HVOF Coatings at Hill AFB

AGENDA

- Design Allowables From A-10 Piston Testing
- On-Going Investigations for landing gear applications
  - Duplex Coatings
  - Coating Adherence After Repair Processes
    - Liquid Nitrogen Exposure (Shrink Fits)
    - 375F Bake (Hydrogen Release)
  - Diamond Grinding of 300M Substrate
- Implementation at Hill AFB
<table>
<thead>
<tr>
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HVOF Coatings at Hill AFB

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<th>a. REPORT</th>
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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
Appearance of Cracks in Coating and Spalled Zone
Coating Integrity Testing Summary

- Piston test program (coated with WC-17%Co)
  - Thick coatings (.010 and .015 inches)
  - Simulated high bending stress conditions
  - Typically 200 cycles above 180 ksi outer fiber bending stress
  - Testing conducted until spallation of coating
    - Spallation occurs near 240 ksi for 0.010 inch thick coating (R= -.33)

- Air Force landing gear fatigue spectrums have been reviewed (in progress)
  - Cycles to 180-200 ksi only 30-40 out of 8000 cycles (1 lifetime)

- Conclusion: HVOF coatings will not spall
  - Based on bend test results
  - Based on fatigue spectrums reviewed to date
## WC-17%Co Coating Design Allowables

<table>
<thead>
<tr>
<th>R ratio: [Stress Min./Stress Max.]</th>
<th>Coating Thickness (as-ground)</th>
<th>Allowable Bending Stress: (Mc/I)</th>
<th>Allowable Strain</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.33</td>
<td>0.010 inches</td>
<td>240 ksi</td>
<td>0.8%</td>
</tr>
<tr>
<td>-0.33</td>
<td>0.015 inches</td>
<td>190 ksi</td>
<td>0.67%</td>
</tr>
<tr>
<td>-0.41</td>
<td>0.010 inches</td>
<td>240 ksi</td>
<td>0.8%</td>
</tr>
<tr>
<td>-0.47</td>
<td>0.010 inches</td>
<td>240 ksi</td>
<td>0.8%</td>
</tr>
<tr>
<td>-1.0</td>
<td>0.010 inches</td>
<td>200 ksi</td>
<td>0.7%</td>
</tr>
</tbody>
</table>
Monotonic Testing of Duplex coatings

- Working with Praxair Surface Technologies (Dr. Daming Wang) to investigate duplex coatings for thick build-up repair of landing gear components
- Using 4-pt bend beams(300M) to study strain to fracture and spallation

4-Point Bend Test Schematic
HVOF Duplex Coatings

- Coatings applied via HVOF process on 300M bar
  - Replacement for sulfamate nickel build-up and cap with chrome plating
  - Bond coat (WC-17%Co)
  - Build-up coat (Ni-5%Al and T-400 investigated)
  - Topcoat (WC-17%Co)

- Benefits
  - No surface prep required after each coating application
  - One booth, Two powder feeders
  - Investigating local (patch) repair
HVOF Duplex Coating Microstructure

- WCCo+NiAl(7 mils) +WCCo (5086-126-1)
- WCCo+T400(7 mils) +WCCo (5086-126-3)
- WCCo+NiAl(17 mils) +WCCo (5086-126-2)
- WCCo+T400(17 mils) +WCCo (5086-126-4)
# HVOF Duplex Coating Bend Test Results

