Chapter 04
What are the stainless steels?
Videos

100 Years of Stainless Steel
https://youtu.be/E-GcuxtWcnc

Alloyed for Lasting Value
https://youtu.be/l4Z1UVWm3DE

Self-repairing for Lasting Value
https://youtu.be/ngnT6dYo-M0
Stainless steels are Iron-base alloys containing at least 10.5% chromium.

Increasing Cr content increases the effectiveness of the passive film... but there are other important factors that influence the corrosion resistance (see Chapter 5).
What are stainless steels?

Stainless steels

Martensitic

Plain chromium stainless steels that can be strengthened by heat treatment.
10-17%Cr
0.1-1.2%C
0-4%Ni

Ferritic

Plain chromium stainless steels, but with low carbon levels, therefore cannot be strengthened by heat treatment.

Generally considered to have poor weldability with the exception of the utility grades

Martensitic structure

Ferritic structure

Add carbon

Add nickel

Duplex structure

Add more nickel

Austenitic

Ni containing stainless steels. Most common grades which accounts for 70% of all stainless steel usage.

Excellent corrosion resistance and associated secondary properties. Suitable for a wide range of applications.

Austenitic structure

Conventional Cr Ni (Mo) Austenitic

Mn N Cr Ni Heat resistant Austenitic

Mixed ferrite - austenitic crystal structure (duplex)

Higher levels of Cr and lower levels of Ni as compared to the austenitic grades. Contain nitrogen.

High strength and good corrosion resistance. Weldable

Lean Duplex

Duplex

Super Duplex

Magnetic

Non-magnetic

Plain chromium (Cr)

Nickel (Ni) addition

Iron (Fe) + Chromium (Cr)
Cr-Ni Grades (Austenitics)\(^4\)

### Sub-groups:
- **Cr-Ni** Typically EN 1.4301/AISI 304  \(\text{Cr: 18} \quad \text{Ni: 9} \quad \text{Fe: Balance}\)
- **Cr-Ni-Mo** Typically EN 1.4401/AISI 316  \(\text{Cr: 18} \quad \text{Ni 10} \quad \text{Mo: 2.5} \quad \text{Fe: Balance}\)

### Common Properties:
- Very good corrosion resistance, increases with alloy content
- ... but can be susceptible to SCC in hot chloride environment (e.g. swimming pools)
- High ductility and impact resistance at all (including very low) temperatures
- Strength can be increased by cold working (but not by heat treatment)
- Very good fire resistance
- Very good cold and hot forming properties (ductility, elongation)
- Easy to weld (TIG, MIG)

The best known and still the most used today
Cr-Mn Grades (Austenitics with Manganese) \(^5\)

**Typical grade:**

- Cr-Mn-Ni-N  Typically EN 1.4372/AISI 201  Cr: 17  Mn: 7  Ni: 4  N:0.15  Fe: Balance

**Common Properties:**

- Lesser corrosion resistance
- ... but far more susceptible to SCC and to pitting, particularly at low Ni and Cr levels
- Higher strength
- Poor cold forming properties due to high work-hardening
- Poor machinability
- More difficult to weld
- Cost less than Cr-Ni Austenitics ... but more than Cr ferritics

Used mostly in India and China
Cr Grades (Ferritics)$^6$

**Sub-groups:**
- **Cr** Typically EN 1.4016/AISI 430  Cr: 17  Fe: Balance
- **Cr-Mo** Typically EN1.4521/AISI 444  Cr: 18  Mo: 2  Ti+Ni: 0.4  Fe: Balance

**Common Properties:**
- **Insensitive to Stress Corrosion Cracking**
- Good ductility (lower than austenitic grades, though)
- Not suitable for use at very low temperatures
- Strength can be somewhat increased by cold working (but not by heat treatment)
- Very good cold forming properties: (less springback, lower tool wear but lower elongation requires a different deep drawing process compared to austenitics)
- Stabilized grades (i.e. with Nb and/or Ti) are easy to weld (TIG, MIG)

Offer an optimum performance/cost for many applications and are increasingly used.

