Corrosion Discussion

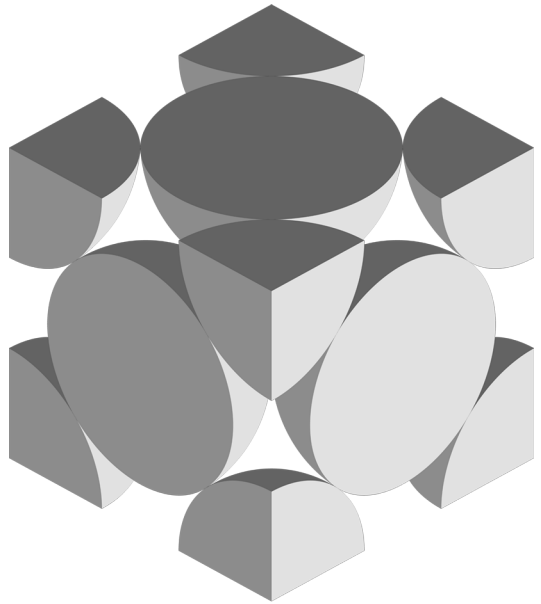
Guide for Mitigating Corrosion on Subsurface Transformers

Glenn Stark, MBA, P.Eng.

e: glenn@starkengineering.ca

m: (604) 363-4664

w: www.starkengineering .ca



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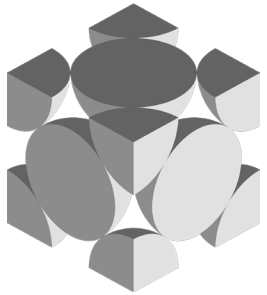
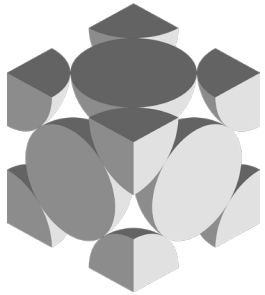
Introduction

- Who am I and what am I doing here?
- Professional Engineer and Materials Engineering Consultant.
- 20+ years of experience practicing in the areas of corrosion engineering, failure analysis, non-destructive testing (NDT), and welding engineering (amongst others).
- Here to share a bit of what I know about corrosion and fabrication to hopefully provide context to your discussions regarding preparation of your guide.



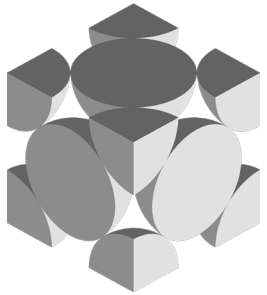
Overview

- Corrosion Resistance of Copper-Bearing Steels.
- Galvanic/Dissimilar Metal Corrosion.
- Stainless Steels (including Type 304 and 316).
- Fabrication of Stainless Steel Enclosures.
  - Tools.
  - Passivation.
- Microbiologically Influenced Corrosion (MIC).



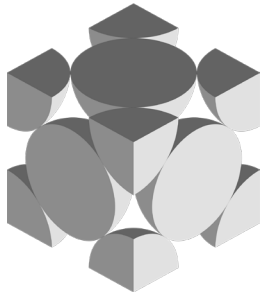
Corrosion Resistance of Copper Bearing Steels

- Copper Bearing Steels – aka Weathering Steels.
- They generally offer better atmospheric corrosion resistance than plain carbon steels, but only under specific conditions.
- They require cycling between wet and dry conditions to offer their enhanced corrosion protection.
- They do not perform well in marine environments (chlorides).
- Not appropriate for submerged applications (Guide Reference §6.2.1).
- Must avoid crevices and pockets that retain water (Guide Reference §5.3).



