AF Cr(VI) Minimize Roadmap

Phase 1 Results

Carl Perazzola P.E.
Chief
AF Corrosion Prevention and Control Office
AFRL/RXSSR
Hexavalent chromium is widely regarded as the highest performing corrosion control treatment for aluminum components. However, due to serious environmental and health risks related to its use, regulations regarding hexavalent chrome exposure are becoming increasingly restrictive. In response, DoD acquisition chief, John J. Young, Jr., published a memo in April 2009 directing all Services to use hexavalent chrome substitutes whenever possible. Yet in many weapon systems, its use has continued due to the lack of chrome-free substitutes able to meet MIL-SPEC requirements and laboratory testing. Hexavalent chrome continues to be used in primers, coatings, and sealants across the Services and aerospace industry. This presentation will discuss efforts the Air Force has already made and its current course in finding suitable replacements for hexavalent chrome.
CURRENT STATE OF AIR FORCE HEXAVALENT CHROMIUM REDUCTION EFFORTS

MR. CARL PERAZZOLA
Air Force Corrosion Prevention & Control Office
325 Richard Ray Blvd.
Building 165
Robins AFB, GA 31098-1639
(478) 926-3284
carl.perazzola@robins.af.mil

Hexavalent chromium is widely regarded as the highest performing corrosion control treatment for aluminum components. However, due to serious environmental and health risks related to its use, regulations regarding hexavalent chrome exposure are becoming increasingly restrictive. In response, DoD acquisition chief, John J. Young, Jr., published a memo in April 2009 directing all Services to use hexavalent chrome substitutes whenever possible. Yet in many weapon systems, its use has continued due to the lack of chrome-free substitutes able to meet MIL-SPEC requirements and laboratory testing. Hexavalent chrome continues to be used in primers, coatings, and sealants across the Services and aerospace industry. This presentation will discuss efforts the Air Force has already made and its current course in finding suitable replacements for hexavalent chrome.
Why Minimize Cr(VI)?

• Long Known to be a Carcinogen
  – Inhalation causes lung cancer
  – Recognized by ACGIH, EPA, IARC
• Increasingly Stricter OSHA regulations
  – Revised standard February 28, 2006
• International Pressure
• OSD Policy (Young Memo)
  – April 8, 2009
  – Extraordinary action to eliminate Cr(VI)
• DFARS Clause (final pending)
  – Draft April 8, 2010
Why a Roadmap?

- Develop a comprehensive approach to Cr(VI) minimization addressing all applications
- Avoid duplication of effort
- Identify opportunities to leverage scarce resources
- Roadmaps proven effective in the development and implementation of new technology
  - Determining gaps
  - Assigning roles and responsibilities
Phase 1

- Perform Literature Search
  - ASETS Defense
  - SERDP/ESTCP Websites
  - Secondary Internet Sources
  - AFRL reports, studies, and test data
- Research/Summarize Potential Alternatives
- Create an AF Cr(VI) Use Matrix
  - By Application
  - Potential alternatives identified
  - Progress toward Cr(VI) minimization estimated
An application is a unique use of Cr(VI), that could be classified as unique due to:

- Technology (hard chrome plating, primer)
- Process (LOS plating, immersion)
- Subsystem (landing gear, fasteners)
- Substrate (aluminum, magnesium, high strength steel)

Phase 1 identified 25 unique AF Cr(VI) applications

Determining applications is critical to developing alternative materials and processes
Phase 1 Findings

- Six AF Cr(VI) Technologies Identified
  - Hard chrome plating
  - Conversion coating
  - Primers
  - Sealants
  - Bonding Primer
  - Wash Primer
- Some alternatives have been implemented
- Tremendous opportunities for further minimization of Cr(VI)
Hard Chrome Plating

- Roadmap identified 6 unique applications
- AF uses include landing gear, engine components, housings, bracket and fasteners
- Existing Cr(VI) process is an immersion process
- Replacement efforts to date:
  - High Velocity Oxygen-Fuel (HVOF) of Cobalt-Tungsten Carbide alloys
  - Limited to line-of-sight processes
  - Limited to high strength steel
  - Mainly landing gear and engine components
Color Coding

- **Green:** Alternative has been implemented for the application by an aircraft or at a specific location (not necessarily fully tested or to be endorsed)
- **Yellow:** Potential alternatives have been identified, and testing or evaluation is underway, or alternative shows some promise for implementation
- **Red:** Potential Alternatives have been identified, but the testing and evaluation indicated some real or potential problems, or the failure to achieve the desired results
- **Gray:** Little or no information was available or discovered concerning RDT&E activities for this application
# Hard Chrome