Colour code: ▪ Corrosion resistance ▪ Mechanical properties ▪ Fabrication
Cr Grades (Martensitics)\textsuperscript{7}

<table>
<thead>
<tr>
<th>Sub-groups:</th>
<th>Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-Cr</td>
<td>Typically EN1.4021/AISI 420 Cr: 13 C:0.2 Fe: Balance</td>
</tr>
<tr>
<td>C-Cr-Ni</td>
<td>Typically EN1.4057/AISI431 Cr: 16 Ni: 2 C: 0.2 Fe: Balance</td>
</tr>
<tr>
<td>Precipitation Hardening</td>
<td>Typically EN1.4542/AISI630 Cr: 17 Ni: 4 Cu:4 Fe: Balance</td>
</tr>
</tbody>
</table>

**Common Properties:**

- **Fair to good corrosion resistance, increases with alloy content**

- **High strength** obtained by heat treatment (not by cold work). Limited elongation.
- Not suitable for use at very low temperatures
- Not suitable for forming, often processed by machining
- Can be welded (TIG, MIG), but require usually post-weld heat treatment

**Are used as engineering steels with corrosion resistance**
Duplex (Austenitic-Ferritic)⁸

Sub-groups:

<table>
<thead>
<tr>
<th>Sub-group</th>
<th>En1.4362</th>
<th>Cr: 23</th>
<th>Ni: 4</th>
<th>Fe: Balance</th>
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</thead>
<tbody>
<tr>
<td>Cr-Ni</td>
<td>Typically</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr-Ni-Mo</td>
<td>Typically</td>
<td>Cr: 22</td>
<td>Ni: 5</td>
<td>Mo: 3</td>
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</tbody>
</table>

**Common Properties:**

- Excellent corrosion resistance, increases with alloy content
- **Insensitive to Stress Corrosion Cracking**
- **High strength**, good ductility
- Strength can be increased by cold working (but not by heat treatment)
- Good cold and hot forming properties (ductility, elongation)
- Weldable (TIG, MIG)

**Colour code:**

- **Corrosion resistance**
- **Mechanical properties**
- **Fabrication**

Offer the best combination of corrosion resistance and mechanical properties
### Physical properties$^9, 10$

<table>
<thead>
<tr>
<th>Materials</th>
<th>Modulus of Elasticity Gpa</th>
<th>Thermal Expansion Coefficient $10^{-6}°K^{-1}$</th>
<th>Thermal Conductivity $W m^{-1}°K^{-1}$</th>
<th>Ferro-Magnetism</th>
<th>Density Kg/dm$^3$</th>
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<tbody>
<tr>
<td>Cr-Ni Austenitics</td>
<td>210</td>
<td>18</td>
<td>15</td>
<td>No</td>
<td>7.8</td>
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<tr>
<td>Cr-Mn Austenitics</td>
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<td>17</td>
<td>15</td>
<td>No</td>
<td>7.8</td>
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<tr>
<td>Cr Ferritics</td>
<td>220</td>
<td>11</td>
<td>23</td>
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</tr>
<tr>
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<td>14</td>
<td>15</td>
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<td>30</td>
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<td>12</td>
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<td>Copper</td>
<td>135</td>
<td>17</td>
<td>380</td>
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<tr>
<td>Aluminum</td>
<td>70</td>
<td>22</td>
<td>230</td>
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<tr>
<td>Glass</td>
<td>65</td>
<td>9</td>
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<tr>
<td>Concrete</td>
<td>48</td>
<td>10</td>
<td>1</td>
<td>No</td>
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</table>
Standards on Stainless Steels

Main World Standards:

<table>
<thead>
<tr>
<th>ISO</th>
<th>EN</th>
<th>ASTM/AISI</th>
<th>UNS</th>
<th>JIS</th>
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<tr>
<td><img src="image" alt="ISO" /></td>
<td><img src="image" alt="Europe" /></td>
<td><img src="image" alt="USA" /></td>
<td><img src="image" alt="USA" /></td>
<td><img src="image" alt="Japan" /></td>
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</tbody>
</table>

Notes:
Most countries refer to the above standards, which are widely accepted. A lot of the grades are very similar in all of the above standards.