<table>
<thead>
<tr>
<th>4 pt Bar Material</th>
<th>Bond Coat</th>
<th>Build-up Coat Sprayed via HVOF process</th>
<th>Topcoat</th>
<th>Spalling near Yield Strength of 300M (230 ksi)??</th>
</tr>
</thead>
<tbody>
<tr>
<td>300M (280-300 ksi)</td>
<td>None</td>
<td>None</td>
<td>WC-17%Co thickness .010</td>
<td>Yes</td>
</tr>
<tr>
<td>300M</td>
<td>WC-17%Co thickness .0005-.001</td>
<td>Ni-5%Al thickness .006-.008</td>
<td>WC-17%Co thickness .003-.004 Duplex thickness .010</td>
<td>No</td>
</tr>
<tr>
<td>300M</td>
<td>WC-17%Co thickness .0005-.001</td>
<td>Ni-5%Al thickness .016-018</td>
<td>WC-17%Co thickness .003-.004 Duplex thickness .020</td>
<td>No</td>
</tr>
<tr>
<td>300M</td>
<td>WC-17%Co thickness .0005-.001</td>
<td>T-400 thickness .006-.008</td>
<td>WC-17%Co thickness .003-.004 Duplex thickness .010</td>
<td>No</td>
</tr>
<tr>
<td>300M</td>
<td>WC-17%Co thickness .0005-.001</td>
<td>T-400 thickness .016-.018</td>
<td>WC-17%Co thickness .003-.004 Duplex thickness .020</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*Note: 300M is a yield strength of 300 ksi.*

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**Spalling near Yield Strength of 300M (230 ksi)??**

- **Yes**
- **No**
Spalling of Thick Duplex Coating

Detection of Spallation Initiation During Loading

Spallation When Load is Removed

WC17Co+T400+WC17Co (0.020”)
(1343VM+CO109-7+1343VM)
4-Point Bend Test Specimens with Duplex Coating Systems

Total Coating Thickness: 0.010”

WC17Co+Ni5Al+WC17Co
(1343VM+NI-356-7+1343VM)

Total Coating Thickness: 0.020”

WC17Co+T400+WC17Co
(1343VM+CO109-7+1343VM)
Test Findings for Duplex Coatings

- Significant improvement using duplex coating system
  - Spalling resistance increase
  - Applied bending stress above Yield Strength
  - Substantial permanent deformation observed in bars after test
  - Crack indications observed in top coat
    - Investigation on-going
- Ni-5%Al appears to be the winner for build-up coat
  - Deposition efficiency higher than WC-17%Co
  - Lower powder cost
  - Weighs less than WC-17%Co
  - Can be sprayed via HVOF process (1 booth set-up)
  - No surface prep required between coating processes
- Further investigation being conducted on duplex coatings
  - Local (patch) repair
  - Fatigue testing
Recent Findings and On-Going Work

- Coating adherence following standard thermal processes
  - Liquid nitrogen testing
    - Fatigue bar placed in liquid nitrogen
      - Bar tested at 190 ksi, R= -.33
      - No detrimental effects
  - Hydrogen bake out cycle (375F)
    - Fatigue bar exposed to two 24 hr bake cycles at 375F
      - Bar tested at 190 ksi, R= -.33
      - No detrimental effects

- Diamond grinding of 300M steel
  - Study conducted with Heroux Devtek
    - After 0.005 inches of material removal
      - Barkhausen inspection; no defects
      - Diamond wheel dressing with Alumina sticks
    - Total material removed 0.030 inches
      - Nital etch; no defects
      - Investigating diamond grinding of chrome plating
Implementation at Hill AFB

- Masking/fixturing challenge
  - Hard masking, only option???

- Grinding concerns
  - Changing wheels from Al-Oxide to Diamond
    - Downtime to swap out wheels

- No specs for spraying and grinding(AMS)
  - Hill has developed in-house specifications
    - Allow tech order changes immediately
Landing gear components approved for HVOF coating at Hill AFB
- A-10 MLG Piston Barrel
- A-10 NLG Piston Barrel
- B-1 MLG Axle Journals
- C-130 MLG Piston Barrel
- KC-135 NLG Piston Barrel
- KC-135 MLG Piston Barrel
- C-5 MLG Roll Pin Journals
- C-5 MLG Ball Screw Journal
- C-5 MLG Outer Pitch Cylinder
- F-15 Drive Keys
- KC-135 MLG Axle Journals