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>PROCESS</th>
<th>SUBSYSTEM</th>
<th>SUBSTRATE</th>
<th>CODE</th>
<th>ALT MATERIAL</th>
<th>ALT PROCESS</th>
<th>DOC #S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Chrome</td>
<td>LOS Plating</td>
<td>Engine Components</td>
<td>High Strength Steel</td>
<td>HC-1</td>
<td>WC/CoCr, Tribaloy 400, Tribaloy 800, Cr3C2/20(80Ni-20Cr)</td>
<td>Thermal Spray (HVOF)</td>
<td>1.4, 1.5, 1.10, 1.15, 1.27, 1.39, 1.64</td>
</tr>
<tr>
<td></td>
<td>LOS Plating</td>
<td>Landing Gear</td>
<td>High Strength Steel</td>
<td>HC-1</td>
<td>WC/CoCr, Tribaloy 400, Tribaloy 800, Cr3C2/20(80Ni-20Cr)</td>
<td>Thermal Spray (HVOF)</td>
<td>1.8, 1.46, 1.15, 1.16, 1.27, 1.39, 1.64</td>
</tr>
<tr>
<td>Hard Chrome</td>
<td>LOS Plating</td>
<td>Engine Components</td>
<td>Nickel Alloys (Inconel)</td>
<td>HC-2</td>
<td>WC/CoCr, Tribaloy 400, Tribaloy 800, Cr3C2/20(80Ni-20Cr)</td>
<td>Thermal Spray (HVOF)</td>
<td>1.4, 1.5</td>
</tr>
<tr>
<td>Hard Chrome</td>
<td>LOS Plating</td>
<td>Landing Gear</td>
<td>Titanium</td>
<td>HC-3</td>
<td>WC/17Co, Electroless Ni</td>
<td>Thermal Spray (HVOF)</td>
<td>1.5, 1.8</td>
</tr>
<tr>
<td>Hard Chrome</td>
<td>Non-LOS</td>
<td>Housings, Brackets</td>
<td>High Strength Steel</td>
<td>HC-4</td>
<td>Electroless Ni, nano-composite plating</td>
<td>Cold Spray, Immersion</td>
<td>1.39</td>
</tr>
<tr>
<td>Hard Chrome</td>
<td>Non-LOS</td>
<td>Fasteners</td>
<td>High Strength Steel</td>
<td>HC-5</td>
<td>Electroless Ni, nano-composite plating</td>
<td>Cold Spray, Immersion</td>
<td>1.24</td>
</tr>
<tr>
<td>Hard Chrome</td>
<td>Non-LOS</td>
<td>Housings, Brackets</td>
<td>Magnesium</td>
<td>HC-6</td>
<td>Hi-pure Al</td>
<td>Cold Spray, Immersion</td>
<td>1.17, 1.44</td>
</tr>
</tbody>
</table>
Conversion Coatings

• Roadmap identified 7 unique AF applications
  – Includes pretreatment, sealers, anodizing and passivation
  – Includes a variety of substrates
• Generally used as part of a paint system containing Cr(VI) primer
• Implemented alternatives include:
  – Trivalent chromium process (TCP) – Navy,
  – Alodine 5200/5700
  – PreKote
• No fully Cr(VI)-free paint system approved to date
## Conversion Coating

