In Search of the Holy Grail (of EHC Alternatives)

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My Related Activities

- Non-Line of Sight (NLOS) Hard Chrome Alternatives
- Advanced Non-Line of Sight (ANLOS) Hard Chrome Alternatives
- Cold Spray Coatings Evaluation
- Effects of Chemicals on HVOF Coatings
- Metal Coated Particles Concept Evaluation
Non-Line of Sight (NLOS)
Hard Chrome Alternatives
NLOS Hard Chrome Alternatives

• Screening Testing Approach
  — AF supplied the bare steel specimen
  — Each vendor applied its own product in order to eliminate any chance of processing anomalies
    • .005” thick coatings were requested
    • Coatings ground to .003”
    • 2 coating variations
      — As deposited
      — Baked at 375°F/24 hrs
NLOS Hard Chrome Alternatives

Short Term Screening Testing Has Been Completed

Adhesion (bend test)
Hardness (Knopp w/ 100 gram indenter)
Profilometry (Smoothness / leveling ability)
Chemical composition (no unacceptable constituents)
Quality (visual analysis IAW EHC specification)
Taber wear index (weight loss per 1000 test cycles)

• Selected the 4 best processes for further evaluation
NLOS Hard Chrome Alternatives

Niplate 700 by Surface Technology
- Electroless Nickel (95%) – Phosphorous (5%) with silicon carbide particles

UltraCem by Universal Chemical
- Electroless Nickel (95%) – Boron (5%) that forms crystalline clusters of nickel boride

Nanon 9 by Nanon Technologies
- Electrolytic Nickel (50-70%) – Cobalt (30-50%) that forms nanocrystalline microstructure

NiCom by US Chrome
- Electrolytic Nickel w/ silicon carbide particles
## NLOS Hard Chrome Alternatives

### Short Term Screening Test Results

<table>
<thead>
<tr>
<th></th>
<th>Niplate 700</th>
<th>UltraCem</th>
<th>Nanon 9</th>
<th>NiCom</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adhesion</strong></td>
<td>Pass</td>
<td>Pass</td>
<td>Fail: as deposited</td>
<td>Fail: as deposited</td>
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<tr>
<td><strong>Hardness</strong></td>
<td>545 (as deposited)</td>
<td>840 (as deposited)</td>
<td>770 (as deposited)</td>
<td>519 (as deposited)</td>
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<tr>
<td></td>
<td>559 (375°F/24 hrs)</td>
<td>857 (375°F/24 hrs)</td>
<td>830 (375°F/24 hrs)</td>
<td>558 (375°F/24 hrs)</td>
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<tr>
<td><strong>Profilometry</strong></td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Acceptable</td>
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<tr>
<td><strong>Composition</strong></td>
<td>As Claimed</td>
<td>As Claimed</td>
<td>As Claimed</td>
<td>As Claimed</td>
</tr>
<tr>
<td><strong>Quality</strong></td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Acceptable</td>
<td>Acceptable</td>
</tr>
<tr>
<td><strong>Taber Wear Index</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>EHC ≈ 2.2</strong></td>
<td>2.8 (as deposited)</td>
<td>9.8 (as deposited)</td>
<td>12.0 (as deposited)</td>
<td>9.7 (as deposited)</td>
</tr>
<tr>
<td></td>
<td>2.6 (325°F/24 hrs)</td>
<td>14.0 (375°F/24 hrs)</td>
<td>10.8 (375°F/24 hrs)</td>
<td>6.0 (375°F/24 hrs)</td>
</tr>
</tbody>
</table>

(EHC ≈ 900KHN\textsubscript{100})
NLOS Hard Chrome Alternatives

• Long Term Screening Testing Started May 04
  – Corrosion
  – Fatigue
  – Hydrogen Embrittlement (completed except for Nanon 9)
    Unbaked Nicom has been the only failure to date
  – Wear (Block on Ring)
  – Grindability determination
  – Strippability determination
NLOS Hard Chrome Alternatives

• Determine the best alternative
  – Selection of the best process will be based upon screening test results and ALC user input

• Conduct validation testing of the best alternative as applied by ALC plating shops

• Develop ALC implementation plan

• Follow-on project for qualification testing is planned
Advanced Non-Line of Sight (ANLOS) Hard Chrome Alternatives
Advanced Non-Line of Sight (ANLOS) Hard Chrome Alternatives

• Non-chrome, non-nickel containing coatings

• Wet or dry processes

• Available and emerging technologies considered
  — Nano structured and nano material coatings are included

• Alternatives identification phase and initial down-selection to be completed by August 2004

• Technical approach will be similar to the NLOS project
Cold Spray Coatings Evaluation
Cold Spray Coatings

• Unique Coat: AC-HVAF WC-17Co
• Inovati: Kinetic Metallization WC-17Co

VS

• OO-ALC HVOF WC-17Co
  – Coating Integrity Fatigue Testing
  – Cyclic Corrosion Testing
  – Metallurgical Analysis

This project based upon promising results of previous investigation

AC-HVAF 185 ksi
AC-HVAF 220 ksi
Cold Spray Coatings Evaluation

• Integrity Testing
  – 2” diameter, 4340, $R_c$ 53, smooth gage specimen
  – 4” long coating patch, ground to .003” and .010”
  – Stress Ratio ($R$) = -.33 & -1 @ .5 Hz
  – Start @ 160 ksi, increase 10 ksi every 20 cycles
  – Photo taken every cycle; NDI as required
  – Acoustic emission to determine onset of coating cracking
Cold Spray Coatings Evaluation

