Super Corr-A Solvent Replacement Study

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Battelle

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Overview

- Project Team
- Background & Objectives
- Technical Approach
- Test Matrix
- Laboratory and Field Testing – Results
- Conclusions
- Recommendations
Project Team

- **Primary Stakeholder** – F-16 SPO, 388th Fighter Wing
- **COTR** – Paul Hoth 501 ACSS/GFLB
- **Program Manager** – John Stropki
- **Task Leader** – Jim Tankersley

**Support Staff**
- Bill Abbott (Consultant)
- Annie Lane (Research Scientist)
- Jill Gregory (Researcher)

**Subcontractor Support**
- Lektro-Tech, Inc., Tampa, FL (Ron Knight and Robert Kay)
  - Assistance w/ solvent down-selection and formulation
- SMI, Inc., Miami, FL
  - Perform first article testing on new formulations
Background

• The Super Corr-A corrosion preventative compound (CPC) is qualified as a MIL-L-87177A, Type I, Grade B material for electrical connector applications
  - The Super Corr-A lubricant has had two solvent-related formulation modifications since 1994 (CFC-113 and HCFC-141B)
  - Super Corr-A has met or exceeded performance requirements in extensive evaluations by Hill AFB
• The current Super Corr-A formulation contains an HCFC AK225T solvent
  - Considered Class II Ozone Depleting Substances (ODS)
  - Banned in the European Union (EU) and Canada on 1 January 2009
• All maintenance and manufacturing operations in the EU requiring use of MIL-L-87177A are currently shutdown with no alternative replacement identified
• Unless a replacement solvent can be implemented, use of these ODSs will also be prohibited in the United States beginning in 2015
Objective & Approach

Objective:
Identify a more environmentally friendly and COTS alternative to the HCFC AK225T solvent currently in the Super Corr-A lubricant.

Program Approach:
• Research US and EU compliant solvents with chemistry compatible with Super Corr-A CPC
• Define material and performance requirements based on previous assessments of lubricants
• Conduct laboratory and field testing for comparative evaluation of the lubricant performance containing the alternative solvents
• As required, update MIL-L-87177A specification and associated process order
Test Matrix

• Test plan includes nine CPC formulations and one control
  1. Existing Super Corr-A formulation with AK225T solvent
  2. Previous Super Corr-A formulation with 141B solvent
  3-6. Super Corr-A formulated with 4 solvent candidates
      a. DuPont Vertrel® SDG w/ current concentration of CPCs
      b. DuPont Vertrel® SDG w/ higher concentration of CPCs
      c. Kyzen Cybersolv® 141R w/ higher concentration of CPCs
      d. Kyzen Cybersolv® 141R w/ current concentration of CPCs
  7. ILFC 1006 CON-TAC
  8. Zip-Chem D-5026NS
  9. Zip-Chem D-5026NS with alternative propellant (Noxit-86)
MIL-L-87177A Assessments

• SMI Laboratories conducted first article testing specified in MIL-SPEC to validate performance characteristic requirements of experimental lubricant formulations

• **Results:** New and old formulations of Super Corr-A do not meet first article requirements of MIL-L-87177A
  - Original formulations were never tested
  - Both formulations perform appropriately for intended application

