Electrodeposited Nano Co-P: Coating Development and Technology Insertion at NADEP-JAX

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Phoenix – February 27th, 2008
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<th>a. REPORT</th>
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History of Cr-Replacement Project

Objectives

- Develop an environmentally benign advanced nanocrystalline based coating technology that:
  - Is compatible with conventional electroplating infrastructure
  - Meets or exceed the performance of hard chrome
  - Costs similar to or less than existing hard chrome processes
  - Will be applied to non-line-of-sight surfaces

Progress

- SERDP Project #PP-1152
  - Nano Co-P developed and demonstrated at the lab scale
- ESTCP Project #PP-0411
  - Scaled up to industrial production & moved to depot (NADEP-JAX)
  - Performance testing (JTP) in progress
nCoP Process & Properties

Simply an electrodeposition process
• Plating Efficiency >90%
• High Deposition rates (0.002”- 0.008” per hour)
• 10x the plating rate of EHC
• 1/10th the power consumption at the same plating rate

<table>
<thead>
<tr>
<th></th>
<th>nCoP</th>
<th>Hard Chrome</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardness</td>
<td>530-580 VHN</td>
<td>800-1200 VHN</td>
</tr>
<tr>
<td>Ductility</td>
<td>Elongation</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Abrasive Wear</td>
<td>CS-17 wheels</td>
<td>17-20 mg/1000 cycles</td>
</tr>
<tr>
<td>(Taber)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adhesive Wear</td>
<td>Volume wear</td>
<td>5-6x10^-6 mm^3/Nm</td>
</tr>
<tr>
<td>(Pin-on-disc)</td>
<td>loss</td>
<td>(Al_2O_3 ball on nCoP disk)</td>
</tr>
<tr>
<td></td>
<td>Coefficient</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>of Friction</td>
<td>(Al_2O_3 ball)</td>
</tr>
<tr>
<td></td>
<td>Salt Spray</td>
<td>Protection rating 7</td>
</tr>
<tr>
<td>Corrosion</td>
<td>(1000 h)</td>
<td></td>
</tr>
</tbody>
</table>

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Industrial Scale-up & Technology Transfer
Industrial Scale-up

Scaled-up process produces acceptable nanostructured coatings

Integran Technologies
- 1300 L system
- In operation for 39 months
- No major issues to date

NADEP-JAX
- 1100 L system
- In operation for 21 months
- Some growing pains – have been resolved
Technology Transfer to NADEP-JAX

Proposed Demo Parts to be Plated at NADEP-JAX

J52 Bevel Gear

P-3 MLG Actuating Cylinder

P3 MLG Cylinder Section, Axle Journal

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Technology Transfer to NADEP-JAX

P-3 MLG Actuating Cylinder – Plating Trials

• 4340 steel
• Area to be plated: 5/8” band, 3” ID
• Cobalt anode rod

ID area to receive plating
Cobalt anode
Technology Transfer to NADEP-JAX

P-3 MLG Actuating Cylinder – Plating Trials

- Plating rate ~ 0.005”/hr
- Thickness
  - 0.010” (as-deposited)
  - 0.005” (following grind)
- Good adhesion
- Visible pit after grinding
Technology Transfer to NADEP-JAX

J52 Coupling, Turbine Shaft Actuating Cylinder – Plating Trials

- 4340 steel
- 4.3” ID
- Anode basket

Demo part shown in rack assembly with anode basket in place

ID area to receive plating
J52 Coupling, Turbine Shaft Actuating Cylinder – Plating Trials

- Plating rate ~ 0.0075”/hr
- Thickness
  - 0.015” (as-deposited)
  - 0.0075” (following grind)
- Good adhesion
- 4 Ra surface finish
Joint Test Protocol (JTP)
Performance Testing

Adhesion
• demonstrated for 4340, 15-5PH, Aermet 100, 7075 Al

Pre-test Grinding Study
• Mil-Std-866 acceptable for nCoP
• Finished to a 2-3µin roughness

Fluid Immersion
• nCoP compatible with most service and overhaul fluids

Corrosion (ASTM B117 & G85) & Rod-Seal Wear
• Samples prepared – testing pending

Hydrogen Embrittlement
• Deposition parameters seem to affect test outcome
• To be resolved in follow-on study
Performance Testing

Axial Fatigue

- 0.003”, 0.010” and 0.015” thick
- 4340, 15-5PH, 7075Al, Aermet 100 substrates
- Data showed debit compared to Cr
  - Found to be artefact of testing
- Post-test evaluation
  - Over 70% of bars failed at transition region (not on gage)
  - Due to high stress concentration (no runout)