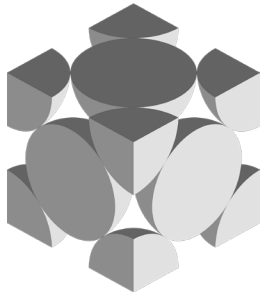
Galvanic Corrosion

- Dissimilar metals in electrical contact with each other in the presence of an electrolyte creates an electrochemical cell.
- Preferential corrosion of the less/least noble metal.
- Effectively we've made a battery.



Galvanic Corrosion

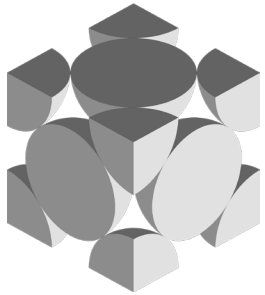
- Example: copper/copper alloy components in contact with steel enclosures (e.g., grounds attached to enclosures).
- Copper and its alloys are more noble (-0.35 to -0.40 V*) than low alloy steels (-0.60 to -0.65V) on the Galvanic Series.
- Copper/copper alloy components are the cathode.
- Low alloy steel is the anode.
- The anode preferentially corrodes.



*Relative to a saturated Calomel Reference Electrode

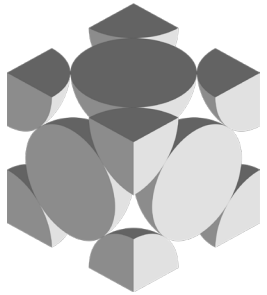
Galvanic Corrosion

- Galvanic Series in Seawater of Common Metals (descending order from most noble):
  - Graphite: 0.20 to 0.25V (MOST NOBLE)
  - Platinum: 0.20 to 0.22V
  - Titanium: -0.05 to 0.05V
  - Type 316 SS (Passive Condition): -0.10 to 0.00V
  - Type 304 SS (Passive Condition): -0.10 to -0.05V
  - Silver: -0.15 to -0.10V
  - Lead: -0.25 to -0.20V
  - Copper: -0.40 to -0.30V
  - Low Alloy Steel: -0.65 to -0.60V
  - Aluminum Alloys: -1.00 to -0.75V
  - Zinc: -1.05 to -1.00V
  - Magnesium: -1.65 to -1.60V (MOST ACTIVE/LEAST NOBLE)



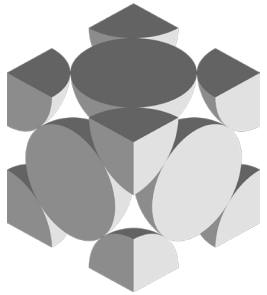
Galvanic Corrosion

- Guide Reference §5.1 *Elimination of All Bare Metal*.
  - 1st Paragraph: good suggestion to barrier coat any bare metal.
- Guide Reference §5.2 *Insulation of Grounding System Conductors*.
  - Typically recommend electrically isolating dissimilar metals: not possible with grounding systems.
  - Remove the possibility of an electrolyte developing between the dissimilar metals.
    - Encapsulate connection locations (similar to NO-OX).



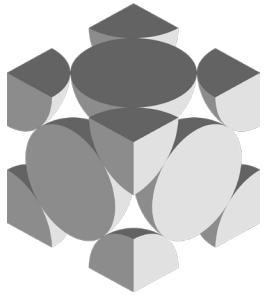
Stainless Steels - Overview

- Stainless steel alloys are a vast material category with five main families:
  1. Austenitic Stainless Steels (AISI Type 3xx Series).
  2. Ferritic Stainless Steels (e.g., AISI Types 409 and 430).
  3. Duplex Stainless Steels (e.g., 2205).
  4. Martensitic Stainless Steels (e.g., AISI Types 410 and 415).
  5. Precipitation-Hardening Stainless Steels (e.g., 17-4PH).
- Type 304 is by far the most common alloy most people think of when they hear stainless steel.
  - All around, average, corrosion resistant steel.



