Stainless Steel

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Outline

1. What is Stainless Steel?
2. Principles
3. Types and Grades
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What is Stainless Steel?
What is Stainless Steel?

- Alloy steels that have at minimum of 10.5 wt% of Chromium (Cr) content
- Chromium content prevents rusting = “stainless”
- Usually no more than 30% Cr or less than 50% iron
- Other alloy elements contribute to their properties
What is Stainless Steel?

- Discovered in the early 1900s by French, German and UK metallurgists
- Developed through the 20th century
- Improved production in 1970s through the argon-oxygen decarburization (AOD) process = more alloys, more widespread
- From aesthetic and consumer uses to industrial and medical uses.
What is Stainless Steel?

<table>
<thead>
<tr>
<th>Application</th>
<th>Percentage (2001)</th>
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<tbody>
<tr>
<td><strong>Industrial equipment</strong></td>
<td></td>
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<tr>
<td>Chemical and power engineering</td>
<td>34</td>
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<tr>
<td>Food and beverage industry</td>
<td>18</td>
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<tr>
<td>Transportation</td>
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<tr>
<td>Architecture</td>
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<tr>
<td><strong>Consumer goods</strong></td>
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<tr>
<td>Domestic appliances, household</td>
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<tr>
<td>utensils</td>
<td></td>
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<tr>
<td>Small electrical and electronic</td>
<td>6</td>
</tr>
<tr>
<td>appliances</td>
<td></td>
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</tbody>
</table>

Source: [https://matdata-s.asminternational.org/asm/CONTENT/MH/D09/A01/index.html/](https://matdata-s.asminternational.org/asm/CONTENT/MH/D09/A01/index.html/)
What is Stainless Steel?
What is Stainless Steel?
Principles
Principles

• Stainless steel “rusts” and it’s a good thing!

• High chromium content reacts with environment and develops a adherent and very thin chromium-oxide layer on surface that protects
  • a.k.a. “Passive Layer”

• Similar to rust on carbon steel – but is tightly adherent and does not expand in volume

• Requires constant oxygen to form and maintain and self-heal

• If covered or oxygen depleted, it can rust similar to carbon steel – or worse depending on environment
Principles

Chromium Oxide

Iron Oxide (Rust)

Base Metal

Stainless Steel

Base Metal

Carbon Steel

Source: https://www.rolledalloys.com/technical-resources/environments/oxidation/
Principles

1. Chromium oxide layer protecting stainless steel
2. Chromium oxide layer damaged (by machining)
3. Chromium oxide layer reformed automatically

Source: https://cougartron.com/blog/best-passivation-method-stainless-steel/
Types and Grades
Types and Grades

Two production types:

• Wrought – hot worked, forged, ie. rolled sheet, most common
• Cast – poured into a mold, ie. investment cast

Five categories based on microstructure:

• Austenitic
• Ferritic
• Duplex
• Martensitic
• Precipitation-hardening
**Austenitic**

- Most common - “base” stainless steel
- Non-magnetic due to crystal structure (FCC)
- Easy to process and form for different uses
- Can have high Ni, Cr composition
- AISI Grade series: 200 and 300
- Typical grades: 304 and 316
- “L” designates low-carbon – better for welding

Source: https://www.azom.com/article.aspx?ArticleID=12731
Types and Grades

Ferritic

- Magnetic due to BCC crystal structure
- Can’t be heat treated
- Lower strength, but good SSC resistance
- Cheaper
- High chromium (Cr), low Ni
- AISI Grade series: 400
- Typical grades: 430 and 446

Source: https://www.azom.com/article.aspx?ArticleID=12731
Types and Grades

Duplex

- Magnetic
- Mix of austenite and ferrite
- Combines positives from austenitic and ferritic
- AISI Grade 329
- Typically UNS grades, specially designated or trade names (ie.