• Corrosion Testing
  – 1” diameter X 6” long 4340, $R_c$ 53 Bars
  – 5” long coating patch, ground to .003” and .010”
  – Cyclic corrosion testing for 1920 hrs
  – Photographs & visual evaluation at least every 168 hrs

• Metallurgical Analysis
  – Carbide distribution must be uniform
  – Interface contamination not > 10%
  – Cracks or delaminates should not exist
  – Voids/oxides not > 1%, no voids > .002”
  – Unmelted particles are not acceptable
Effects of Chemicals on HVOF Coatings
Project Overview

- Environmentally Assisted Cracking / Stress Corrosion Cracking is a major cause of landing gear failures
- Cyclic corrosion testing has shown that HVOF WC-17Co coatings will corrode
- Landing gear have WC-17Co coatings adjacent to IVD aluminum or cadmium
- Landing gear are exposed to various chemicals
- Determine effect of chemical exposure on specimen coated with WC-17Co in contact with IVD aluminum or cadmium while being stressed at a constant load
Testing Approach

¼” diameter, 4340 steel, Rc53, smooth gage specimen

- ½ coated with WC-17Co, ground to .003”
- ½ coated with IVD aluminum or cadmium

or

- ½ coated with EHC, ground to .003”
- ½ coated with IVD aluminum or cadmium
Testing Approach

- Specimen exposed to chemicals while subjected to a constant stress of 180 ksi
- Specimen wetted with chemical every 24 hrs
- 150 hrs without failure is considered passing
- Testing stopped after 196 hours
Testing Approach

- 6 chemicals
  - Type III cleaner
  - Type IV cleaner
  - Aircraft deicer
  - Runway deicer
  - Paint stripper
  - Decontaminant
# Chemicals Used for Evaluation

<table>
<thead>
<tr>
<th>Type</th>
<th>Specification</th>
<th>Name</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cleaner</td>
<td>MIL-PRF-87937 Type III</td>
<td>Air Force Gel</td>
<td>Space Chemical, Inc.</td>
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<tr>
<td>Cleaner</td>
<td>MIL-PRF-87937 Type IV</td>
<td>Cee Bee A-882</td>
<td>McGean-Rohco, Inc.</td>
</tr>
<tr>
<td>A/C Deicer</td>
<td>AMS 1424</td>
<td>Octaflo EF</td>
<td>Octagon Process, Inc.</td>
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<tr>
<td>Runway Deicer</td>
<td>AMS 1435</td>
<td>Cryotech E36</td>
<td>Cryotech Deicing Technology</td>
</tr>
<tr>
<td>Paint Stripper</td>
<td>MIL-R-81294</td>
<td>Cee Bee A-235</td>
<td>McGean-Rohco, Inc.</td>
</tr>
</tbody>
</table>
Observations So Far

- 100% of 55 EHC / IVD alum specimen passed
- 95% of 19 EHC / cadmium specimen passed
- 50% of 48 WC-17Co / IVD alum specimen passed
- 17% of 12 WC-17Co / cadmium specimen passed
- WC-17Co coatings cracked when stressed to 180 ksi
- WC-17Co coated specimen fail in the WC-17Co region with intergranular initiation
- Supplemental testing of 12 uncoated specimen (2 per chemical) saw only 1 failure prior to 150 hrs
EHC / IVD Al coated 4340 steel specimens in High Humidity Air (HHA) and Various Chemicals

180 ksi Sustained Stress  8 specimens per fluid

Baseline Minimum for Passing

- HHA only
- Type III Cleaner
- Type IV Cleaner
- Aircraft Deicer
- Decontaminent
- Paint Stripper
- Runway Deicer
EHC / Cadmium coated 4340 steel specimens in High Humidity Air (HHA) and Various Chemicals

180 ksi Sustained Stress

BASELINE MINIMUM FOR PASSING

HHA only
Type III Cleaner
Type IV Cleaner
Aircraft Deicer
Decontaminant
Paint Stripper
Runway Deicer
WC-17Co / IVD Al coated 4340 steel specimens in High Humidity Air (HHA) and Various Chemicals

180 ksi Sustained Stress  8 specimens per fluid
WC-17Co / Cadmium coated 4340 steel specimens in High Humidity Air (HHA) and Various Chemicals

180 ksi Sustained Stress

BASELINE MINIMUM FOR PASSING

HHA only
Type III Cleaner
Type IV Cleaner
Aircraft Deicer
Decontaminent
Paint Stripper
Runway Deicer
Bare 4340 steel specimens in High Humidity Air (HHA) and Various Chemicals

180 ksi Sustained Stress

Hours Completed

Baseline Minimum for Passing

Type III Cleaner
Type IV Cleaner
Aircraft Deicer
Decontaminent
Paint Stripper
Runway Deicer
Discoloration of substrate under cracks in WC-17Co coating
Intergranular region consistent with embrittlement
Status

- Testing of WC-17Co / cadmium coated specimen being completed “as we speak”
- Metallurgical analysis to determine the exact cause of failures is ongoing
- Final report Dec 04
Metal Coated Particles
Proof of Concept Evaluation
This approach may improve the ductility of HVOF WC-17Co coatings and enhance coating integrity

- Federal Technology Group will nickel plate 5 micron WC particles
- Coating WC particles with cobalt probably a better choice, but too expensive for this limited evaluation
- Sulzer-Metco will agglomerate WC particles into 45 micron clumps for making WC-17Co powder
- AFRL will provide ¼” diameter, 4340 steel, Rc53 fatigue specimen and evaluate coating integrity