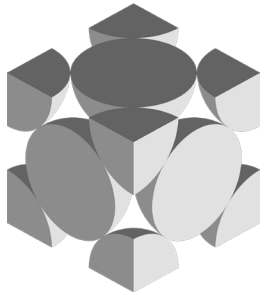
Stainless Steels - Overview

- Basic metallurgy of all stainless steels:
  - A steel is considered stainless if it contains a minimum of 12 weight percent chromium (Cr).
  - The mechanism by which a stainless steel gains its corrosion resistance in atmospheric environments:
    - Chromium on the surface of the steel very aggressively bonds with oxygen in the atmosphere to form chromium oxides (passivation).
    - A layer of chromium oxide builds up on the surface of the steel forming a barrier between the exposure environment and the underlying steel.
    - When regions of the coating/barrier are damaged, the underlying chromium grabs oxygen and reforms the barrier (self-passivating).



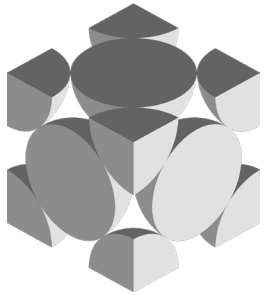
Type 304/304L SS in Marine Atmospheric Environments

- Type 304 SS:
  - Good general corrosion resistance in most natural *atmospheric* environments.
  - Pitting corrosion resistance is not great, especially in chloride bearing (marine) environments. This leads to corrosion pitting.
- Type 316 SS:
  - Developed specifically to combat the corrosion pitting problems experienced Type 304 SS, primarily through the addition of molybdenum (~2.5 weight % Mo addition).
  - Even Type 316 SS has an upper threshold for chloride content, beyond which it will actively corrode.



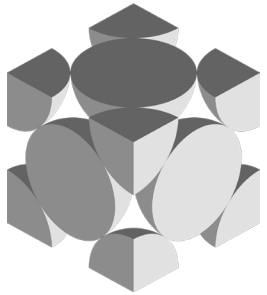
Type 304/304L SS in Marine Immersion Environments

- Both Type 304 and 316 suffer deep corrosion pitting and crevice corrosion in immersion service in seawater, especially in stagnant or near stagnant conditions.
- To gain good corrosion resistance in immersion service, alternate specialty stainless steel alloy or other alloy system is required.



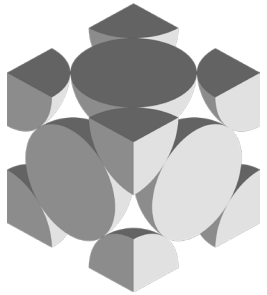
Type 3xx (Austenitic) SS in Marine Environments

- Type 3xx Series (austenitic) stainless steels can suffer from stress corrosion cracking (SCC) in hot, chloride containing environments.
- SCC needs 3 things to occur:
  1. Susceptible alloy.
  2. Tensile stress in the component.
  3. Environmental constituent.



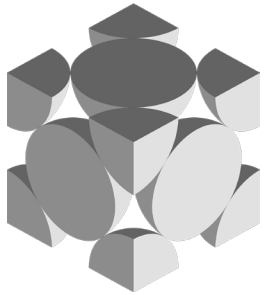
Stainless Steels – Guide References

- Guide Reference §6.2.2 - First Paragraph – there are several electrochemical parameters to use to assess aggressivity. Suggest a framework like:
  - Atmospheric Exposure: ISO 9223 *Corrosion of Metals and Alloys, Corrosivity of Atmospheres – Classification, Determination and Estimation* and ISO 9224 *Corrosion of Metals and Alloys, Corrosivity of Atmospheres – Guiding Values for the Corrosivity Categories*.
  - Soil (Buried) and Water (Immersion) Exposure: DIN 50 929 *Corrosion of Metals – Corrosion Likelihood of Metallic Materials when Subject to Corrosion from the Outside – Part 3: Buried and Underwater Pipelines and Structural Components*.
  - Soil (Buried) Exposure: AWWA C105 *Polyethylene Encasement for Ductile-Iron Pipe Systems*, *Appendix A – Notes on Procedures for Soil Survey Tests and Observations and Their Interpretation to Determine Whether Polyethylene Encasesment Should Be Used*.



