Summary of HVOF Testing and Experience

Presented by Antonio Garcia
Shamban Aerospace Sealing Systems – North America
# Summary of HVOF Testing and Experience

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**Abstract:**
23rd Replacement of Hard Chrome Plating Program Review Meeting, November 18-19, 2003, Cape Canaveral, FL. Sponsored by SERDP/ESTCP.
Market Drivers

- Higher Life Expectancy from “today's” Aircraft Hydraulic Systems
- Higher Pressure Hydraulic System Designs
- Multiple Fluids for Hydraulic Systems
- Replacement of Hexavalent Chrome Coatings
HVOF vs. Chrome Testing

- Pressure: 3,000 PSI Constant
- Stroke: 3 Inch
- Stroke Rate: 1 Hz
- Fluid: MIL-PRF-83282
- Duration: 300,000 Cycles
- Gland Dimensions: Per MIL-G-5514 F, -214 2 BU Width
- Gland Temperature: 250° F
- Seals Tested: MoS₂ Filled PTFE vs. Elastomer AMS-P-83461 Contact
- Rod Material: C1045 Steel
- Coatings:
  - Tungsten Carbide/Cobalt (Wc-Co) Praxair D-Gun Process Ground & Superfinished to 2-4 μinch Ra
  - Induction Hardened Chrome Plating – Hand polished to 6-10 μinch Ra
HVOF vs. Chrome Baseline Testing

PTFE Contact Test Results

Elastomer Contact Test Results
1) Based on PTFE and Elastomer Contact Seal performance in terms of leakage and wear, HVOF applied Tungsten Carbide coated Rods provide superior seal performance over Chrome plated Rods at stated finish levels (PTFE on HVOF averaged 8.5 gms leakage and 0.1% weight loss, while PTFE on Chrome averaged 173 gms leakage and 2% weight loss).

2) Test Results imply that HVOF applied Tungsten Carbide is at least equivalent to Chrome Plating (Elastomer Seal Leakage was consistent between two finishes while weight loss was roughly 10X PTFE).

3) Test Results confirm that Rod/Bore profile (not necessarily Ra alone) drastically affects seal performance. For Optimum Performance, control of peak height (Rp, Rpk) and bearing ratio (Tp, Mr) must also be achieved.
PTFE Contact Seals on Various HVOF Coatings

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure</td>
<td>3,000 PSI Constant</td>
</tr>
<tr>
<td>Stroke</td>
<td>3 Inch</td>
</tr>
<tr>
<td>Stroke Rate</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Fluid</td>
<td>MIL-PRF-83282</td>
</tr>
<tr>
<td>Duration</td>
<td>500,000 Cycles</td>
</tr>
<tr>
<td>Gland Dimensions</td>
<td>Per MIL-G-5514F, -214 2 BU Width</td>
</tr>
<tr>
<td>Gland Temperature</td>
<td>250° F</td>
</tr>
<tr>
<td>Seals Tested</td>
<td>MoS₂ Filled PTFE Contact</td>
</tr>
<tr>
<td>Rod Material</td>
<td>C1045 Steel</td>
</tr>
<tr>
<td>Coatings</td>
<td>1) Tungsten Carbide - Cobalt (83/17) @ 2-4 μinch Ra</td>
</tr>
<tr>
<td></td>
<td>2) Tungsten Carbide - Cobalt - Chrome (86/10/4) @ 2-4 μinch Ra</td>
</tr>
<tr>
<td></td>
<td>3) Tungsten Carbide – Chrome - Nickel @ 2-4 μinch Ra</td>
</tr>
</tbody>
</table>
PTFE Contact Test Results and Conclusions

1) All three coating systems yielded consistent results regardless of HVOF coating composition applied.

2) All systems yielded between 40-50 grams leakage. Best performance was Tungsten Carbide Chrome Nickel at 40 grams.

3) All systems yielded between 2-2.75% weight loss. Best performance was Tungsten Carbide Chrome Nickel at 2%.
Landing Gear Testing Parameters

Test Conditions

<table>
<thead>
<tr>
<th>Test Condition</th>
<th>Oil Temperature</th>
<th>Pressure Extend (psi)</th>
<th>Pressure Retract (psi)</th>
<th>Total Cycles Upon Successful Test Completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Takeoff Taxi</td>
<td>&lt;= 150°F</td>
<td>2175</td>
<td>2500</td>
<td>105000</td>
</tr>
<tr>
<td>Cruise</td>
<td>-40°F Cooling</td>
<td>275</td>
<td>275</td>
<td>0</td>
</tr>
<tr>
<td>Landing Taxi</td>
<td>&lt;= 150°F</td>
<td>1175</td>
<td>1500</td>
<td>105000</td>
</tr>
<tr>
<td>Landing</td>
<td>-40°F Start</td>
<td>275</td>
<td>2500</td>
<td>22500</td>
</tr>
</tbody>
</table>