• **Recommendation:** Update first article requirements and revise MIL-SPEC
  - Stakeholders include; Hill AFB, DLA-Richmond, AFRL/CTIO, and AFCPCO
<table>
<thead>
<tr>
<th>Requirement</th>
<th>Test Method Specification</th>
<th>Limit</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dryness</td>
<td>MIL-SPEC 4.6.1</td>
<td>0.0100 gram (max)</td>
<td>Failed</td>
</tr>
<tr>
<td>Flash Point</td>
<td>ASTM D1310</td>
<td>243 °C/470 °F (min)</td>
<td>Inconclusive</td>
</tr>
<tr>
<td>Dielectric Breakdown</td>
<td>ASTM D877</td>
<td>24,000 volts (min)</td>
<td>Failed</td>
</tr>
<tr>
<td>Lubricity</td>
<td>ASTM D226</td>
<td>1.20 mm wear scar diameter (max)</td>
<td>Failed</td>
</tr>
<tr>
<td>Residue Solubility</td>
<td>MIL-SPEC 4.6.3</td>
<td>No visible residue</td>
<td>Failed</td>
</tr>
<tr>
<td>Leakage</td>
<td>MIL-SPEC 4.6.4</td>
<td>No leakage or distortion</td>
<td>Passed</td>
</tr>
<tr>
<td>Content</td>
<td>MIL-SPEC 4.6.5</td>
<td>16 ounces (min)</td>
<td>Failed (container content 12 oz.)</td>
</tr>
<tr>
<td>Performance of pressurized containers</td>
<td>MIL-SPEC 4.6.6</td>
<td>Uniform spray, panel adherence, no sagging</td>
<td>Passed</td>
</tr>
<tr>
<td>Oxidation Stability</td>
<td>ASTM D942</td>
<td>&lt;5 pounds/100 hours</td>
<td>Failed</td>
</tr>
<tr>
<td>Grade B Corrosion</td>
<td>ASTM B117</td>
<td>No corrosion after 168 hours</td>
<td>Passed</td>
</tr>
<tr>
<td>Sprayability</td>
<td>MIL-SPEC 4.6.9</td>
<td>Sprayable w/ no clogs</td>
<td>Passed</td>
</tr>
</tbody>
</table>
Battelle Laboratory Results

• Grade B Corrosion Testing
  - Alternative Super Corr-A formulations showed improved corrosion resistance in salt fog exposure testing
  - Most extensive pitting damage noted with the control and CON-TAC
  - “Streaked” pitting noted on Noxit-86, D5026NS; may have been caused by formation and collection of water droplets along top edge
Battelle Laboratory Results - Connector Card Testing

Conditions:
- 1000 hours
- 80° C (176° F)

Requirements:
- ΔR < 10 milliohms

Results:
- All passed

Change in Contact Resistance Resulting from Thermal Aging Exposure Testing of Coated Electrical Connectors
Battelle Laboratory Results -
Low Temperature Testing

Conditions:
- 15 minutes @ each temperature

Requirements:
- $\Delta R < 10$ milliohms

Results:
- Only CPC No. 1 failed
Battelle Laboratory Results - Disturbance Cycle Testing

**Conditions:**
- 100 demate/remate cycles

**Requirements:**
- $\Delta R < 10$ milliohms

**Results:**
- All passed

Change in Contact Resistance Resulting from 100 Disturbance Cycles Completed on Coated Coupons attached to Connector Card
Battelle Laboratory Results - Class II Flowing Mixed Gas Testing

Conditions:
- 10 day exposure

Requirements:
- $\Delta R < 10$ milliohms

Results:
- CPCs No. 1 & 3, CON-TAC, and Noxit-86 failed
### Battelle Laboratory Results - Grade B Corrosion Testing

#### Photographs Documenting Placement of Coated Panels in ASTM B117 Salt Fog Cabinet and Corrosion Pitting Noted on Coupons Coated with CON-TAC CPC

<table>
<thead>
<tr>
<th>CPC</th>
<th>Panel 1</th>
<th>Panel 2</th>
<th>Panel 3</th>
<th>Average Score (Max: 5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5.0</td>
</tr>
<tr>
<td>CPC No. 1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2.0</td>
</tr>
<tr>
<td>CPC No. 2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1.3</td>
</tr>
<tr>
<td>CPC No. 3</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.0</td>
</tr>
<tr>
<td>CPC No. 4</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1.3</td>
</tr>
<tr>
<td>Super Corr A</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>2.0</td>
</tr>
<tr>
<td>Super Corr B</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>1.3</td>
</tr>
<tr>
<td>CON-TAC</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>4.7</td>
</tr>
<tr>
<td>Noxit-86</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2.7</td>
</tr>
<tr>
<td>D-5026NS</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>2.7</td>
</tr>
</tbody>
</table>