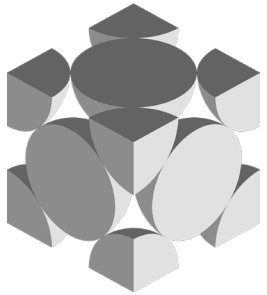
Stainless Steels – Guide References

- Guide Reference §6.2.2 – Second and Third Paragraphs – remember that neither Type 304 or 316 perform well in stagnant, saltwater immersion service.
- Guide Reference §6.2.2 – Fourth Paragraph – Agree that not all stainless steels are appropriate for immersion service in saltwater, including Type 316.



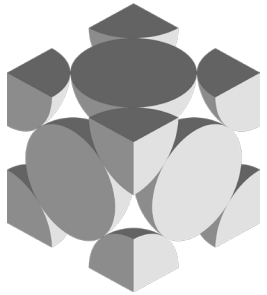
Stainless Steels – Guide References

- Guide Reference §7.1 – Title suggests that this section is discussing weathering steels (see Slide 4), but the text discusses the use of stainless steels.
  - Type 304 in less aggressive environments.
  - Type 316 in aggressive environments in combination with cathodic protection.
  - Again: neither Type 304 or Type 316 does well in stagnant immersion service with chlorides.



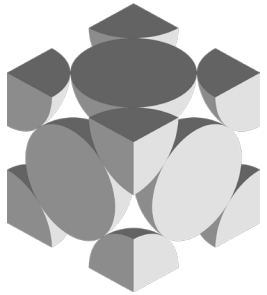
Fabrication of Stainless Steel Enclosures - Tools

- Stainless steel fabrication must be segregated from carbon steel fabrication.
- ONLY stainless steel wire brushes and wheels and non-steel bearing blast media (e.g., glass beads) can be used on stainless steel fabrication (Guide Reference §7.2.2).
- If carbon steel wire wheels, brushes, or blast media are used on stainless steel:
  - A thin layer of carbon steel transfers to the stainless steel surface, which then interrupts the normal self-passivating behaviour of the stainless.
  - The transferred carbon steel will actively corrode.
  - Once exhausted the corrosion will proceed into and through the stainless steel as though the chromium isn't present.
  - Carbon steel contamination is effectively poison to stainless steel fabrication.



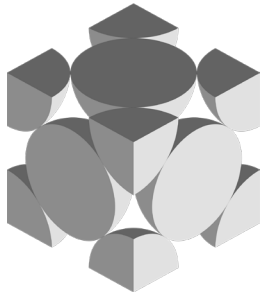
Fabrication of Stainless Steel Enclosures - Passivation

- Passivation of stainless steel welds: forcing the natural passivation process further into the stainless steel surface, including heat affected zone (HAZ) of welds, where chromium depletion can occur. Encourages a full passive layer to form and protect a welded structure (Guide Reference §7.2.2).
- Chemicals are aggressive and if not completely (100%) removed (washing and rinsing) can remain on the finished surfaces and cause significant problems.



Microbiologically Influenced Corrosion (MIC)

- Guide Reference §5.6.2.
- MIC does not just occur in environments where biological activity is high (like raw sewage).
- The micro-organisms associated with MIC are ubiquitous in our environment (found in everything from dam intakes to drinking water systems, fresh and seawater).
- Often a suite or ecosystem of several classes of micro-organisms working together.
- Under some conditions, they can cause extensive damage in a very short amount of time.
- There are kits that can help determine what classes of micro-organisms are present in an environment.



