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Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18
Xtallic Technology

• Crystal (xtal) size and structure strongly influence materials properties
  – Wear
  – Corrosion resistance
  – Appearance

• Xtalic’s technology dynamically controls crystal size and structure
  – Proprietary chemistry
  – Patented waveforms

• Xtalic’s materials deliver dramatically enhanced performance
Waveform control makes it possible to create tailored, nanocrystalline structures chosen to optimize performance.
Engineering the Optimum

• Xtalic tunes the crystal structure to optimize properties
  – Wear
  – Corrosion protection

• A crystal structure can be selected that creates optimal properties within a single layer
• Multiple layers with tailored properties are created in a single process step

• Dynamic control of crystal size and structure: crystal size, structure and alloy composition are variably controlled

• Superior composite performance is achieved

**Dynamic Nanostructure Control™**
Xtalic Delivers

• Enhanced performance
  – Wear, Corrosion, Appearance

• Multiple properties in a single step
  – Potential for reduced thickness and material usage
  – Fewer steps required, less energy required

• Low environmental and worker health and safety impact
  – Replaces Hexavalent Chromium in a range of applications
  – In some cases, only workable alternative to Chromium

• Easily implemented production solution
Xtalic Application Areas

• Decorative – XBRIGHT®
  – Distinctive, high performance, environmentally friendly decorative coating

• Electronics – XTRONIC®
  – Very low porosity, slow diffusing barrier layer coating for electronics applications

• Functional – XPROTECT®
  – Engineering coating for functional wear + corrosion applications (typically replacing hexavalent chrome or electroless Ni)
XPROTECT®

- Excellent corrosion protection
- Superior wear performance
- Improved properties under heat
- Replicates substrate $R_a$
- Good coating uniformity
- Chromium free
XPROTECT®: Superior Wear

Light-optical micrographs of the pin-on-disc wear tracks

- XPROTECT (3N load)
- Hard Cr (3N load)
- EN (1N load)

Profilometer measurements of wear tracks

Vertical Distance [µm]

Lateral Distance [µm]

0 200 400 600 800 1000
0 2 4 6 8 10 12
XPROTECT
Hard Cr
EN
NSST (B117) of 25 microns of XPROTECT on 1566 precision ground rods with no post finishing

Cr (typical results for a proprietary chromium deposit)

> 4400 hours
XPROTECT: Corrosion Protection

12 µm XPROTECT coated steel shafts after NSST, with exposure times as shown.

12 µm hard Cr coated commercial steel shafts after 48 hours of NSST
XPROTECT – Hydraulic Shaft Example

• 12 µm XPROTECT™ coated hydraulic shaft
• 500 hours of exposure to NSST
• No corrosion sites; rating = 10
• Sample size: 2”x12”

4 inches
XPROTECT® – Shock Absorber Example

- 25 µm XPROTECT coated shock absorber
- 500 hours of exposure to NSST
- Sample size: 0.62”x12”
- Significant defects from transport of unplated substrates led to isolated corrosion spots.

4 inches

Rating (10 = no red rust)

Hours in NSST

9.0 9.2 9.4 9.6 9.8 10.0

0 100 200 300 400 500
XPROTECT ® – Shock Absorber Example

Head to Head with Hard Chromium

• Compression adhesion test
  – Equivalent to Chromium

• NSST Corrosion test
  – XPROTECT > 744 hours
  – Chromium < 250 hours

• Russian Mud Test
  – XPROTECT pass

• Coefficient of friction with 300N Load
  \[
  \left( \frac{\text{XPROTECT with no post-finishing}}{\text{Hard Chromium with post-finishing}} \right) > 0.5
  \]

• Endurance wear testing
  – In Progress
XPROTECT®: Strengthens Under Heat

- Simple heat treat
  - Six hours at 191º C (375º F)
- Increased hardness
  - HV$_{100g}$ = 900 - 950
  - 15% increase
- Stable structure
  - Key properties maintained or enhanced

Customer-Reported Sample Hardness Data

<table>
<thead>
<tr>
<th>Sample #</th>
<th>Temperature</th>
<th>Time</th>
<th>Hardness, HVN100</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>none</td>
<td>N/A</td>
<td>679</td>
</tr>
<tr>
<td>2</td>
<td>375º F (191º C)</td>
<td>3</td>
<td>758</td>
</tr>
<tr>
<td>3</td>
<td>375º F (191º C)</td>
<td>8</td>
<td>840</td>
</tr>
<tr>
<td>4</td>
<td>375º F (191º C)</td>
<td>24</td>
<td>862</td>
</tr>
<tr>
<td>5</td>
<td>500º C</td>
<td>2</td>
<td>1040</td>
</tr>
<tr>
<td>6</td>
<td>500º C</td>
<td>5</td>
<td>1078</td>
</tr>
<tr>
<td>7</td>
<td>500º C</td>
<td>98</td>
<td>888</td>
</tr>
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</table>
**Plating Uniformity, Complex Geometry**

Direct comparison, XP to hard Cr

**Gear with aspect ratio 1.2:1**

<table>
<thead>
<tr>
<th></th>
<th>XP</th>
<th>Hard Cr</th>
</tr>
</thead>
<tbody>
<tr>
<td>76</td>
<td>Avg peak thickness, µm</td>
<td>66</td>
</tr>
<tr>
<td>21</td>
<td>Avg valley thickness, µm</td>
<td>7.2</td>
</tr>
<tr>
<td>3.6</td>
<td>Peak to valley ratio</td>
<td>9.2</td>
</tr>
</tbody>
</table>
Hydrogen Embrittlement Resistance

