Qualifying Ultrahigh-Strength, Corrosion Resistant Landing Gear Steel for Flight

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6/23/08
Outline

• QuesTek Innovations
  – *Materials by Design®*

• *Ferrium S53®*
  – Background
  – Properties
  – Processing

• Demonstration/Implementation

• Conclusions
QuesTek- Materials Solutions
Ferrium S53: A Nanostructured UHS Corrosion-Resistant Steel

Accidents by Aircraft System
Commercial Jet Transport Aircraft
1958-1993

Issues:
- Over $200 million spent in LG per year
- 80% corrosion related
- SCC failures
- Cad plating used to protect current steel known carcinogen (Hill AFB ~ 2000 lbs/yr)

Benefits:
- Dramatic reduction in LG cost (60%) savings of $120 million per year
- Significant reduction in SCC failures
- Cadmium plating not required
- General corrosion mitigated
- 80% of Steel Condemnations Avoided

Source: FLIGHT SAFETY FOUNDATION-FLIGHT SAFETY DIGEST-DECEMBER 1994
Ferrium S53 Design

**PROCESSING**
- Tempering
- Solution Treatment
- Hot Working
- Solidification
- Deoxidation
- Refining

**STRUCTURE**
- Matrix
  - Lath Martensite
  - Ni: Cleavage Resistance
  - Co: SRO Recovery Resistance
  - Cr: Corrosion Resistance
- Strengthening Dispersion
  - (Cr,Mo,V,Fe)_2C
  - Avoid Fe}_3C, M}_5C, M}_7C}_3, M}_23C}_6
- Passive Film Formation
  - Cr partitioning into oxide film
  - Epp and icrit
- Microsegregation
  - Cr, Mo, V
- Grain Refining Dispersion
  - d/f
  - Microvoid Nucleation Resistance
- Grain Boundary Chemistry
  - Cohesion Enhancement: B, Re
  - Impurity Gettering: La, Ce

**PROPERTIES**
- Strength
  - σUTS ≥ 280 ksi
  - σYS ≥ 213 ksi
- Aqueous Corrosion Resistance
  - Similar to 440C
- Stress Corrosion Resistance
  - Improved Over 300M
- Fatigue Resistance
  - Exceeds that of 300M
- Core Toughness
  - KIC ≥ 50 kts/\sqrt{in}

*Materials by Design®*
Ferrium S53 Properties

Mechanical Properties
Fatigue
Corrosion
SCC
Strength vs. Toughness

![Graph showing typical fracture toughness vs. ultimate tensile strength for various materials.](image)

- 15-5PH
- 13-8Mo
- Custom 465
- AF 1410
- AerMet 100
- Ferrium S53
- 4340/300M

Materials by Design®

QUESTEK INNOVATIONS LLC

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Ferrium S53 Mechanical Properties

Ferrium S53 and 300M Average Longitudinal Properties:

<table>
<thead>
<tr>
<th></th>
<th>UTS (ksi)</th>
<th>YS (ksi)</th>
<th>El. (%)</th>
<th>RA (%)</th>
<th>Fcy (ksi)</th>
<th>Fsu (ksi)</th>
<th>Hardness (Rc)</th>
<th>CVN (ft-lb.)</th>
<th>Kic (ksi√in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S53</td>
<td>288</td>
<td>226</td>
<td>15</td>
<td>56</td>
<td>255</td>
<td>181</td>
<td>54</td>
<td>17</td>
<td>65</td>
</tr>
<tr>
<td>300M</td>
<td>284</td>
<td>237</td>
<td>9</td>
<td>38</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60</td>
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</tbody>
</table>

Ferrium S53 and 300M A-basis *Minimum* Longitudinal Properties:

<table>
<thead>
<tr>
<th></th>
<th>UTS (ksi)</th>
<th>YS (ksi)</th>
<th>El. (%)</th>
<th>RA (%)</th>
<th>Fcy (ksi)</th>
<th>Fsu (ksi)</th>
<th>Kic (ksi√in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S53</td>
<td>280</td>
<td>213</td>
<td>11</td>
<td>44</td>
<td>245</td>
<td>176</td>
<td>50</td>
</tr>
<tr>
<td>300M</td>
<td>280</td>
<td>230</td>
<td>8</td>
<td>30</td>
<td>247</td>
<td>162</td>
<td>--</td>
</tr>
</tbody>
</table>
SAE AMS 5922 Published

Steel, Corrosion-Resistant, Bars, and Forgings
10Cr - 5.5Ni - 14Co - 2Mo - 1W (0.19-0.23C)
Vacuum Induction Melted, Vacuum Arc Remelted, Normalized, Annealed

http://www.sae.org (877) 606-7323

Commercial Suppliers:
- Carpenter Technology
- Latrobe Specialty Steel
MMPDS Approved

Over 1200 data points from 10 production heats of AMS 5922 has been approved in MMPDS. The data will publish in MMPDS-05 and is currently available from MMPDS by request.

