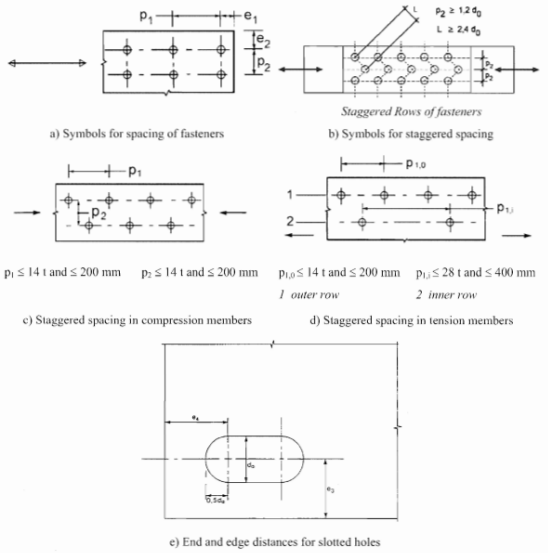



**Figure 3.1: Symbols for end and edge distances and spacing of fasteners**

**Table 8.2 - Minimum, regular and maximum spacing, end and edge distances**

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| Distances and spacings, see Figures 8.1 and 8.2 | Minimum | Regular distance | Maximum[1) 2) 3)] | |
| | | | Structures made of aluminium according to Table 3.1a | |
| | | | Aluminium exposed to the weather or other corrosive influences | Aluminium not exposed to the weather or other corrosive influences |
| End distance $e_1$ | $1{,}2d_0$ [6)] | $2{,}0d_0$ | $4t + 40$ mm | The larger of $12t$ or 150 mm |
| Edge distance $e_2$ | $1{,}2d_0$ [6)] | $1{,}5d_0$ | $4t + 40$ mm | The larger of $12t$ or 150 mm |
| End distance $e_3$ for slotted holes [4)] | Slotted holes are not recommended. Slotted holes of category A see [EN] 8.5.1(5) [CS] – (10) | | | |
| Edge distance $e_4$ for slotted holes [4)] | Slotted holes are not recommended Slotted holes of category A see [EN] 8.5.1(5) [CS] – (10) | | | |
| Compression members (see Figure 8.2): Spacing $p_1$ | $2{,}2d_0$ | $2{,}5d_0$ | Compression members: The smaller of $14t$ or 200 mm | Compression members: The smaller of $14t$ or 200 mm |
| Tension members (see Figure 8.3): Spacing $p_1$, $p_{1,0}$, $p_{1,i}$ | $2{,}2d_0$ | $2{,}5d_0$ | Outer lines: The smaller of $14t$ or 200 mm Inner lines: The smaller of $28t$ or 400 mm | 1,5 times the values of column 4 |
| Spacing $p_2$ [5)] | $2{,}4d_0$ | $3{,}0d_0$ | The smaller of $14t$ or 200 mm | The smaller of $14t$ or 200 mm |

1) Maximum values for spacings, edge and end distances are unlimited, except in the following cases:
- for compression members in order to avoid local buckling and to prevent corrosion in exposed members and;
- for exposed tension members to prevent corrosion.

2) The local buckling resistance of the plate in compression between the fasteners should be calculated according to [EN] 6.3 [CS] [EN] *text deleted* [CS] by using $0{,}6\ p_1$ as buckling length. Local buckling between the fasteners need not to be checked if $p_1/t$ is smaller than $9\varepsilon$. The edge distance should not exceed the maximum to satisfy local buckling requirements for an outstand part in the compression members, see 6.4.2 - 6.4.5. [EN] *Text deleted* [CS]

3) $t$ is the thickness of the thinner outer connected part.

4) Slotted holes are not recommended, slotted holes of category A see 8.5.1 (5)

5) For staggered rows of fasteners a minimum line spacing $p_2 = 1{,}2d_0$ may be used, if the minimum distance between any two fasteners in a staggered row is $p_1 = 2{,}4d_0$, see Figure 8.2.

6) The minimum values of $e_1$ and $e_2$ should be specified with no minus deviation but only plus deviations.