➢ Offset of .015” to one side, remaining side = .005”; approximate to .060” scaled to represent B767 Main Gear
➢ Pressure and Temperature testing profile models in-service conditions for LG as supplied by Boeing CAG
➢ Testing produced 2 active candidates for in-service evaluation at the Airline level
➢ Testing produced several designs that are continuously being developed and evaluated
➢ All test represent a minimum of 4 data points
High Pressure Material Technology

- Performance requirements developed from combined characteristics of several materials; best wear resistance (weight and wall loss), low friction performance, leakage control, non-abrasiveness to sliding hardware (impact on Roughness Average (Ra))

Test Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gland Temperature</td>
<td>190°F</td>
</tr>
<tr>
<td>Stroke</td>
<td>.050”</td>
</tr>
<tr>
<td>Stroke Rate</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Pressure</td>
<td>5000 psi constant</td>
</tr>
<tr>
<td>Rod Coating</td>
<td>HVOF applied</td>
</tr>
<tr>
<td></td>
<td>Wc-Co-Cr</td>
</tr>
<tr>
<td>Duration</td>
<td>5,000,000 Cycles</td>
</tr>
</tbody>
</table>
High Pressure Material Technology

- Minimal impact on Ra
- Measurement Tolerance of “skidded” Profilometer
- Leakage performance equal to base-lined materials
High Pressure Material Technology

- Weight loss due to wear is minimal
- Wall loss due to wear is minimal
High Pressure Non-abrasive PTFE Compound (20372)

- Thermoplastic-filled PTFE with proprietary lubrication package
- Improved wear resistance, leakage control and non-abrasiveness in high pressure systems
- Excellent lab test results supported by customer test results
- Strengthens Shamban Aerospace current material portfolio
High Pressure Material - Aerospace Case Study

**APPLICATIONS**
5k psi Development Program

**MOTION**
Reciprocating – with Dither

**HARDWARE**
Rod (HVOF) – < 5uin. Ra max.
Housing (Bare Steel) – 8uin. Ra max.

**LEAKAGE MEASURED**
- Zero (insufficient to form a drop)

**SPECIFICATIONS**
- Media: Phosphate Ester
- Speed: 3 to 4 Hz
- Stroke Length (in.): 4” Max.
- Pressure: 0 to 5000 psi
- Temperature Range: -65F to 275F
Commercial Aircraft - Aerospace Case Study

APPLICATIONS
Outboard, Inboard Aileron and Elevator Actuators

MOTION
Reciprocating – with high Hz dither

HARDWARE
Rod (HVOF) – 4uin. Ra max.
Housing (Bare Steel) – 8uin. Ra max.

LEAKAGE MEASURED
- Zero (insufficient to form a drop) In-service since early 2000. Performed to 30,000 Flight Hours.

SPECIFICATIONS

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<tr>
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<tr>
<td>Speed</td>
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</tr>
<tr>
<td>Stroke Length (in.)</td>
<td>2.95</td>
</tr>
<tr>
<td>Pressure</td>
<td>0 to 3000 psi</td>
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<tr>
<td>Temperature Range</td>
<td>-65F to 275F</td>
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</table>
Commercial Aircraft - Aerospace Case Study

APPLICATIONS
Yaw Damper

MOTION
Reciprocating – with 40 Hz dither

HARDWARE
Rod (HVOF) – 4in. Ra max.
Housing - Unknown

LEAKAGE MEASURED
➢ Zero. Performed to 25,000 Flight Hours with less than 1 Drop/3,000 Cycles.

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Conclusions on HVOF and Sealing Surfaces

Sealing Surface Finish

- Ra alone is insufficient to accurately describe a sealing surface.
- Must control/measure other surface parameters such as Rp, Rpk, Rsk, Rtm and tp.
- Sealing surface recommendations:
  - Ra - < 5 μin
  - Rp - 8 μin maximum
  - Rtm - 40 μin maximum
  - Rsk - negative
  - tp - 70 -90 % @ depth of p = 0.25 Rtm relative to reference line = 5 % tp

Sealing Surface Coatings

- Standard coatings are quickly becoming HVOF applied technology.
- Alternative chrome coatings; HVOF have demonstrated excellent performance.
- The combination of advanced coatings and surface finish technology has proven effective at improving seal system performance; leakage control, seal wear and service life for “today’s” generation of Aircraft hydraulic systems.