Longitudinal tensile data from 10 heats and over 300 lots
Longitudinal Notched Fatigue

Maximum Stress (ksi) vs. Nf (cycles to failure) for different materials and stress ratios.

- **Ferrium S53**
  - Kt = 3.2
  - R = 0.05
  - R = -0.33
  - R = -1.0

300M Trendline
- R = -0.33; Kt = 3.0
- R = -1.0; Kt = 3.0

**Materials by Design®**
Corrosion Fatigue, R = -0.33, Longitudinal

Corrosion Fatigue at R = -0.33
May 30, 2006

Tested at 40 Hz, in 3.5wt.% NaCl (following 20 hr presoak; pH ~7.0 per ASTM G47) or in air (no presoak).

All axial - fatigue, longitudinal, unpeened, ground specimens, tested at WMT&G per ASTM E466, at 72°F (GA PO #JA803051).

S53 specimens were passivated at Questek

UTS values:
- 289 KSI for 300M
- 285 KSI for S53
- 243 KSI for 4330V

Materials by Design®
Marine Exposure Studies (Kure Beach, NC)

Initial Studies: 3 months

PH 15-5 (195 ksi)  
~ 0.0005” pit depth

Follow-up Studies: 3 months

S53 (AMS 5922) (288 ksi)  
0.001” ~ 0.002” pit depth

Conclusions: Both 15-5 and S53 would require prime and paint in aggressive environments.
Outdoor Exposure Studies (Chicago, IL)
Evaluation of Surface Treated Test Panels Exposed in the Indoor Plating Shop
Atmosphere at Hill, AFB

Exposure Date: 6/20/2006
Inspection Date: 9/20/2006
Exposure Period: 3 Months

<table>
<thead>
<tr>
<th>Panel ID</th>
<th>Observation</th>
<th>Pre-Test Surface Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>209126-1</td>
<td>2&quot;</td>
<td>Ground + Grit-Blast + Passivation</td>
</tr>
<tr>
<td>209126-6</td>
<td>2&quot;</td>
<td>Ground + Passivation + Air Bake @375F for 23 hr</td>
</tr>
<tr>
<td>209126-10</td>
<td>2&quot;</td>
<td>Ground + Passivation</td>
</tr>
<tr>
<td>209193-4</td>
<td>2&quot;</td>
<td>Ground + Grit-Blast + Passivation + Air Bake @375F for 23 hr</td>
</tr>
<tr>
<td>209193-6</td>
<td>2&quot;</td>
<td>Ground + Passivation + Air Bake @475F for 23 hr</td>
</tr>
<tr>
<td>#14</td>
<td>2&quot;</td>
<td>Mill-annealed + Machined</td>
</tr>
</tbody>
</table>

Observation Comment List
2 - No visual change since last inspection
* - No corrosion spots detected
Stress Corrosion Testing

- ASTM F1624, 3.5wt% NaCl Solution

Range of S53 data measured at OCP. Measurements at OCP are difficult. The potentiostatic system is not able to hold the sample at OCP and drives the material anodic.

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Component Level Corrosion Test

- A-10 drag brace strut
- Salt solution is sprayed on threaded area. Caps are removed and placed back on to simulate inspection criteria.
- Cd plated 300M cylinder demonstrating worn-away zones of Cd on the thread zone
Ferrium S53
Demonstration Components
Demonstration Target Components

A-10 Main Landing Gear

- A-10 main landing gear piston (4330 – 240 ksi)
  - More complex loading
  - Forged component
  - Currently in production for spares

A-10 Nose Gear

- A-10 drag brace (300M - 270 ksi)
  - Simple tension loading
  - No forging required
  - Corrosion related failures

Materials by Design®

Questek Innovations LLC

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Demonstration

- A-10 Main Landing Gear Piston (4 Produced)
  - Analysis and Design to Achieve Final Qualification
  - Perform landing gear strut testing of S53 Main Landing Gear Piston to qualification standards
    - 3-Axis full scale fatigue test Per Mil-A-8866
    - Limit Load test
    - Ultimate Load test
  - Conduct a Field Service Evaluation with a fully processed (painted) component on an A-10 aircraft

- A-10 Nose Landing Gear Drag Brace Strut (7 Produced)
  - Qualification Testing
    - Ultimate Load test
    - Component Corrosion Testing
  - Conduct a Field Service Evaluation with a fully processed (painted) component on A-10 aircraft
Air Force Implementation

First Articles in Production for:

- T-38
- A-10
- F-15

Identified 31 components over 10 platforms for potential implementation of S53

- Flight safety
- Condemnation frequency
Conclusions

• Drivers for value
  – Reduced part condemnation
  – Eliminates Cadmium
  – Improved SCC
  – Reduces risk of Hydrogen embrittlement
  – Reduces risk of grinding burns
  – Extends overhaul interval

• Currently being implemented

• Commercially available
  – Carpenter Technology Corporation
  – Latrobe Specialty Steel
Questions?

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For material, contact:

• Carpenter Technology
• Latrobe Specialty Steel