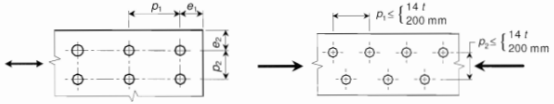
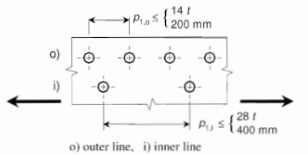



**Figure 8.1 - Symbols for spacing of fasteners** **Figure 8.2 - Staggered spacing – compression**




o) outer line, i) inner line

**Figure 8.3 - Spacing in tension member**

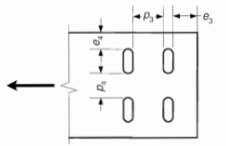



**Figure 8.4 - Slotted holes**

# CATEGORIES OF BOLTED CONNECTION IN EN 1999-1-1

- **Category A : Bearing type**
  - **Steel, stainless steel, aluminium bolts (mostly in IDEA StatiCa)**
- Category B: Slip-resistant at serviceability limit state
  - Preloaded bolts, the slip cannot be violated
- Category C: Slip-resistant at ultimate limit state
- Category D: Connections with non-preloaded bolts
  - Frequently subjected to variation of tensile loads (cyclic, wind)
- Category E: Connections with preloaded high strength bolts

**Table 8.4 - Categories of bolted connections**

| **Shear connections** | | |
|---|---|---|
| Category | Criteria | Remarks |
| A; bearing type | $F_{v,Ed} \le F_{v,Rd}$<br>$F_{v,Ed} \le F_{b,Rd}$<br>$\Sigma F_{v,Ed} \le N_{net,Rd}$ | No preloading required.<br>All grades from 4.6 to 10.9.<br>$N_{net,Rd} = 0{,}9 A_{net} f_u / \gamma_{M2}$ |
| B; slip resistant at serviceability | $F_{v,Ed,ser} \le F_{s,Rd,ser}$<br>$F_{v,Ed} \le F_{v,Rd}$<br>$F_{v,Ed} \le F_{b,Rd}$<br>$\Sigma F_{v,Ed} \le N_{net,Rd}$<br>$\Sigma F_{v,Ed,ser} \le N_{net,Rd,ser}$ | Preloaded high strength bolts.<br>No slip at the serviceability limit state.<br><br>$N_{net,Rd} = 0{,}9 A_{net} f_u / \gamma_{M2}$<br>$N_{net,Rd,ser} = A_{net} f_o / \gamma_{M1}$ |
| C; slip resistant at ultimate | $F_{v,Ed} \le F_{s,Rd}$<br>$F_{v,Ed} \le F_{b,Rd}$<br>$\Sigma F_{v,Ed} \le N_{net,Rd}$<br>Ⓐ $\Sigma F_{v,Ed} \le N_{net,Rd,ser}$ Ⓐ | Preloaded high strength bolts.<br>No slip at the ultimate limit state.<br>$N_{net,Rd} = 0{,}9 A_{net} f_u / \gamma_{M2}$<br>$N_{net,Rd,ser} = A_{net} f_o / \gamma_{M1}$ |
| **Tension connections** | | |
| Category | Criterion | Remarks |
| D; non-preloaded | $F_{t,Ed} \le F_{t,Rd}$<br>$F_{t,Ed} \le B_{p,Rd}$ | Bolt class from 4.6 to 10.9. |
| E; preloaded | $F_{t,Ed} \le F_{t,Rd}$<br>$F_{t,Ed} \le B_{p,Rd}$ | Preloaded 8.8 or 10.9 bolts. |

Key:
- $F_{v,Ed}$ design shear force per bolt for the ultimate limit state
- $F_{v,Ed,ser}$ design shear force per bolt for the serviceability limit state
- $F_{v,Rd}$ design shear resistance per bolt
- $F_{b,Rd}$ design bearing resistance per bolt
- $F_{s,Rd,ser}$ design slip resistance per bolt at the serviceability limit state
- $F_{s,Rd}$ design slip resistance per bolt at the ultimate limit state
- $F_{t,Ed}$ design tensile force per bolt for the ultimate limit state
- $F_{t,Rd}$ design tension resistance per bolt
- $A_{net}$ net area, see 6.2.2.2 (tension members only)
- $B_{p,Rd}$ design resistance for punching resistance, see Table 8.5.