List of the American Standards: ref 11
List of European Standards: ref 12

Correspondance tables are available: refs 13 - 15
Main grades in Architecture Building and Construction: EN 10088-4 (for sheet/plate/strip)\textsuperscript{16, 17}

<table>
<thead>
<tr>
<th>Grade</th>
<th>ASTM UNS</th>
<th>C Wt%</th>
<th>Cr Wt%</th>
<th>Ni Wt%</th>
<th>Mo Wt%</th>
<th>Other Wt%</th>
<th>Typical use \textsuperscript{3,4}</th>
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</thead>
<tbody>
<tr>
<td>4003</td>
<td>S40977</td>
<td>0,02</td>
<td>11,5</td>
<td>0,5</td>
<td>-</td>
<td>-</td>
<td>heated and unheated interiors</td>
</tr>
<tr>
<td>4016</td>
<td>430</td>
<td>0,04</td>
<td>16,5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>decorative interior cladding</td>
</tr>
<tr>
<td>4509</td>
<td>S43932</td>
<td>0,02</td>
<td>18</td>
<td>-</td>
<td>-</td>
<td>Nb Ti Ti</td>
<td>inland roofing and rainwater goods - often Tin-coated for patina</td>
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<tr>
<td>4510</td>
<td>439</td>
<td>0,02</td>
<td>17</td>
<td>-</td>
<td>-</td>
<td>Ti Ti</td>
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<tr>
<td>4521</td>
<td>444</td>
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<td>-</td>
<td>2,1</td>
<td>Ti Ti</td>
<td>domestic plumbing market</td>
</tr>
<tr>
<td>4301</td>
<td>304</td>
<td>0,04</td>
<td>18,1</td>
<td>8,1</td>
<td>-</td>
<td>-</td>
<td>building interiors and exteriors in normal industrial atmospheres away from the coast</td>
</tr>
<tr>
<td>4307</td>
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<td>10,1</td>
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</tr>
<tr>
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<td>316</td>
<td>0,04</td>
<td>17,2</td>
<td>10,1</td>
<td>2,1</td>
<td>-</td>
<td>permanently wet applications, locations in a coastal atmosphere, polluted industrial atmospheres or near roads where de-icing salts can be an issue</td>
</tr>
<tr>
<td>4404</td>
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<td>17,2</td>
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<tr>
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<tr>
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<td>N, Cu</td>
<td>road tunnels and indoor swimming pools</td>
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</tr>
<tr>
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</tbody>
</table>

ABC = Architecture, Building and Construction
Main grades in Architecture Building and Construction: EN 10088-5 (for bars/wires/sections)\textsuperscript{18}

<table>
<thead>
<tr>
<th>Grade</th>
<th>ASTM UNS</th>
<th>C Wt%</th>
<th>Cr Wt%</th>
<th>Ni Wt%</th>
<th>Mo Wt%</th>
<th>Other Wt%</th>
<th>Typical use \textsuperscript{6}</th>
</tr>
</thead>
<tbody>
<tr>
<td>4003</td>
<td>S40977</td>
<td>0,02</td>
<td>11,5</td>
<td>0,5</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>4016</td>
<td>430</td>
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<td>16,5</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Slate hooks</td>
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<tr>
<td>4542</td>
<td>630</td>
<td>0,04</td>
<td>16,0</td>
<td>4,0</td>
<td>-</td>
<td>Cu,Nb</td>
<td>Tie bars</td>
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<td>304</td>
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<td>-</td>
<td>-</td>
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<td>4307</td>
<td>304L</td>
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<td>8,1</td>
<td>-</td>
<td>-</td>
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<tr>
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<td>17,1</td>
<td>8,6</td>
<td>-</td>
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<tr>
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</tr>
<tr>
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<td>24,8</td>
<td>6,5</td>
<td>N, Cu</td>
<td>Road tunnels and indoor swimming pools</td>
</tr>
<tr>
<td>4547</td>
<td>S31254</td>
<td>0,01</td>
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<td>18,0</td>
<td>6,1</td>
<td>N, Cu</td>
<td></td>
</tr>
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<td>4362</td>
<td>S32304</td>
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<td>3,6</td>
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<td>N, Cu</td>
<td>Rebar and mechanical components</td>
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<td>4462</td>
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<td>N</td>
<td>Rebar and mechanical components</td>
</tr>
</tbody>
</table>
Breakdown of the stainless steel production worldwide by family
High Ni prices favour the replacement of popular CrNi grades by Cr-Mn or Cr Grades. Duplex grades marginal today, are expected to grow in the future.
World stainless meltshop production (slab/ingot equivalent)
What are stainless steels?
What are stainless steels?

References (1/2)


Thank you!

Test your knowledge of stainless steel here:

https://www.surveymonkey.com/r/3BVK2X6