Salt Fog CPC Ratings Calculated from Pit Density Evaluation Referenced in ASTM G46-94 and ASTM D610-08
Battelle Laboratory Results - Polycarbonate Compatibility (canopies)

Consistent with previous testing, crazing noted with CON-TAC, AK225T (slight), 141-B (dramatic)

Polycarbonate Stressed Coupons: CON-TAC (left), Control (right)
## UC Laboratory Testing Results

### Ranking of EIS Data

<table>
<thead>
<tr>
<th>Product</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noxit86</td>
<td>1</td>
</tr>
<tr>
<td>D-5026NS</td>
<td>2</td>
</tr>
<tr>
<td>Super Corr-A</td>
<td>3</td>
</tr>
<tr>
<td>CPC-4</td>
<td>4</td>
</tr>
<tr>
<td>CPC-3</td>
<td>5</td>
</tr>
<tr>
<td>Super Corr-B</td>
<td>6</td>
</tr>
<tr>
<td>CPC-2</td>
<td>7</td>
</tr>
<tr>
<td>CON-TAC</td>
<td>8</td>
</tr>
<tr>
<td>CPC-1</td>
<td>9</td>
</tr>
<tr>
<td>Control (uncoated)</td>
<td>10</td>
</tr>
</tbody>
</table>
## Battelle Field Testing

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Tests</th>
<th>Test Reference</th>
<th>Sample Size</th>
<th>Time Periods</th>
<th>Replicates</th>
<th>Sample Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field Exposure Testing</td>
<td>Connector Field Testing</td>
<td>Abbott 1996 report</td>
<td>10 CPCs</td>
<td>3 (1 mo, 3 mo, 6 mo)</td>
<td>50 (pin count)</td>
<td>Test connectors with gold-plated bars (2 to a PC board)</td>
</tr>
<tr>
<td>Corrosion Coupons</td>
<td>Abbott 1996 report</td>
<td>10 CPCs</td>
<td>3 (1 mo, 3 mo, 6 mo)</td>
<td>1</td>
<td>Rack with 5 steel coupons</td>
<td></td>
</tr>
<tr>
<td>Lap Splice Testing</td>
<td>Rice 2004 report</td>
<td>10 CPCs</td>
<td>3 (1 mo, 3 mo, 6 mo)</td>
<td>1</td>
<td>Lap splice fixture with steel coupon fastened to 2024 T3 Al coupon</td>
<td></td>
</tr>
<tr>
<td>Steel Sensors</td>
<td>Recent Abbott work</td>
<td>10 CPCs</td>
<td>Measurements in place at 1 mo, 3 mo, 6 mo</td>
<td>1</td>
<td>Steel sensors</td>
<td></td>
</tr>
</tbody>
</table>

### Corrosion Coupons
![Corrosion Coupons Image]

### Lap Splice Fixtures
![Lap Splice Fixtures Image]

### Steel Sensor
![Steel Sensor Image]
Battelle Field Testing Results - Corrosion Testing Summary

<table>
<thead>
<tr>
<th>CPC</th>
<th>Average Weight Loss (g)</th>
<th>Average Corrosion Rate (mpy)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-5026NS</td>
<td>0.14590</td>
<td>2.22</td>
</tr>
<tr>
<td>CPC 2</td>
<td>0.21215</td>
<td>3.23</td>
</tr>
<tr>
<td>CPC 4</td>
<td>0.21465</td>
<td>3.27</td>
</tr>
<tr>
<td>Noxit 86</td>
<td>0.23494</td>
<td>3.58</td>
</tr>
<tr>
<td>CPC 1</td>
<td>0.32854</td>
<td>5.01</td>
</tr>
<tr>
<td>CPC 3</td>
<td>0.33280</td>
<td>5.07</td>
</tr>
<tr>
<td>Super Corr-A</td>
<td>0.33346</td>
<td>5.08</td>
</tr>
<tr>
<td>Super Corr-B</td>
<td>0.35096</td>
<td>5.35</td>
</tr>
<tr>
<td>CON-TAC</td>
<td>0.43267</td>
<td>6.59</td>
</tr>
<tr>
<td>Control</td>
<td>0.51872</td>
<td>7.91</td>
</tr>
</tbody>
</table>