QUESTIONS & DISCUSSION

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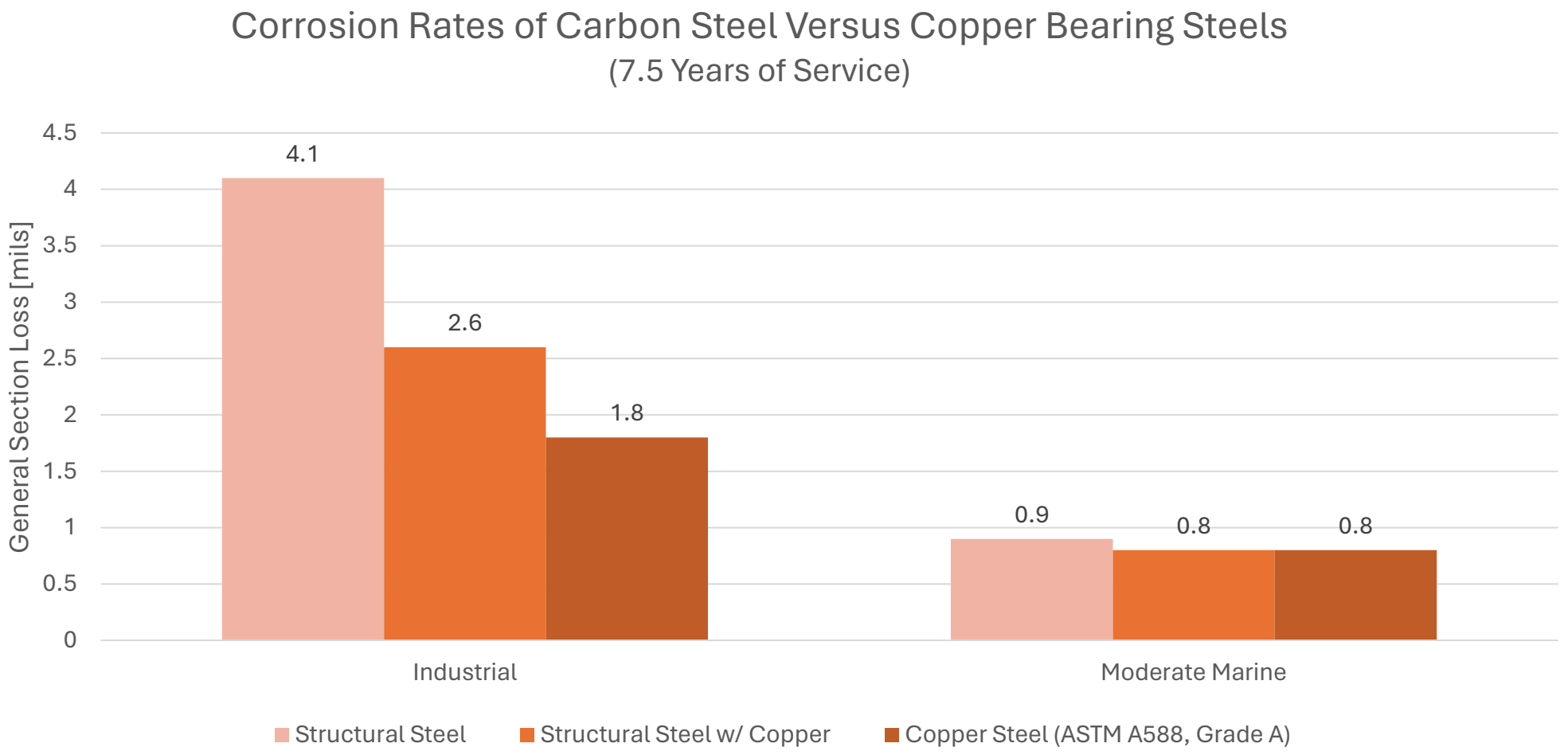
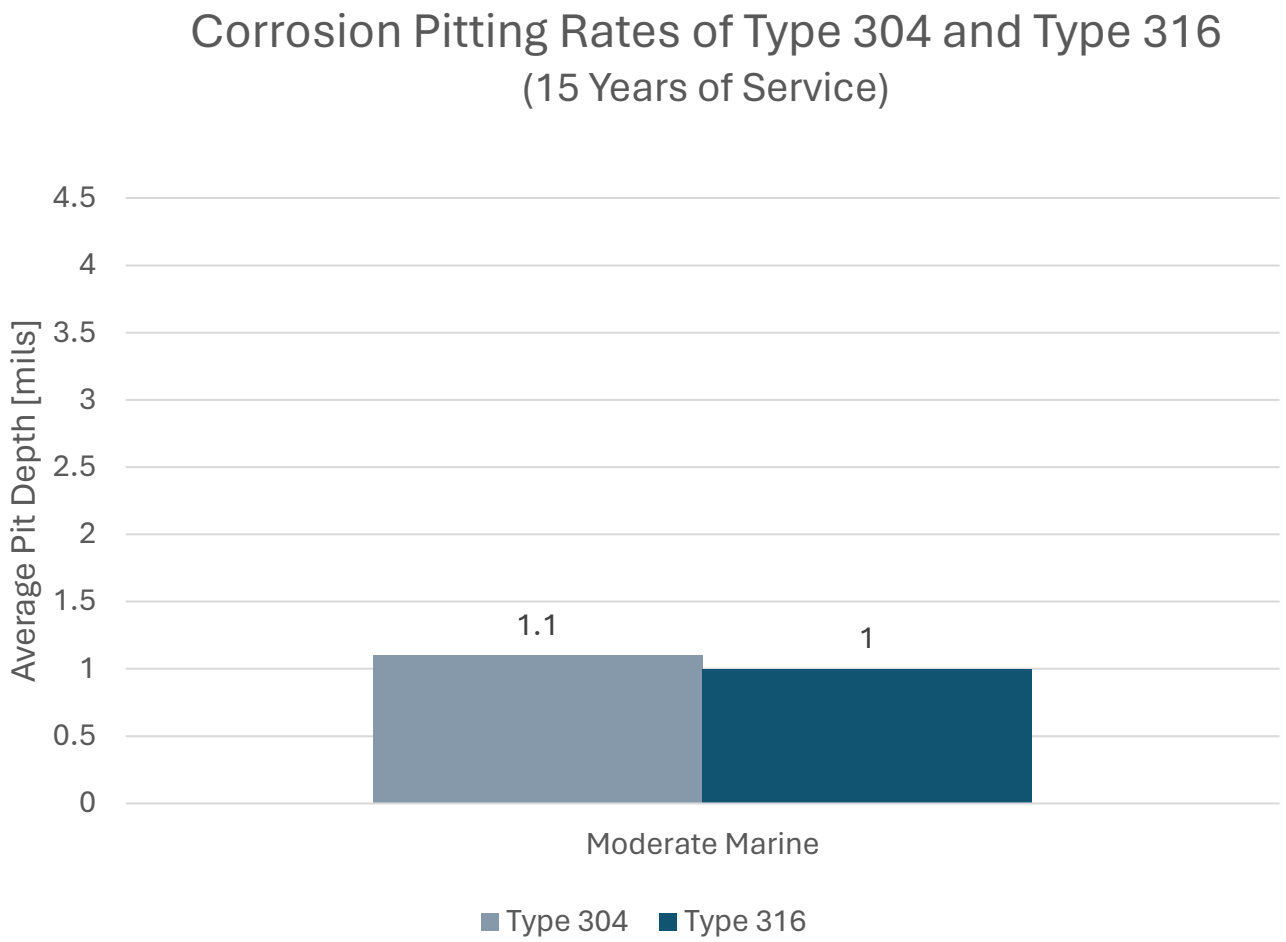
Corrosion Resistance of Copper Bearing Steels



Moderate Marine: Kure Beach, NC, 250m from the ocean
Ref: NACE Corrosion Engineer's Reference Book, 3rd Edition

Atmospheric Corrosion Resistance of Type 304 and 316



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