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# SHEAR RESISTANCE CHECK

- The shear resistance check has the same parameters and equation, and guarantees the consistency between the EN 1999-1-1 and EN 1993-1-8

## EN 1993-1-8

| Failure mode | Bolts | Rivets |
|---|---|---|
| Shear resistance per shear plane | $F_{v,Rd} = \frac{\alpha_v \, f_{ub} \, A}{\gamma_{M2}}$<br>- where the shear plane passes through the threaded portion of the bolt ($A$ is the tensile stress area of the bolt $A_s$):<br>- for classes 4.6, 5.6 and 8.8:<br>$\alpha_v = 0,6$<br>- for classes 4.8, 5.8, 6.8 and 10.9:<br>$\alpha_v = 0,5$<br>- where the shear plane passes through the unthreaded portion of the bolt ($A$ is the gross cross section of the bolt): $\alpha_v = 0,6$ | $F_{v,Rd} = \frac{0,6 \, f_{ur} \, A_0}{\gamma_{M2}}$ |

## EN 1999-1-1

| Failure mode | Bolts | Rivets |
|---|---|---|
| Shear resistance per shear plane: | $F_{v,Rd} = \frac{\alpha_v \, f_{ub} \, A}{\gamma_{M2}}$ (8.9)<br>- where the shear plane passes through the threaded portion of the bolt ($A$ is the tensile stress area of the bolt $A_S$):<br>- for steel bolts with classes 4.6, 5.6 and 8.8: $\alpha_v = 0,6$<br>- for steel bolts with classes 4.8, 5.8, 6.8 and 10.9, stainless steel bolts and aluminium bolts: $\alpha_v = 0,5$<br>- where the shear plane passes through the unthreaded portion of the bolt ($A$ is the gross cross section of the bolt): $\alpha_v = 0,6$<br>$f_{ub}$ = characteristic ultimate strength of the bolt material | $F_{v,Rd} = \frac{0,6 \, f_{ur} \, A_0}{\gamma_{M2}}$ (8.10)<br>$f_{ur}$ = characteristic ultimate strength of the rivet material<br>$A_0$ = cross sectional area of the hole |



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# BEARING RESISTANCE CHECK

- The bearing resistance check has the same parameters and equation, and guarantees the consistency between the EN 1999-1-1 and EN 1993-1-8

## EN 1993-1-8

| | |
|---|---|
| Bearing resistance [1), 2), 3)] | [AC2] $F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$ [AC2]<br>where $\alpha_b$ is the smallest of $\alpha_d$ ; $\frac{f_{ub}}{f_u}$ or 1,0;<br>in the direction of load transfer:<br>- for end bolts: $\alpha_d = \frac{e_1}{3d_0}$ ; for inner bolts: $\alpha_d = \frac{p_1}{3d_0} - \frac{1}{4}$<br>perpendicular to the direction of load transfer:<br>[AC2]- for edge bolts: $k_1$ is the smallest of $2{,}8\frac{e_2}{d_0} - 1{,}7, 1{,}4\frac{p_2}{d_0} - 1{,}7$ and $2{,}5$ [AC2]<br>- for inner bolts: $k_1$ is the smallest of $1{,}4\frac{p_2}{d_0} - 1{,}7$ or $2{,}5$ |

## EN 1999-1-1

| | |
|---|---|
| Bearing resistance 1) 2) 3) 4) 5) 6) | $F_{b,Rd} = \frac{k_1 \alpha_b f_u d t}{\gamma_{M2}}$ (8.11)<br>where $\alpha_b$ is the smallest of $\alpha_d$ or $\frac{f_{ub}}{f_u}$ or 1,0; but $\leq 0{,}66$ for slotted holes (8.12)<br>in the direction of the load transfer:<br>- for end bolts: $\alpha_d = \frac{e_1}{3d_0}$; for inner bolts: $\alpha_d = \frac{p_1}{3d_0} - \frac{1}{4}$; (8.13 and 8.14)<br>perpendicular to the direction of the load transfer:<br>- for edge bolts: $k_1$ is the smallest of $2{,}8\frac{e_2}{d_0} - 1{,}7$ or $2{,}5$ (8.15)<br>- for inner bolts: $k_1$ is the smallest of $1{,}4\frac{p_2}{d_0} - 1{,}7$ or $2{,}5$ (8.16)<br>$f_u$ is the characteristic ultimate strength of the material of the connected parts<br>$f_{ub}$ is the characteristic ultimate strengths of the bolt material<br>$d$ is the bolt diameter<br>$d_0$ is the hole diameter<br>$e_1$, $e_2$, $p_1$, $p_2$ see Figure 8.1 [5)] |



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# TENSION RESISTANCE CHECK

- The tension resistance check has the same parameters and equation for steel bolts, and guarantees the consistency between the EN 1999-1-1 and EN 1993-1-8
- The countersunk and aluminium bolts are not supported
- IDEA StatiCa does not support rivets from the code-check pespective

