Failure Analysis in Space: International Space Station (ISS) Starboard Solar Alpha Rotary Joint (SARJ) Debris Analysis

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Space Shuttle mission STS-117 delivered the S3/S4 truss segment to the ISS, which included a SARJ that rotates 360° to position the solar arrays facing the sun. Three months after installation, vibration was observed in a camera mounted on the SARJ, and an investigation commenced to find the source. Debris was collected from the starboard SARJ during an extra-vehicular activity (EVA) of STS-120 and returned to the Kennedy Space Center so that a remote failure analysis could be performed on Earth. A plan was formulated to identify the source of the debris and to determine the failure mechanism. This presentation will show the data from the analysis—including stereomicroscopy, scanning electron microscopy, energy dispersive spectroscopy, and laser confocal microscopy—and interpret the data in support of the failure analysis. The debris originated from the race ring and failure of the fragments appeared to be the result of contact stress fatigue.
Failure Analysis in Space
International Space Station (ISS) Starboard Solar Alpha Rotary Joint (SARJ) Debris Analysis

National Aeronautics and Space Administration
Kennedy Space Center, FL
The SARJ is 10 feet in diameter and rotates $360^\circ$ in order to keep the solar arrays facing the sun.
A plan was developed to identify the failure mechanism based on surface morphology and to determine the source of debris through elemental and particle analysis.

- Perform photodocumentation and stereomicroscopy.
- Conduct baseline studies on reference materials.
- Perform initial SEM/EDS analysis.
  - Variable pressure mode.
  - Backscattered electron detector.
- Remove several fragments from the tapes and examine via SEM.
- Mount and cross-section several fragments for metallographic analysis.
- Perform microhardness tests on the mounted fragments.

<table>
<thead>
<tr>
<th>Location</th>
<th>Plating</th>
<th>Material</th>
<th>UNS</th>
<th>C</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Fe</th>
<th>Mo</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>N</th>
<th>Al</th>
<th>Cu</th>
<th>Nb + Ta</th>
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<tbody>
<tr>
<td>Primary Ring</td>
<td>Nitrided 15-5 PH</td>
<td>S15500</td>
<td>.07 max</td>
<td>1.0 max</td>
<td>14-15.5</td>
<td>3.5-5.5</td>
<td>bal</td>
<td>0.04 max</td>
<td>0.03 max</td>
<td>1.0 max</td>
<td></td>
<td>2.5-4.5</td>
<td>0.15-4.5</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Rollers</td>
<td>Gold</td>
<td>440C</td>
<td>S44004</td>
<td>0.95-1.20</td>
<td>1.0 max</td>
<td>16-18</td>
<td>bal</td>
<td>0.75 max</td>
<td>0.04 max</td>
<td>0.03 max</td>
<td>1.0 max</td>
<td></td>
<td></td>
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<td></td>
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<td>Pinnions</td>
<td>Gold</td>
<td>13-8Mo</td>
<td>S13800</td>
<td>0.05 max</td>
<td>0.1 max</td>
<td>12.25-13.25</td>
<td>7.50-8.50</td>
<td>bal</td>
<td>2.0-2.5</td>
<td>0.01 max</td>
<td>0.008 max</td>
<td>0.1 max</td>
<td>0.1 max</td>
<td>0.9-1.35</td>
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<tr>
<td>Centering Spring</td>
<td>Ni-P</td>
<td>17-7 PH</td>
<td>S17700</td>
<td>0.09 max</td>
<td>1.0 max</td>
<td>16-18</td>
<td>6.5-7.75</td>
<td>bal</td>
<td>0.04 max</td>
<td>0.03 max</td>
<td>1.0 max</td>
<td></td>
<td>0.75-1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Potential Debris Compositions, wt.%. Highlighted boxes indicate the constituents that vary significantly between the expected alloys in the SARJ.

Source: ASM Handbook Vol. 1
• Following landing and de-stow, samples were delivered to the Materials Failure Analysis Laboratory.
• Three sample tapes were received for analysis and were photographed, as-received.
• Initial analysis was performed overnight.
Representative particles from the tapes.

- Wide particle size distribution.
- Distinct particle morphologies.
- Scale bars are 1 mm.
Overlay of representative spectrum from debris (red) on the baseline 15-5 PH spectrum. Nitrogen peak indicates that the debris is from the nitrided layer. The silicon peak is from the silicone adhesive used on the sampling tape.
Representative tape showing the analysis locations. The majority of the particles were nitrided 15-5 PH stainless steel.

Nitrogen observed throughout
Extrusion damage; possible agglomeration.

Gold particle showing atomic contrast.

Evidence of possible cleavage.

Original 15-5 PH nitrided surface with machine markings.
Nitrided 15-5 PH surface with machine markings on obverse (L) and flipped over revealing scalloped reverse (R).
Secondary electron (SE) SEM image of a fragment removed from tape and imaged under high vacuum.

Area in red box appears to be a fracture initiation site and elliptical region suggests crack arresting. Features typical of spalled fragments.
Backscattered electron image of outlined area in red box from previous slide showing atomic contrast.

X-ray elemental dot map of the boxed area, showing niobium-rich precipitates in an iron-rich matrix.
Backscattered electron image showing atomic contrast of the niobium-rich precipitates at typical subsurface fracture initiation sites.
SEM images showing the 3-dimensional topography of the SARJ fragments. Note the relatively flat fracture path and the sharp, perpendicular edges.
Confocal microscopy was used for in-situ (non-destructive) thickness measurements at 100X magnification of several particles.
Particle thickness measurements of a large particle in the SEM correlated with measurements taken using laser confocal microscopy, which were 100 to 165 µm for this particle.
• Specimens were ground, polished, and etched to examine the cross sectional microstructure.
• Real-time X-ray was utilized to locate the specimen in the metallographic mount and provide orientation and progress during polishing (right).
Typical nitrided stainless steel.

SARJ fragment cross section.

Microhardness of the mounted cross section was converted to approximately 71 Rockwell C (HRC).
The precipitates in the SARJ fragment were similar in size and distribution to stock 15-5 PH stainless steel.
Contact stress fatigue, i.e. spalling, with subsurface initiation:

- Location of origin — “Short distance below surface, usually at a nonmetallic inclusion”
- Initial size — “Small”
- Initial shape — “Irregular”
- Crack angle with respect to surface — “Roughly parallel at bottom, perpendicular at sides”
- Apparent occurrence — “Sudden”
KSC Engineering Directorate
Materials Science Division

Failure Analysis Team

Starboard SARJ Debris Failure Analysis Team at KSC:

Victoria Long        Peter Marciniak
M. Clara Wright      Thad Johnson
Steve McDanels       Phil Howard
Dave Lubas           Hae Soo Kim
Bryan Tucker          Kathy Loftin