What is stainless steel?

- Corrosion resistant steel with chromium content >10.5%
- More than 200 grades, but only a few are commonly used in construction
Corrosion resistance mechanism

Passive film
- Transparent
- Adherent
- Forms spontaneously
- ~ 5 micron thick
- Self-healing
Groups used in construction

- Austenitic
- Duplex
- Ferritic
- Precipitation hardening
- Martensitic
## Characteristics of groups used in construction

<table>
<thead>
<tr>
<th>Group</th>
<th>Strength</th>
<th>Ductility</th>
<th>Magnetic</th>
<th>Weldable</th>
<th>Formability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austenitic</td>
<td>● ●</td>
<td>● ● ●</td>
<td>×</td>
<td>✓</td>
<td>● ● ●</td>
</tr>
<tr>
<td>Duplex</td>
<td>● ● ●</td>
<td>● ●</td>
<td>✓</td>
<td>✓</td>
<td>● ●</td>
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</tbody>
</table>
Grade characteristics

<table>
<thead>
<tr>
<th>Grade</th>
<th>Alloying elements</th>
<th>Relative durability</th>
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<tbody>
<tr>
<td><strong>Austenitics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>304 and 304L</td>
<td>Cr, Ni</td>
<td>●●●●</td>
</tr>
<tr>
<td>316 and 316L</td>
<td>Cr, Ni, Mo</td>
<td>●●●●●●●●●●●●●●</td>
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<tr>
<td><strong>Duplexes</strong></td>
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<tr>
<td>‘Lean duplex’ e.g. LDX2101</td>
<td>Cr, Ni, Mo, N</td>
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</tr>
<tr>
<td>2205</td>
<td>Cr, Ni, Mo, N</td>
<td>●●●●●●●●●●●●●●</td>
</tr>
</tbody>
</table>
Why use stainless steel?

- Corrosion resistance and long life
- When maintenance & inspection is difficult
- Attractive metallic surface
- Hygienic properties
- Non-magnetic properties
- Good toughness at very low temperatures
Grade selection 1

1) General environment & direct surroundings
   - distance from sea
   - presence of de-icing salts
   - exposure to washing from rain
   - access for maintenance & inspection

2) Strength

3) Welding and fabrication
Grade selection 2

4) Surface finish
   - Less risk of staining/pitting with smoother finish

5) Customer’s expectations
   - Aesthetic requirements
   - Design life

6) Product form
   - Not all grades available in all product forms/sizes
Grade selection 3

7) Temperature of operation
   - High temps might speed up corrosion
   - Low temps need a grade with good toughness

8) Special requirements
   - Non-magnetic properties

9) Availability within required time

10) Cost
    - Material cost and whole life costs
<table>
<thead>
<tr>
<th></th>
<th>AISI</th>
<th>EN</th>
<th>UNS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ASTM A240</td>
<td>EN 10088</td>
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<tr>
<td>Basic Cr-Ni</td>
<td>304</td>
<td>1.4301</td>
<td>S30400</td>
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<tr>
<td>austenitic</td>
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<td></td>
<td></td>
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<tr>
<td>Basic Cr-Ni</td>
<td>304L</td>
<td>1.4307</td>
<td>S30403</td>
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<tr>
<td>austenitic</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Cr-Ni-Mo</td>
<td>316</td>
<td>1.4401</td>
<td>S31600</td>
</tr>
<tr>
<td>austenitic</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lean duplex</td>
<td>316L</td>
<td>1.4404</td>
<td>S31603</td>
</tr>
<tr>
<td></td>
<td>1.4435</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duplex</td>
<td>LDX2101®</td>
<td>1.4162</td>
<td>S32101</td>
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<tr>
<td></td>
<td>2304</td>
<td>1.4362</td>
<td>S32304</td>
</tr>
<tr>
<td></td>
<td>2205</td>
<td>1.4462</td>
<td>S32205</td>
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</tbody>
</table>
Chinese stainless steel material standards

- GB/T 20878-2007 Stainless and heat-resisting steels – designation and chemical composition
- GB/T 4237-2007 Hot rolled stainless steel plate, sheet and strip
- GB/T 3280-2007 Cold rolled stainless steel plate, sheet and strip
Austenitic grades 304 and 304L

- Standard Cr-Ni grade
- Most common grade in construction
- Suitable for external rural and light urban environments
- ‘L’ = low carbon content
- Suitable for cryogenic applications
- Available in a wide range of product forms
Austenitic grades 316 and 316L

- Cr-Ni-Mo grade
- Widely used grade in construction
- Suitable for urban, industrial and coastal environments
- ‘L’ = low carbon content
- Suitable for cryogenic applications
- Available in a wide range of product forms
Lean duplex grades 2101 and 2304

- Relatively new, not yet widely used in construction
- Cr with very low additions of Ni & Mo
- Corrosion resistance between 304 & 316
- Available in a few product forms
- Twice as strong as 304 & 316
- Not suitable for service temps > 300°C
Duplex 2205

- Most common duplex grade, but not yet widely used in construction
- Highly alloyed Cr-Ni-Mo
- Suitable for severely corrosive environments e.g. heavy industrial, coastal, de-icing salts
- Available in a reasonably wide range of product forms
- Twice as strong as 304 & 316
- Not suitable for service temps > 300°C
Does stainless steel ever stain or corrode?

