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<th>1. REPORT DATE</th>
<th>2. REPORT TYPE</th>
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<td>00-00-2010 to 00-00-2010</td>
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<td>Electroplate Alternatives to Hard Chrome: Nanocrystalline Metals and Alloys</td>
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| 5a. CONTRACT NUMBER |
| 5b. GRANT NUMBER |
| 5c. PROGRAM ELEMENT NUMBER |
| 5d. PROJECT NUMBER |
| 5e. TASK NUMBER |
| 5f. WORK UNIT NUMBER |

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<td>Integran Technologies Inc., 1725 Washington Road, Suite 305, Pittsburgh, PA, 15241-1209</td>
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<td>DOD Vehicle Workshop, 15-16 June 2010, Grand Rapids, MI. Sponsored by SERDP/ESTCP.</td>
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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
About Integran

- **Background**
  - Over 100 patents dealing with the production of metallurgical nanostructures, including one of the first nanotechnology patents ever issued.
  - Facilities and partnerships in Toronto, Canada, Pittsburgh, PA USA, and Carlsbad, CA and Tijuana, Mexico.

- **Intellectual Property**
  - Over 100 patents on production of metallurgical nanostructures.
  - First nanomaterial technology patent ever issued.

- **Facilities**
  - Pioneer in microstructurally engineered metals.
  - Nanostructure alloys - Enhanced durability, strength, wear resistant.
  - Coatings, CFRP/composite tools/parts, and functional hybrid polymer-nanometal parts for aerospace and automotive applications.
  - Applications company - Facilities and partnerships in Toronto, Canada, Pittsburgh, PA USA, and Carlsbad, CA and Tijuana, Mexico.
Nanovate™
Production Process

Patented pulsed current electrodeposition process provides a cost-effective, versatile synthesis method to produce high quality nanocrystalline metals and alloys.

Integran’s Electrodeposition Method

- Fully dense coatings
- Ultra-fine grain structure throughout entire coating
- Cost-effective, versatile, scalable
- Does not use or produce potentially harmful nanoparticles

Thin Coatings
Thick Plates
Foil
Structural Shells
Metal Foams
Free Standing Parts
Tubes
Nanovate™ CR nanocrystalline cobalt alloy

- Developed and demonstrated at the lab scale
- Scaled up to industrial production & moved to DoD depot

SERDP PP-1152

ESTCP WP-0411

Dem/Val installation at ITI

CTC (USAF) NLOS Phase I

Dem/Val installation at FRC-SE

CTC (USAF) NLOS Phase 2

ESTCP Supplement

ESTCP WP-0936

2000

TRL 1-4

TPC 710-492064

Commercial coupon/component testing

2002

TRL 5-6

Pilot Line installed at Enduro Industries (hydraulic bars)

2004

TRL 7

SDTC 2008-A-1455

Commercial aerospace dem/val installation (Q3, 2010)

2006

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Nanovate™ CR Process (at TRL 7)

Nanovate™ CR provides significant process improvements over chrome

- Environmentally compliant
- High deposition rate
- High current efficiency
- Drop-in technology
- Excellent bath stability
- JAX, Enduro, SDTC–DemVal Aerospace

<table>
<thead>
<tr>
<th>Deposition Method</th>
<th>Nanovate™ CR</th>
<th>Hard Chrome</th>
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<tbody>
<tr>
<td>Applicable Geometries</td>
<td>Electrodeposition</td>
<td>Electrodeposition</td>
</tr>
<tr>
<td>Efficiency</td>
<td>85-95%</td>
<td>15-35%</td>
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<tr>
<td>Deposition Rate</td>
<td>50 – 200 µm per hour</td>
<td>12 – 25 µm per hour</td>
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<tr>
<td>Emission Analysis</td>
<td>Below OSHA limits</td>
<td>Cr+6</td>
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Nanovate™ CR reduces friction, enhances wear & corrosion resistance

<table>
<thead>
<tr>
<th>Property</th>
<th>Nanovate™ CR</th>
<th>Hard Chrome</th>
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<tbody>
<tr>
<td><strong>Appearance</strong></td>
<td>Free of pits, pores &amp; cracks</td>
<td>Microcracked</td>
</tr>
<tr>
<td><strong>Hardness (VHN)</strong></td>
<td>530 – 680</td>
<td>Min. 600</td>
</tr>
<tr>
<td><strong>Wear volume loss (10^-6 mm^3/Nm)</strong></td>
<td>6 – 7</td>
<td>9 – 11</td>
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<tr>
<td><strong>Coefficient of Friction</strong></td>
<td>0.4 - 0.5</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Corrosion Resistance (1000 h)</strong></td>
<td>Protection Rating 8</td>
<td>Protection Rating 2</td>
</tr>
<tr>
<td><strong>Hydrogen Embrittlement</strong></td>
<td>Pass with bake</td>
<td>Pass with bake</td>
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Nanovate™ CR provides enhanced corrosion protection

Nanovate™ CR

Properties

ASTM B537 Ranking following 1000h ASTM B117 Salt Spray

µ-EDXRF Spectra

Coating Oxidation

Hard Chrome

µ-EDXRF Spectra

Substrate Corrosion
Nanovate™ CR provides corrosion protection in aqueous environments.

In 3.56wt% NaCl, aerated

Linear Polarization

Nanovate™ CR enhances fatigue life

Rotating Beam Fatigue
- 4340 substrate (UTS: 1790-1930 MPa)
- Significant credit vs. chrome
- Comparable to bare

Axial Fatigue
- 4340 substrate (UTS: 1240-1380 MPa)
- Preliminary data
- Credit vs bare & chrome
Nanovate™ CR

Applications

• FRC-SE (NAVAIR JAX) Dem/Val Process Line
  • 250 gallon Plating Tank (2.5’x4’x4’)
  • 370 gallon Activation Tank (3’x3’x6’)
  • Pulse Power supply (1500A Peak Current)
  • Remote Controller (Dynatronix)
Nanovate™ CR

Applications

- **Sample Aerospace Applications**
  - OEM and rebuild/repair
  - Gas turbine engines
  - Actuators
  - Landing gear
  - Propeller hubs
  - Valves
  - Pistons
  - Shocks

**Success Story:**
Enduro Industries

- Commercial scale deployment of Nanovate™ CR
- Produce Nanovate™ CR-coated hydraulic actuators for fluid power

Nanovate CR production plating line at Enduro Industries (Hannibal, MO)
Nanovate™ CR
Applications - NAVAIR

T-45 Arresting Hook Pivot Assembly

Pivot Assembly

T-45 Goshawk Trainer Aircraft

Extended Disassembled Actuator Assembly

Spotting Dolly

A/S32A-32 Aircraft Towing Tractor “Spotting Dolly” Spread Cylinder Hydraulic Rod
Nanovate™ CR
Applications - NAVSEA

- Marine Corps MK48 LVS (Logistic Vehicle System) Hydraulic Cylinders
  - Reduce corrosion maintenance requirements and repair costs of vehicles
- Test plan
  - Bench testing on carburized steel panels (in progress)
  - Accelerated corrosion testing (GM9540P)
  - Field test on MK48 vehicles
Summary

Nanovate™ CR Hard Chrome Alternative

• Environmentally compliant EHC alternative
• Process compatible with existing plating infrastructure
• Reduced energy consumption, increased throughput
• Enhanced corrosion and wear
• Non-embrittling
• Improved fatigue performance vs. EHC