5. Connections of stainless steel elements
Mechanical bolted and other connections, welding, materials for connection. Design of connections. Execution of connections.

Bolted connections

Materials
- stainless steel bolts, nuts and washers acc. to EN ISO 3506. The strength and corrosion resistance should be at least equivalent to parent material:

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<th>Class</th>
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<tbody>
<tr>
<td>50</td>
<td>210 MPa</td>
<td>500 MPa</td>
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<tr>
<td>70</td>
<td>450 MPa</td>
<td>700 MPa</td>
</tr>
<tr>
<td>80</td>
<td>600 MPa</td>
<td>800 MPa</td>
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Note: Bolts of other material (carbon or galvanized steel) should be avoided. In connection of carbon and stainless steels the use of non-metallic insulating washers and bushes is necessary (otherwise bimetallic corrosion occurs, see chapter 6).

- stainless steel washers acc. to EN ISO 7089 and 7090 are greater in size,
- common are screwing bolts (EN ISO 3506), used in connection of sheeting, (their resistance should be determined by testing),
- preloaded high strength bolts may be used only if proved by tests.

Design of bolted connections
The procedure is the same as for carbon steel (EN 1993-1-8).

Dissimilarities:
- Classes 50, 70, 80 are to be treated as bolt Classes 4.6, 5.6, 8.8
- shear resistance:
  \[ F_{V,Rd} = \frac{\alpha f_{ub} A}{\gamma M_2} \]
  \( \alpha = 0.6 \) (unthreaded shank in shear)
  \( \alpha = 0.5 \) (threaded part in shear)

- bearing strength:
  common calculation as for carbon steel, i.e.:
  \( k = 2.5 \) (bearing area)
  \[ F_{b,Rd} = k_1 \alpha_f f_d t / \gamma_w^2 \]
  but with strength \( f_u \) replaced by reduced value: \( f_{u,red} = 0.5 f_y + 0.6 f_u \) but \( f_u \leq f_{u,red} \)
Welded connections

- Common welding processes can be used, with stainless steel consumables, without preheating (except MAG process → causing decomposition of CO₂, pickup of carbon and chromium oxidation).
- At welds a drop in corrosion resistance may occur ("weld decay" → proper consumables, process and experienced welder is required.
- By welding stainless and carbon steels together, the weld and part of stainless steel must be painted as well as carbon steel.

Weldability of stainless steels (up to -40 °C).

- austenitic steels: insensitive to hot cracking, excellent toughness and ductility.
- duplex steels: insensitive to hot cracking, excellent toughness and ductility.

The stainless steels, subjected to prolonged heating of 550-900 °C, are prone to embrittlement and intergranular corrosion (if content of C > 0.03 %: carbon precipitates on grain boundaries to chromium carbide, steel is "sensitized"). This phenomenon is called "weld decay".

Note: Shielding gases are mixture of Ar, He, H₂ (possibly CO₂ max. up to 3%).
No hydrogen H₂ may be used for duplex (and ferritic or martensitic) steels.

Description of welding processes:

Electric arc processes

1. GTAW (Gas Tungsten Arc Welding) (=TIG=WIG): Arc between tungsten electrode and work piece, always direct current. Shielding gas Ar+He+H₂, workpiece thickness 0.5÷4 mm. Excellent quality of weld.
2. PAW (Plasma Arc Welding): As GTAW, but uses high-energy plasma stream with temperature 10000÷20000 °C produced by a nozzle (Ar) and also shielding gas. Workpiece thickness 0.1÷3.5 mm (up 10 mm for automatic keyhole process). Remarkable stability of the arc.
3. GMAW (Gas Metal Arc Welding) (=MIG): Gas Ar+ 2÷3%CO₂, Skill of welder is important.
4. FCAW (Flux Cored Arc Welding): Variant of GMAW, electrode composed of stainless steel sheath with core of flux (slag forming material, powdered metal). Efficiency, thickness 1÷5 mm.
5. SMAW (Shielded Metal Arc Welding) (=MMA): Manual welding with covered electrode (rutile = titania or basic = lime). Workpiece thickness of single run is 1÷2.5 mm; multipass 3÷10 mm.
6. SAW (Submerged Arc Welding): Automatic process, arc under powdered flux for stainless steels, forming slag. Mainly for heavy plates (10÷80 mm), current up to 2000 A. To avoid formation of a sigma phase subsequent annealing at 1050 °C is recommended.