Prior fatigue data invalid – testing to be repeated
Follow-on Study

Repeat fatigue testing
• Small scale study
• Obtain preliminary view of CoP fatigue performance

Re-evaluate process window
• Previously optimized for hardness, composition, appearance, wear
• Current work will optimize for embrittlement

Data Acquisition
• As required, re-evaluate properties using new deposition parameters

Producibility
• Plate tube IDs & flat test specimens and evaluate

Cost benefit analysis

Reporting
Thin Dense Chrome (TDC) Alternative
TDC Alternative Development

- Investigated Range of CoP Alloys (0-12wt%P)
- Benchmark comparison made against TDC (AMS 2438A)
# TDC Alternative Properties

<table>
<thead>
<tr>
<th>Application Types</th>
<th>Class 1 nCoP (low P)</th>
<th>Class 2 nCoP (high P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>When corrosion resistance is required and the substrates cannot be HT</td>
<td>When corrosion resistance is not required and the substrates can be HT</td>
<td></td>
</tr>
<tr>
<td>Surface Morphology</td>
<td>Nodular (similar to TDC)</td>
<td></td>
</tr>
<tr>
<td>Thickness Uniformity</td>
<td>Need proper masking/shielding to achieve</td>
<td></td>
</tr>
<tr>
<td>Surface Finish</td>
<td>Unaltered after coating to 0.0005”</td>
<td></td>
</tr>
<tr>
<td>Adhesion</td>
<td>Pass</td>
<td>Pass</td>
</tr>
<tr>
<td>Ductility</td>
<td>2-7%</td>
<td>~1%</td>
</tr>
<tr>
<td>Salt Spray Corrosion</td>
<td>Pass</td>
<td>Fail</td>
</tr>
<tr>
<td>Hardness</td>
<td>530-580 VHN</td>
<td>1000-1150 VHN</td>
</tr>
<tr>
<td>Wear (Sliding)</td>
<td>Good</td>
<td>Good</td>
</tr>
<tr>
<td>Wear (Abrasive)</td>
<td>17-20 mg/1000cycles</td>
<td>8-10 mg/1000cycles</td>
</tr>
<tr>
<td>Hydrogen Embrittlement</td>
<td>Pass (Type 1a2)</td>
<td>Not tested</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Testing planned (Q2)</td>
<td>-</td>
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Technology Commercialization
## Commercialization Status

### nCoP Development and Testing

<table>
<thead>
<tr>
<th></th>
<th>EHC replacement</th>
<th>TDC replacement</th>
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<tbody>
<tr>
<td>Process Development</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Process Stability</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Basic Property Testing</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Advanced Property Testing</td>
<td>Q4</td>
<td>Q2</td>
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### New Product Introduction

<table>
<thead>
<tr>
<th></th>
<th>NADEP-JAX</th>
<th>Aerospace</th>
<th>Industrial Enduro</th>
<th>Other Industrial</th>
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<tbody>
<tr>
<td>Coupon Testing</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Advanced Samples &amp; Testing</td>
<td>In progress</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Deploy Dem/Val Tank</td>
<td>✓</td>
<td>’08</td>
<td>✓</td>
<td>’08</td>
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<tr>
<td>Production</td>
<td>TBD</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
</tbody>
</table>

Looking for customers to participate in Dem/Val (2H08)
Commercial Deployments

Example: Enduro Industries
- Hydraulic / Fluid Power Industry
- Carbon steel bars
- Cr replacement

1. Coupon Testing
   - “Thin” coating – up to 1 mil
   - No post plate grind or polish required
   - Even distribution – to specifications

2. Advanced Samples & Testing
   - Completed full performance testing for fluid power industry
   - Tests include: salt spray, adhesion, sliding wear, elastomer seal wear, deflection testing, endurance testing with side loads

3. Commercial Scale Deployment
   - As pictured at their facility

4. Production
   - Material deployed with customers
Summary

- nCoP developed as alternative to EHC and TDC
- NADEP-JAX Dem/Val
  - Demo parts plated successfully
- JTP Testing
  - Prior fatigue testing invalid
  - Follow-on study initiated
- TDC Alternative Development
  - Development and preliminary testing complete
  - Fatigue testing planned
- Technology Commercialization
  - Industrial deployments successful to date
  - New product testing and validation ongoing
  - Additional deployments planned
The End

THANK YOU FOR LISTENING!