## EN 1993-1-8

| | | |
|---|---|---|
| Tension resistance [2] | $F_{t,Rd} = \frac{k_2 \, f_{ub} \, A_s}{\gamma_{M2}}$<br>where $k_2 = 0{,}63$ for countersunk bolt,<br>otherwise $k_2 = 0{,}9$. | $F_{t,Rd} = \frac{0{,}6 \, f_{ur} \, A_0}{\gamma_{M2}}$ |

## EN 1999-1-1

| | | | |
|---|---|---|---|
| Tension resistance | $F_{t,Rd} = \frac{k_2 \, f_{ub} \, A_s}{\gamma_{M2}}$<br>where $k_2 = 0{,}9$ for steel bolts,<br>$k_2 = 0{,}50$ for aluminium bolts and<br>$k_2 = 0{,}63$ for countersunk steel bolts, | (8.17) | $F_{t,Rd} = \frac{0{,}6 \, f_{ur} \, A_0}{\gamma_{M2}}$<br>For solid rivets with head dimensions according to Annex C, Figure C.1 or greater on both sides. | (8.18) |



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# PUNCHING RESISTANCE CHECK

- The punching resistance check has the same parameters and equation for steel bolts, and guarantees the consistency between the EN 1999-1-1 and EN 1993-1-8

.

## EN 1993-1-8

| | | |
|---|---|---|
| Punching shear resistance | $B_{p,Rd} = 0{,}6\,\pi\,d_m\,t_p\,f_u\,/\,\gamma_{M2}$ | No check needed |

## EN 1999-1-1

| | |
|---|---|
| Punching shear resistance | $B_{p,Rd} = 0{,}6\,\pi\,d_m\,t_p\,f_u\,/\,\gamma_{M2}$ (8.19)<br>where:<br>$d_m$ is the mean of the across points and across flats dimensions of the bolt head or the nut or if washers are used the outer diameter of the washer, whichever is smaller;<br>$t_p$ is the thickness of the plate under the bolt head or the nut;<br>$f_u$ characteristic ultimate strength of the member material. |

# COMBINED SHEAR AND TENSION CHECK

- The combined shear and tension resistance check has the same parameters and equation for steel bolts, and guarantees the consistency between the EN 1999-1-1 and EN 1993-1-8

.

## EN 1993-1-8

| | |
|---|---|
| Combined shear and tension | $\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1{,}4\,F_{t,Rd}} \le 1{,}0$ |

1) The bearing resistance $F_{b,Rd}$ for bolts
   - in oversized holes is 0,8 times the bearing resistance for bolts in normal holes.
   - in slotted holes, where the longitudinal axis of the slotted hole is perpendicular to the direction of the force transfer, is 0,6 times the bearing resistance for bolts in round, normal holes.

2) For countersunk bolt:
   - the bearing resistance $F_{b,Rd}$ should be based on a plate thickness $t$ equal to the thickness of the connected plate minus half the depth of the countersinking.
   - for the determination of the tension resistance $F_{t,Rd}$ the angle and depth of countersinking should conform with 1.2.4 Reference Standards: Group 4, otherwise the tension resistance $F_{t,Rd}$ should be adjusted accordingly.

3) When the load on a bolt is not parallel to the edge, the bearing resistance may be verified separately for the bolt load components parallel and normal to the end.

## EN 1999-1-1

| | | |
|---|---|---|
| Combined shear and tension | $\frac{F_{v,Ed}}{F_{v,Rd}} + \frac{F_{t,Ed}}{1{,}4\,F_{t,Rd}} \le 1{,}0$ | (8.20) |



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# 5

# CONNECTION DESIGN – FRICTION BOLTS

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# FRICTION BOLTS

## EN 1993-1-8

for a category C connection: $$F_{s,Rd} = \frac{k_s \, n \, \mu \, (F_{p,C} - 0{,}8 F_{t,Ed})}{\gamma_{M3}} \quad \text{... (3.8b)}$$

| Class of friction surfaces (see 1.2.7 Reference Standard: Group 7) | Slip factor $\mu$ |
|---|---|
| A | 0,5 |
| B | 0,4 |
| C | 0,3 |
| D | 0,2 |

**NOTE 1:** The requirements for testing and inspection are given in 1.2.7 Reference Standards: Group 7.

**NOTE 2:** The classification of any other surface treatment should be based on test specimens representative of the surfaces used in the structure using the procedure set out in 1.2.7 Reference Standards: Group 7.