Resistance processes

As for carbon steel (spot, seam, projection; flash), headed studs:
Finishing treatment for welds

“Heat tint” is often seen in weld affected areas (colours from straw to blue). It is necessary to remove weld spatter and brighten the area, usually by:

- Mechanical finishing (hammering, brushing with stainless steel brush, grinding, polishing).
- Acid pickling followed by passivation treatment and washing.

Practical procedure:

- By removal of welding slag and spatter handle with caution (to avoid damage of metal surface); it is recommended to protect the sheet surface adjacent to weld with plastic coatings.
- During grinding (by wheels with corundum of carborundum) do not exceed surface temperature 200 °C, otherwise arises heat discoloration.
- During polishing use fine-grained abrasive, low pressure (to exclude overheating).
- Pickling to remove coloured oxide (solution of nitrid acid + hydrofluoric acid + water), or using pickling pastes and gels for 15 minutes to 3 hours. After pickling all parts must be rinsed with chlorine-free water. Metal is then unprotected and passive layer must be restored.
- Passivation in acid bath (52 % nitric acid + water, in ration 1:3) for 15-60 min. Then carefully rinse with water.

Consumables for common stainless steels (acc. EN 1600, EN 12072, EN 12073):

1.4301 covered electrode E 19 9 wire G 19 9 L
1.4401 covered electrode E 19 12 2 wire G 19 12 3 L
1.4462 covered electrode E 25 7 2 N L wire G 25 7 2 L

Weld design

The procedure is the same as for carbon steel (EN 1993-1-8). Design strength of a weld in shear (for simplified method, instead of directional method):

\[ f_{\text{sw,d}} = f_{\mu} / \sqrt{3} \beta_w \gamma_{M2} \]

The difference: correlation factor for stainless steel \( \beta_w = 1.0 \).

It means, that the lower strength of the weld in shear is considered in comparison to carbon steel (in which the weld in shear as compared to parent material in shear is made more favourable by factor \( \beta_w = 0.8 + 0.9 \)).
Other types of stainless steel connections

• Thin sheeting, drains, ventilation tubes etc. may be joined by soldering:
  - solder from high-purity tin (melting point about 230 °C),
  - solver from tin-silver alloys or tin-lead alloys (215 ÷ 250 °C),
  - necessary to use suitable flux: orthophosphoric acid give excellent results,
  - when subjected to higher loading the joint parts should be fastened also by rivets or spot-welds.

• Joint of thin sheeting (0.4 ÷ 0.5 mm) by “standing seam method”:
  - single or double fold, by hand tools or folding machines.

• Continuously welded standing seam (commonly for steel 1.4404):
  - welding of standing joints by special machine with wheel electrodes and folding by another machine (watertight).

• Plasma and laser welding:
  - attains importance for industrial production of I, L profiles etc. (see next slide).

Laser welding (or cutting)

• concentrated beam (about 0.5÷1.0 mm) with high energy, giving narrow and deep weld (in one layer up to 12 mm);
• high quality (homogeneous weld without pores), small residual stresses and deformations;
• usually using shielding gas mixture of N₂, Ar, CO₂, He;
• welding without additional wire or with wire (for a wider gap).

Lasers:

• solid lasers
  (Nd:YAG laser - isotropic crystal of Yttrium Aluminium Garnet)

• gas lasers
  (e.g. CO₂ laser: mixture of He 80%, CO₂ ≤ 10%, N₂ ≤ 10%)

• semiconducting (diode lasers)