- If the wrong grade is selected for the environment,
- or if there is exposure to unexpected conditions
- or if the component is not cleaned, then...

...some grades may be susceptible to localised corrosion
Pitting

- Starts as tiny points of attack
- Usually in chloride environments
- Rarely leads to structural damage
- Corrosion products cause surface staining

*Prevent by:*
- Regular cleaning
- Appropriate grade selection
Crevice Corrosion

- Stagnant solutions – build-up of chlorides and lack of oxygen

- Between nuts and washers, around the thread of a screw, under deposits on steel surface

*Prevent by:* - Careful detailing – no crevices
- Appropriate grade selection
Poor detail

Good detail

Detailing for durability
Bimetallic (Galvanic) Corrosion

- Metals in contact of different electro-chemical potential in a conducting liquid
- Less noble metal (anode) corrodes faster than if metals not in contact
- Area effect
- Don’t use carbon steel bolts in stainless steel members

Prevent by: - Excluding water (painting/taping)  
- Isolating the metals
Stress Corrosion Cracking (SCC)

- Rarely occurs in structural applications
- Tensile stresses + chloride environment + temperatures above 65°C

*Prevent by:*  Appropriate grade selection

*Swimming pool environments can be particularly aggressive*
Surface Iron Contamination

- Iron particles from carbon steel brushes, tools etc embed in surface of stainless steel and rusts within hours/days
  Stainless steel appears to be rusting

Prevent by:
- Using a quarantined work area
- Not using carbon steel tools or equipment on stainless steel
- Protect surface with plastic film
Stress-Strain Characteristics – low strain

Carbon steel (grade S355)

Duplex stainless steel

Austenitic stainless steel
# Mechanical properties

<table>
<thead>
<tr>
<th>Grade</th>
<th>Strength N/mm²</th>
<th>Ductility %</th>
<th>Stiffness N/mm²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Austenitic stainless</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>304 and 304L</td>
<td>220-250</td>
<td>40</td>
<td>200,000</td>
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<tr>
<td>316 and 316L</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Duplex stainless</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>‘Lean duplex’ e.g. 2101</td>
<td>400-450</td>
<td>20</td>
<td>200,000</td>
</tr>
<tr>
<td>2205</td>
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<tr>
<td><strong>Carbon steel</strong></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>S355</td>
<td>355</td>
<td>22</td>
<td>210,000</td>
</tr>
</tbody>
</table>
Design standards – Eurocode 3

- Eurocode 3 Part 1.4: 2006
  Design of steel structures.
  Supplementary rules for stainless steels
- Welded, hot rolled & cold formed members
- Austenitic, duplex (and ferritic) grades
- Modifies and supplements rules for carbon steel where necessary
- Applies to buildings, bridges, tanks etc
Stainless steel exhibits fundamentally different behaviour to carbon steel.

Carbon steel has a sharply defined yield point with a plastic yield plateau. Stainless steel exhibits gradually yielding behaviour, with high strain-hardening.
Design of tension members, columns & beams

- In general use same approach as for carbon steel
- But use lower buckling curve for buckling of columns and unrestrained beams
Comparison of AISC flexural buckling curves for carbon steel & proposed curve for stainless steel
Comparison of AISC lateral torsional buckling curves for carbon steel & proposed curve for stainless steel
Deflections

- Non-linear stress-strain curve means that stiffness of stainless steel $\downarrow$ as stress $\uparrow$
- Deflections are greater in stainless steel than in carbon steel
- Use secant modulus at the stress in the member at the SLS
Design of bolted connections

- Rules for carbon steel bolts in clearance holes can generally be applied to stainless steel (tension, shear)
- Special rules for bearing resistance are required to limit deformation due to high ductility of stainless steel
Design of welded connections

- Carbon steel design rules can generally be applied to stainless steel
- Use the correct consumable for the grade of stainless steel
- After welding stainless to carbon steel, the painted coat on the carbon steel should extend over the weld & 5 cm onto the stainless steel
Strength reduction at high temperatures

\[ k_{0.2p,\theta} = \frac{f_{0.2p,\theta}}{f_y} \]

- **\( k_{0.2p,\theta} \)** = strength reduction factor at 0.2\% proof strain
- **\( k_{2,\theta} \)** = strength reduction factor at 2\% total strain
Stiffness reduction at high temperatures

$k_{E,\theta} = \frac{E_\theta}{E}$

![Graph showing stiffness reduction factors for Carbon Steel and Stainless Steel as temperature increases.](image)
How sustainable is stainless steel?

- Durability and low maintenance *(Economic)*
- Appearance *(Social)*
- No coatings needed *(Environmental, Economic)*
- Recyclable and reusable *(Environmental)*
  - 70% scrap content, 100% recyclable
  - No change in inherent properties
  - High value ensures recovery
- Factory production *(Environmental, Economic, Social)*
  - minimum waste
  - high standards of health and safety
Resources for structural engineers

European Design Manual
- Design guidance
- Worked examples
- Commentary
- Online design software

www.steel-stainless.org/designmanual

Stainless in Construction Information Centre

www.stainlessconstruction.com
Design guidance aligned to British Standards

- Guidance
- Design examples
- Tables of design data

Online design software:
www.steel-stainless.org/uksoftware
Erection & Installation of Stainless Steel Components

www.euro-inox.org

Computer aided learning on stainless steel:

www.steel-stainless.org/steelcal

Fabrication of duplex stainless steels

www.imoa.info