**NOTE 3:** The definitions of the class of friction surface are given in 1.2.7 Reference Standards: Group 7.

**NOTE 4:** With painted surface treatments a loss of pre-load may occur over time.

## EN 1999-1-1

$$F_{s,Rd} = \frac{n \, \mu \, (F_{p,C} - 0{,}8 F_{t,Ed})}{\gamma_{Ms,ult}}$$

**Table 8.6 - Slip factor of treated friction surfaces**

| Total joint thickness mm | Slip factor $\mu$ |
|---|---|
| $12 \le \Sigma t < 18$ | 0,27 |
| $18 \le \Sigma t < 24$ | 0,33 |
| $24 \le \Sigma t < 30$ | 0,37 |
| $30 \le \Sigma t$ | 0,40 |

# 6

# CONNECTION DESIGN - WELD

# WELDS – CHARACTERISTIC STRENGHT

- MIG and TIG welding processes
- Structures mostly static loads
- Heat-treatable alloys in temper T4 and above (6xxx and 7xxx series)
- The characteristic strengths $f_{u,haz}$ for the material in the HAZ

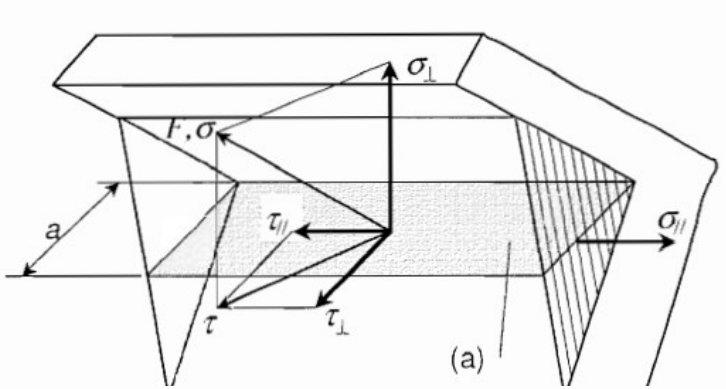


**Table 8.8 - Characteristic strength values of weld metal $f_w$**

| Characteristic strength | Filler metal | Alloy | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 3103 | 5052 | 5083 | 5454 | 6060 | 6005A | 6061 | 6082 | 7020 |
| $f_w$ [N/mm$^2$] | 5356 | - | 170 | 240 | 220 | 160 | 180 | 190 | 210 | 260 |
| | 4043A | 95 | - | - | - | 150 | 160 | 170 | 190 | 210 |

1 For alloys EN AW-5754 and EN AW-5049 the values of alloy 5454 can be used;
for EN AW-6063, EN AW-3005 and EN AW-5005 the values of alloy 6060 can be used;
for EN AW-6106 the values of alloy 6005A can be used;
for EN AW-3004 the values of alloy 6082 can be used;
for EN AW-8011A a value of 100 N/mm² for filler metal Type 4 and Type 5 can be used.

2 [A1] If filler metals 5056,5356A, 5556A/5556B, 5183/5183A are used [A1] then the values for 5356 have to be applied.

3 If filler metals 4047A or 3103 are used then the values of 4043A have to be applied.

4 For combinations of different alloys the lowest characteristic strength of the weld metal has to be used.

# WELDS – COMPARISON

- The welded zone is almost half as strong
- This is why welded aluminium structures require more conservative geometry or require using 6082-T6 only in extrusions and avoiding welds where strength is critical

| Topic | EN 1999 – Aluminium | EN 1993 – Steel |
|---|---|---|
| **Which material strength is used in welded zones?** | **HAZ strength must be used** (reduced yield and ultimate strength). | **Base material characteristic strength used** (no explicit HAZ reduction for common structural steels S235–S460). |
| **Why?** | Aluminium alloys lose strength in the HAZ due to thermal softening. The loss is systematic, significant, and permanent. | Carbon steels typically regain strength after cooling; HAZ softening is negligible or covered within safety factors. |
| **Relevant clauses** | EN 1999-1-1: **Cl. 3.1.7, Annex C, Table 3.2** → HAZ reduction factors for each alloy type. | EN 1993-1-8 and EN 1993-1-1 → Weld design uses nominal steel grades without HAZ modification. |
| **How is resistance checked?** | Welded members must be checked at the **reduced HAZ strength $f_{o,HAZ}$**. | Use **f_y** and **f_u** of the steel grade (S355, etc.) directly. |
| **Design consequences** | Member capacity in the HAZ may be **30–60% lower** than base material. Often governs design. | Welds rarely govern member strength unless there is high restraint, fatigue, or brittle fracture risk. |