Source: https://www.azom.com/article.aspx?ArticleID=12731
**Types and Grades**

### Martensitic

- Magnetic due to BCT crystal structure
- Heat-treated: Quench and tempered
- High yield strengths
- Low Ni, low Cr, higher Carbon content
- AISI Grade series: 400
- Typical grades: 410 and 420

Source: https://www.azom.com/article.aspx?ArticleID=12731
Types and Grades

Precipitation-hardening

- Known as PH alloys

- Addition of other elements (Cu, Ti, Al, etc.)

- Can be hardened by aging heat treatment

- Austenitic, semi-austenitic and martensitic types

- High yield strengths, better corrosion resistance than martensitic SS

- Typically UNS or trade name grades

Types and Grades

Things to note

- Don’t rely on the “magnet test”
  - only austenitic SS is non-magnetic
  - other types (ferritic, duplex and martensitic) becoming more common

- Each grade is designed for different types of service and environments
  - One grade may work well in one environment and not another

- IEEE transformer enclosures: 304L and 316L are specified
  - generally appropriate for most conditions
  - relatively cost-effective (easy to produce) vs more specialized grades
  - other grades should be considered based on severity of service environment
Challenges
Corrosion

- Stainless steel can be subjected to the same corrosion phenomena as carbon steels if the passive layer is removed.

- Design and service considerations have to be made to prevent corrosion – cannot rely on the material alone.

- Galvanic corrosion is the most typical for stainless steel due to lack of foresight.
Challenges

Galvanic Corrosion

- Dissimilar metals in contact
- Metal which is more active in the galvanic series corrodes
- Potentially rapid corrosion rates (driving force)
- Easy to remedy (replace or separate)

Dissimilar Metals

- Typically mild steel hardware in contact with the stainless steel

- Ensure all SS hardware and the tank is the same grade as the different grades of SS may have a different potentials

- Potentials can also change if the stainless steel loses its passive oxide layer – may accelerate corrosion rate!
Challenges

Source: https://commons.wikimedia.org/wiki/File:Stainless-steel-mild-steel.jpg
Iron Contamination

- Iron particles in dust or from contact with corroded steel

- Could be from the fabrication plant atmosphere, incorrect blast media, incorrect wire brush (i.e., steel used on stainless)

- Can initiate active corrosion – breakthrough of the passive layer

- Surface may look rusty

- Can transfer the contamination to contents (i.e., oil)
Challenges

Iron Contamination

• Passivation treatment after stainless steel components are assembled

• Acidic solution or gel, also called “pickling”

• Process: cleaned (remove grease, etc), put in solution/gel, water rinsed, repeat

• Helps build uniform and thicker chromium-oxide layer after exposure to oxygen
Challenges

Source: https://www.anopol.com/pickling/
Challenges

Welding

- Can be subject to “sensitization”

- High-temp can precipitate carbides at the grain boundaries which can promote intergranular corrosion

- Preferential attack at the weld heat-affected zones

- Lower carbon contents mitigate this effect

- Usually handled by using “L” grades of stainless (ie. 316L)
Challenges

Challenges
Challenges

Source: http://www.amteccorrosion.co.uk/stainlesssteel.html
Welding

- Can also cause crevice corrosion due to weld flux and entrained slags
- Lack of fusion creates “microfissures” or “hot cracks” which can allow accelerated corrosion

Source: https://www.researchgate.net/figure/Microphotograph-of-the-hot-crack-in-austenitic-weld-metal-30_fig5_250166825
Challenges

Coatings

- Emissivity concerns for transformer performance

- Stainless steels are typically very smooth, proper surface preparation is key

- Clean prep and paint environment to prevent iron contamination

- Blast media – no steel grit

- Entrained contaminants can lead to accelerated corrosion
Challenges

Coatings

- **Holidays may perform similar to steel if passive layer is missing**
  - Paint application may block the formation of a strong passive layer
  - Oxygen depletion in the holiday = minimal passive layer formation

- **Cost comparison vs well-coated steel enclosures**
  - More than 4 times the material cost at current prices
  - Additional cost of SS tank + hardware + coating for emissivity

- **Maintenance concerns – risk of galvanic corrosion from improper replacement hardware**

- **Cost vs. benefit**

Questions?

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Thank You!

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