*Average for each CPC over the 4 month period with the three location sets combined

CPC Lubricant Ranking of Coated Corrosion Coupons
Based on Weight Loss
Battelle Field Testing Results - Summary

• The worst corrosion resistance was measured for the control or uncoated coupon sets,

• The best corrosion resistance was measured for the coupon sets coated with the D-5026N lubricant,

• The corrosion resistance of the CPC-2 lubricant was only slightly lower than the performance measured for the D-5026N material,

• The corrosion related performance of the coupons coated with the Noxit-86, CPC-3, CPC-4, Super Corr-A and Super Corr-B was identical.
Battelle Field Testing Results - Lap Splice Testing

Area of CPC Application Along Upper Edge of Lap Splice Coupons

Lap Splice Coupon Sets Mounted on Chain Link Fence at FMRF
## Battelle Field Testing Results - Lap Splice Testing Summary

### West Jefferson vs FMRF

<table>
<thead>
<tr>
<th>CPC</th>
<th>1 mo.</th>
<th>3 mo.</th>
<th>4 mo.</th>
<th>1 mo.</th>
<th>3 mo.</th>
<th>4 mo.</th>
<th>Total (Max: 60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>CPC No. 1</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>CPC No. 2</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>CPC No. 3</td>
<td>2</td>
<td>5</td>
<td>9</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>CPC No. 4</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>14</td>
</tr>
<tr>
<td>Super Corr A</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>Super Corr B</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>7</td>
</tr>
<tr>
<td>CON-TAC</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>Noxit-86</td>
<td>10</td>
<td>5</td>
<td>10</td>
<td>10</td>
<td>3</td>
<td>3</td>
<td>41</td>
</tr>
<tr>
<td>D-5026NS</td>
<td>10</td>
<td>9</td>
<td>8</td>
<td>9</td>
<td>4</td>
<td>4</td>
<td>44</td>
</tr>
</tbody>
</table>

### Ranking Scores for CPC Coated Lap Splice Coupons
(ref. ASTM D610-08)
Battelle Field Testing Results – Steel Sensors at FMRF and West Jefferson

• Horizontally mounted sensors had increased corrosion

• Visual corrosion on controls, CON-TAC, and D5026NS variants

• CPC No. 2 consistently showed the least change in resistance
Conclusions

• No tested lubricants met all first article testing requirements
• DuPont Vertrel SDG and Kyzen Cybersolv C141R performed well
• Independent testing conducted by SMI Laboratories confirm solvent alternatives are not corrosive or embrittling to high strength aerospace alloys
• Performance of formulations blended with compliant solvents and higher concentrations of proprietary CPC was equal to, or greater than lubricants approved per MIL-L-87177A and MIL-PRF-81309F
• Demonstrated superior performance of the D-5026NS, CPC No. 3 and CPC No. 4 lubricants
• Compliant solvent alternatives can replace the 225T solvent in the current Super Corr-A formulation without compromising the performance of the lubricant
Recommendations

• Work closely with representatives at Hill AFB, DLA, AFRL, and AFCPCO to revise or update the chemical, physical and performance requirements currently referenced in the MIL-L-87177A specification

• A preliminary set of deletions, modifications or additions include:
  - Update flash point requirement based on lubricant chemistry
  - Update or delete the dielectric breakdown requirement based on lubricant chemistry and intended use applications
  - Assess and update oxidation stability requirements
  - Input compatibility requirement with MIL-PRF-32033 and MIL-PRF-81309F lubricants
  - Input Electronics Lubricant Effectiveness tests referenced in MIL-PRF-81309F
    - Initial contact resistance (fixed and disturbed)
    - Low temperature exposures
    - Thermal aging
    - Durability cycling
    - Corrosive gas exposures
    - Compatibility with electrical insulating compounds
Questions & Discussion

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