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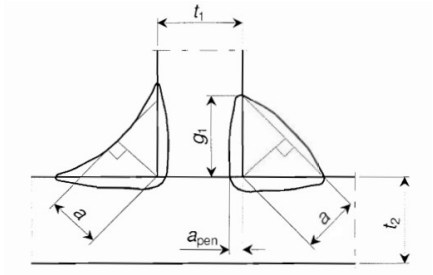
# WELD – TYPES

- Butt welds
  - Strength as the HAZ
- Partial Penetration Butt welds
  - Secondary non-bearing members
  - Effective throat thickness
- Fillet welds
  - Effective throat thickness
  - a=1.2a, a=a+$a_{pen}$
  - In IDEA StatiCa use conservatively „a“
- The Von-Mises condition of plasticity is used as the failure criterion. It aligns with the assumption in EN 1993-1-8. The ultimate strength is the HAZ strength.




a) Tensile force perpendicular to the failure plane (see Figure 8.21):

- HAZ butt welds:

$$\sigma_{haz,Ed} \le \frac{f_{u,haz}}{\gamma_{Mw}}$$ [A1] at the toe of the weld (full cross section) for full penetration welds and effective throat section te for partial penetration welds; [A1] (8.38)

- HAZ fillet welds:

$$\sigma_{haz,Ed} \le \frac{f_{u,haz}}{\gamma_{Mw}}$$ at the fusion boundary and at the toe of the weld (full cross section). (8.39)

$$\tau_{haz,Ed} \le \frac{f_{v,haz}}{\gamma_{Mw}}$$ [A1] at the toe of the weld (full cross section) for full penetration welds and effective throat section te for partial penetration welds [A1] (8.40)

- HAZ fillet welds:

$$\tau_{haz,Ed} \le \frac{f_{v,haz}}{\gamma_{Mw}}$$ [A1] at the fusion boundary and at the toe [A1] of the weld (full cross section) (8.41)

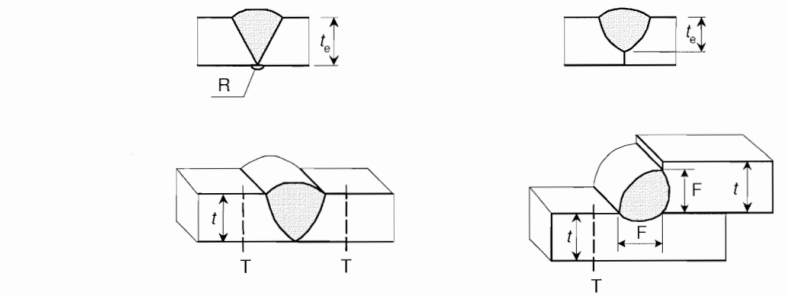
- HAZ butt welds:

$$\sqrt{\sigma_{haz,Ed}^2 + 3\,\tau_{haz,Ed}^2} \le \frac{f_{u,haz}}{\gamma_{Mw}}$$ [A1] at the toe of the weld (full cross section) for full penetration welds and effective throat section te for partial penetration welds [A1] (8.42)

- HAZ fillet welds:

[A1] $$\sqrt{\sigma_{haz,Ed}^2 + 3\,\tau_{haz,Ed}^2} \le \frac{f_{u,haz}}{\gamma_{Mw}}$$ at the fusion boundary and at the toe of the weld (full cross section) (8.43) [A1]

Symbols see 8.6.3.4a) and b).




The line F = HAZ in the fusion boundary; the line T = HAZ in toe of the weld, full cross section,
$t_e$ = effective throat section, R = root bead

**Figure 8.21 - Failure planes in HAZ adjacent to a weld**



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# 7 CONCLUSION

# CONCLUSION

- Partial factors are harmonized between the codes – compatibility guaranteed
- The in-built material database in IDEA is missing
- E1 – hardening is different between Al and Steel
- The user-defined material with elasto-plastic material properties can be used. EN 1999-1-1 supports the bilinear diagram with hardening and plastic limit up to user definition.
- The vicinity of welding area is undergoing the softening – the HAZ material properties need to be used – feasible in IDEA StatiCa with user-defined properties on material side.
- Code-checks for standard and prestressed steel bolts are compatible with the current setup in IDEA StatiCa == no problem to do the code-check.
- Weld code-checks are also compatible based on the Von-Mises failure criterion

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