Competitive Threats to Titanium: Chromium-Bearing Alloys

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October 7, 2013
Presentation Overview

*Ti Competition from Fe-Cr and Ni-Cr Alloys:*

- CP Ti vs. Adv. Stainless Steels in **Cooling Waters**
- Ti Alloys vs. Ni-Cr-Mo Alloys in **Oilfield OCTG**
- Ti Aluminide vs. Ni Superalloys in **Gas Turbines**
- Ti Alloys vs. High-Strength Steel in **Landing Gear**
- Ti-6242 vs. Ni-Cr Alloys for **Hot Pylon Sheet Parts**

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Process Plant Cooling Systems

- Chemical/Petrochem/Power Gen./Oil Refinery/Offshore platforms
- **Seawater** (coastal) and/or **recycled water streams**
- Cold-hot, naturally-aerated, **chloride-rich** streams
Process Cooling Competition/Threat

- Evolution of Duplex Stainless Steels (increase Cr+Mo to better resist aqueous chlorides)
- 22% Cr (DSS) $\rightarrow$ 25% Cr (Super-Duplex SS)
- **Super Duplexes:** 2507, Xeron 100, Uranus 52N
  
  [25%Cr-4%Mo-7%Ni-0.25%N]

- **Other competitor:** 6 Moly Super-Austenitic Stainless Stl
  
  AL-6XN

  [20%Cr-6%Mo-(18-25)%Ni-0.2%N]
## Comparative Features

<table>
<thead>
<tr>
<th>Aspect</th>
<th>CP Titanium</th>
<th>Super Duplex SS</th>
<th>6 Moly Super-Austenitic SS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride Resistance Limits</td>
<td>~175°F (~80°C)</td>
<td>95-120°F (35-50°C)</td>
<td>85-112°F (30-45°C)</td>
</tr>
<tr>
<td>Chlorinated SW or Recycled Water</td>
<td>No effect</td>
<td>Reduces limits</td>
<td>Reduced limits</td>
</tr>
<tr>
<td>Weld Corrosion Resistance</td>
<td>Same as wrought</td>
<td>Reduced limits</td>
<td>Reduced limits</td>
</tr>
<tr>
<td>Bio-Attack/ MIC Resistance</td>
<td>Immune</td>
<td>Resistant</td>
<td>Susceptible</td>
</tr>
</tbody>
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<tbody>
<tr>
<td>Weldability</td>
<td>Robust, proper gas shielding</td>
<td>More complex, component specific, sensitive to heat input &amp; HAZ effects</td>
<td>Robust, proper gas shielding, possible HAZ effects</td>
</tr>
<tr>
<td>Product Availability</td>
<td>Lower volume and availability</td>
<td>Larger production/Supply base/infrastructure</td>
<td>Larger production/Supply base/infrastructure</td>
</tr>
<tr>
<td>Component Price</td>
<td>Higher price (even on volumetric basis)</td>
<td>~30% lower</td>
<td>~5-10% lower</td>
</tr>
</tbody>
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Corrosion—Resistant Alloy Price Comparison

0.25" Plate Prices On a Volumetric Basis -2013

<table>
<thead>
<tr>
<th>Material</th>
<th>Price Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super DSS</td>
<td>0.7</td>
</tr>
<tr>
<td>6Mo SS</td>
<td>0.9</td>
</tr>
<tr>
<td>Gr. 2 Ti</td>
<td>1.0</td>
</tr>
<tr>
<td>Cu-Ni</td>
<td>1.2</td>
</tr>
<tr>
<td>Ni-Cr-Mo</td>
<td>2.9</td>
</tr>
</tbody>
</table>

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Gr2 Ti Now Dominates Worldwide in Seawater-Cooled Power Plant Steam Surface Condensers

- No Ti corrosion-related failure in over 40 years service
- Competition from superferritic stainless steel (Seacure) primarily in North America
- Superferritic SS susceptible to localized attack (crevice/MIC) and hydrogen embrittlement
- Similar in tube cost, but SS may have cost edge in condenser tube retrofits

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Continued CP Titanium Penetration

Navy ship and oil platform seawater coolers
(need for high reliability for critical, remote exchangers, and weight reduction)

- CP Ti is fully SW resistant, light-weight, and now very competitive with traditional Cu-Ni coolers

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Key Points – Competition in Cooling Waters

- Advanced Stainless competition/threat primarily limited to lower -temp. (<120 degF) cooling waters, and may be further limited by MIC/bio-activity (stagnant conditions), chlorination, and/or weld condition.