• Notch tensile specimens plated with 50 µm of XPROTECT®
  • no post-bake
• Five samples tested per ASTM F519 (standard specimen, 1a.1)
• All samples passed loading requirement of 200 hours at 75% of ultimate tensile strength
• Samples do not require baking to pass the test
Confidential to Xtalic Corporation

Plating at Scale: Evaluation Process

Xtalic pilot line in Marlborough, MA
- 375 liter (100 gallon) capacity
- Maximum part dimension up to ~50 cm (20 in)
- Part weights up to ½ ton

Xtalic partner shops
- Up to 1500 gal (6000 l) capacity
- Maximum part dimension up to ~4 m (12 ft)
- Part weights up to 1 ton

Xtalic
Xtalic: A Platform Technology

- Dynamically controlled structure allows tailored materials properties
- Multiple alloy systems maximize the accessible property sets
- Enhanced performance can be achieved across many markets
  - Aerospace
  - Automotive
  - Security
  - Medical Device
  - Home Appliances
  - Consumer Goods
  - Sports Equipment
  - Electronics
  - Communications
  - Industrial Equipment
Contact Us

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Marlborough, MA 01752
(508) 485-9730
www.xtalic.com

Joseph Montano, Product Manager
jmontano@xtalic.com
### Conclusions

Performance properties are summarized in the table below:

<table>
<thead>
<tr>
<th>Coating</th>
<th>Sliding Wear Resistance</th>
<th>NSST Corrosion Resistance</th>
<th>Surface Texture</th>
<th>Coating Distrib.</th>
</tr>
</thead>
<tbody>
<tr>
<td>XPROTECT®</td>
<td>++</td>
<td>+++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>XPROTECT®, HT</td>
<td>++</td>
<td>+++</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cr</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>EN-P↑</td>
<td>-</td>
<td>++</td>
<td>0</td>
<td>+++</td>
</tr>
<tr>
<td>EN-P↑, HT</td>
<td></td>
<td>+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coating</td>
<td>Load [N]</td>
<td>COF</td>
<td>Penetration depth [µm]</td>
<td>Wear rate [mm³/hr]</td>
</tr>
<tr>
<td>------------------</td>
<td>----------</td>
<td>-----</td>
<td>------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>XP</td>
<td>3</td>
<td>0.5</td>
<td>0.2</td>
<td>1.0x10⁻³</td>
</tr>
<tr>
<td>XP, 400ºC/4hr</td>
<td>3</td>
<td>-</td>
<td>0.1</td>
<td>4.0x10⁻⁴</td>
</tr>
<tr>
<td>Hard Cr</td>
<td>3</td>
<td>0.85</td>
<td>1.5</td>
<td>2.3x10⁻²</td>
</tr>
<tr>
<td>EN (high P)</td>
<td>1</td>
<td>0.62</td>
<td>10.5</td>
<td>2.9x10⁻¹</td>
</tr>
</tbody>
</table>

Non-lubricated Pin-on-Disc Apparatus with a Tungsten Carbide Pin
XPROTECT® Corrosion Protection

Hard Chromium

• Failures were rapid at 12 µm \(< 4\) hours
• Functional chromium deposits with a thickness of 25 µm (1 mil) will last in NSST for between (Jones) 10 and 500 hours depending upon pre-finishing, plating and post finishing.

XP Coating

• XP coatings with between 12 and 25 µm (0.5 to 1.0 mils) lasted in NSST for between
  • 350 and > 4400 hours
• When the coatings did corrode, the corrosion sites were typically very small and did not expand rapidly.
## XPROTECT ® Corrosion: Acid Data

Performance properties XPROTECT ® vs. Cr

<table>
<thead>
<tr>
<th>Coating</th>
<th>Corrosion Rates, mm/year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HCl</td>
</tr>
<tr>
<td>Acid 10% (v/v) Temp, C</td>
<td></td>
</tr>
<tr>
<td>XPROTECT (Immersion)</td>
<td>0.0030</td>
</tr>
<tr>
<td>XPROTECT (EC) (minimum)</td>
<td>0.054¹</td>
</tr>
<tr>
<td>Cr²</td>
<td>rapid</td>
</tr>
</tbody>
</table>

¹Room Temp - 5 day test
²Corrosion data from Uhlig

24
### XPROTECT ® : Corrosion Protection

#### Corrosion Panels after 1000 hrs B-117 Exposure
(Note: Panel 1 was exposed for only 24 hrs)

**Sample #** | **Hours Exposed** | **Observation**
--- | --- | ---
1 | 24 | Red rust
2 | >1000 | No red rust
3 | >1000 | 10 isolated spots (small)
4 | >1000 | No red rust
5 | >1000 | 4 isolated spots (small)
6 | >1000 | No red rust
**Plating Uniformity, Shaft/Rod**

- Sample dimensions: 25 mm diameter and 300 mm length
- Tank anodes used on each side of part; no conforming anodes
- 300 mm anode to cathode separation
- Plating time: 1 hour

<table>
<thead>
<tr>
<th>Location around rod (degrees)</th>
<th>Thickness (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>41.9</td>
</tr>
<tr>
<td>90</td>
<td>40.9</td>
</tr>
<tr>
<td>180</td>
<td>39.9</td>
</tr>
<tr>
<td>270</td>
<td>40.6</td>
</tr>
<tr>
<td>Average</td>
<td>40.9</td>
</tr>
</tbody>
</table>

- Uniformity around the circumference (eddy current): ±2.4%