- With it’s current attractive relative price, CP Titanium’s enhanced range of chloride/MIC/weld resistance makes it preferred for cold, warm, and hot service conditions:
  (power plant, process plant, and refinery cooling systems; multi-stage evaporator desalination components, offshore platform cooling/process equipment)

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Key Points- Competition in Cooling Waters

- Titanium component supply base/infrastructure must continue to expand to compete with these Advanced SS alloys.

- Vital that Ti component suppliers ensure that designers/users properly utilize/integrate titanium into systems

(address galvanic compatibility, welding practice, optimal design for Ti’s unique combination of properties)
Offshore Hydrocarbon Production

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Ti Alloy Oilfield Production Strings (OCTG)

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## Comparative OCTG Features

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<tr>
<th>Aspect</th>
<th>Ti Alloy</th>
<th>Ni-Cr-Mo</th>
</tr>
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<tbody>
<tr>
<td>HPHT Sour Fluids</td>
<td>Highly resistant to 500-550°F</td>
<td>Resistant to ~450°F</td>
</tr>
<tr>
<td>Strength (Min. 0.2%YS)</td>
<td>125-135 ksi</td>
<td>Typically 125 ksi</td>
</tr>
<tr>
<td>Tubular String Weight</td>
<td>~50% lower (high YS/density)</td>
<td>Heavy (high axial loading)</td>
</tr>
</tbody>
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<tr>
<td>Producibility</td>
<td>Up to large ODs and 40 ft. lengths</td>
<td>Cold-worked OD and/or length limits</td>
</tr>
<tr>
<td></td>
<td>Need fully conditioned surfaces</td>
<td>Less surface condition/contamination concern</td>
</tr>
<tr>
<td>Use/History/Availability</td>
<td>Limited (geothermal well casing/OCTG joint prototypes)</td>
<td>Substantial in deep sour wells over past 20 yrs. (larger, proven production/infrastructure supply)</td>
</tr>
<tr>
<td>Tubular Price</td>
<td>~10 times steel</td>
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High-End OCTG Arena

- Current HPHT sour reservoirs 300-450°F
- Current HPHT onshore/offshore well depths ≤30-35K ft. (where Ni-Cr-Mo OCTG works)

⇒ deeper, hotter, more sour (favors Ti)

**Near-Future:** drill to 40-50K ft. depths

( Ti Alloys favored where enablement is key)
Ti Alloy vs. Ni-Cr-Mo OCTG Competition

- Ni-Cr-Mo preferred selection in current HPHT sour gas well arenas
- **Ti Alloys become favored where:**
  - Ultra-deep well string weight limits
  - Ni-Cr-Mo use beyond ~35K ft. depth
  - Deep gas wells of large OCTG size and wall
  - Wells where field development economics favor ultra/extended horizontal-reach drilling/completion (>20K ft.)
TiAl for Jet and Automobile Engines
High Temperature and Low Density

- GE GEnx engine for Boeing 787 airplane
- Last two stages of low pressure turbine blades
- Replace nickel-base superalloy cast blades
- Other engines are in development

- Turbocharger wheels
- Diesel engine – 1470°F (800°C)
  Gasoline engine – 1830°F (1000°C)
- Now mostly for diesel engines in Europe
- Environmental requirements
- Replace nickel-base superalloy cast wheels

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Aircraft Landing Gear

- Traditionally made by very high strength steels such as 300M and AerMet 100 (~300 ksi tensile strength)

- Boeing 777 is the first commercial airplane using titanium alloy (Ti-10-2-3, 170 ksi) for landing gear

- Ti-5553 (180 ksi) is used for Airbus 380 and Boeing 787 landing gear

- Airbus 350 and Boeing 777-X will also use titanium landing gear

- Smaller airplanes such as 737 MAX and A320 NEO will still use steel landing gear; volume limitation is the main reason
High Temperature Sheet Materials

- **Alloy Ti-6242** [1000°F (540°C) max. temperature] sheet is commonly used for making SPF parts near aircraft pylon area

- New engines have higher exhaust gas temperatures. Parts may experience higher temperatures that Ti-6242 cannot withstand.

- Nickel-base alloy sheet is a solution with **heavy weight penalty**

- Airframe manufacturers want to have a titanium alloy with temperature capability higher than Ti-6242 to avoid using nickel-base alloy sheet