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>PROCESS</th>
<th>SUBSYSTEM</th>
<th>SUBSTRATE</th>
<th>CODE</th>
<th>ALT MATERIAL</th>
<th>ALT PROCESS</th>
<th>DOC #S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion Coating</td>
<td>Pretreatment</td>
<td>Plate &amp; Sheet</td>
<td>Aluminum</td>
<td>CC-1</td>
<td>TCP + EPA</td>
<td>Conventional (immersion)</td>
<td>1.23</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>PreKote, Alodine 5700, Sol-Gel, Dorado Kote 7, Low Chrome (LC) 1 and 2, Garabond X 4707</td>
<td>Conventional</td>
<td></td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Pretreatment</td>
<td>Plate &amp; Sheet</td>
<td>Aluminum</td>
<td>CC-1</td>
<td>Ac-131BB, AC-X67, Alodine 871, Alodine 5700, Chemseal 100, PreKote</td>
<td>Conventional</td>
<td>1.1, 1.35, 1.61</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Touch-up</td>
<td>Plate &amp; Sheet</td>
<td>Aluminum</td>
<td>CC-2</td>
<td>AC-131BB, AC-X67, Alodine 871, Alodine 5700, Chemseal 100, PreKote</td>
<td>Conventional</td>
<td>1.1</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Immersion, brush-on</td>
<td>Housings</td>
<td>Magnesium</td>
<td>CC-3</td>
<td>Tagnite (Si-based)</td>
<td>Conventional (immersion)</td>
<td>1.18, 1.30</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Immersion, brush-on</td>
<td>Plate, sheet &amp; component</td>
<td>Aluminum</td>
<td>CC-4</td>
<td>Alodine 5200/5700, K permanganate, fluorotitanic acid, TCP+ and Iridite</td>
<td>Conventional (immersion)</td>
<td>1.19</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Immersion, brush-on</td>
<td>Plate, sheet &amp; component</td>
<td>Aluminum</td>
<td>CC-4</td>
<td>Hi-Silicon zeolite (SiO4-AlO4)</td>
<td>Conventional (immersion)</td>
<td>1.41</td>
</tr>
<tr>
<td>APPLICATION</td>
<td>PROCESS</td>
<td>SUBSYSTEM</td>
<td>SUBSTRATE</td>
<td>CODE</td>
<td>ALT MATERIAL</td>
<td>ALT PROCESS</td>
<td>DOC #S</td>
</tr>
<tr>
<td>-------------------</td>
<td>--------------------------------</td>
<td>------------------------------</td>
<td>---------------</td>
<td>------</td>
<td>----------------------------------------</td>
<td>----------------------------------</td>
<td>--------</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Immersion, brush-on</td>
<td>Plate, sheet &amp; component</td>
<td>Aluminum</td>
<td>CC-4</td>
<td>Electro-active polymers (EAP)</td>
<td>Conventional (immersion)</td>
<td>1.43</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Immersion, brush-on</td>
<td>Plate &amp; Sheet</td>
<td>Aluminum</td>
<td>CC-4</td>
<td>TCP+</td>
<td>Conventional (immersion)</td>
<td>1.5, 1.25</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Immersion, brush-on</td>
<td>Plate, sheet &amp; component</td>
<td>Aluminum</td>
<td>CC-4</td>
<td>TCP+</td>
<td>Conventional (immersion)</td>
<td>1.1, 1.5, 1.6, 1.23, 1.27</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Immersion, brush-on</td>
<td>Plate, sheet &amp; component</td>
<td>Aluminum</td>
<td>CC-4</td>
<td>TCP+</td>
<td>Conventional (immersion)</td>
<td>1.12, 1.23</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Immersion, brush-on</td>
<td>Plate, sheet &amp; component</td>
<td>Aluminum</td>
<td>CC-4</td>
<td>Sol-gel</td>
<td>Plasma Spray</td>
<td>1.2, 1.5, 1.7</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Anodizing</td>
<td>Plate, sheet &amp; component</td>
<td>Aluminum</td>
<td>CC-5</td>
<td>Sulfuric/TCP rinse, Boric-sulphuric anodize, Keronite/Tagnite</td>
<td>Conventional (immersion)</td>
<td>1.12</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Passivation</td>
<td>Plate, sheet &amp; component</td>
<td>Steel</td>
<td>CC-5</td>
<td>TCP+</td>
<td>Conventional (immersion)</td>
<td>1.12, 1.45</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Post Treatment</td>
<td>Fasteners</td>
<td>Steel: SS, Cd-plated</td>
<td>CC-6</td>
<td>Pur Aluminum, Metal flake dip-spin</td>
<td>Organic topcoat</td>
<td>1.11</td>
</tr>
<tr>
<td>Conversion Coating</td>
<td>Post Treatment</td>
<td>PAD/CAD</td>
<td>Stainless Steel</td>
<td>CC-7</td>
<td>TCP over Zinc-phosphate</td>
<td>Conventional (immersion)</td>
<td>1.36</td>
</tr>
</tbody>
</table>
Primer

- Single largest use of Cr(VI) by volume
- Roadmap identified 4 primer applications
  - Interior v. Exterior
  - Primer removal
- Generally used in a paint system that implements a Cr(VI) pretreatment
- Promising/implemented alternatives;
  - Two Deft primers (02GN084 and 44GN098)
  - Akzo 2100 MgRP
- No fully Cr(VI)-free paint system approved to date
<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>PROCESS</th>
<th>SUBSYSTEM</th>
<th>SUBSTRATE</th>
<th>CODE</th>
<th>ALT MATERIAL</th>
<th>ALT PROCESS</th>
<th>DOC #S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primer</td>
<td>Coating</td>
<td>Interior/Structure</td>
<td>Aluminum</td>
<td>PR-1</td>
<td>Akzo 2100MgRP; Deft 44GN098; Deft 02GN084</td>
<td>Conventional</td>
<td>1.1, 1.27</td>
</tr>
<tr>
<td>Primer</td>
<td>Coating</td>
<td>Interior/Structure</td>
<td>Al, SS, Mg, Ti, Composite</td>
<td>PR-1</td>
<td>Magnesium-rich</td>
<td>Conventional</td>
<td>1.63</td>
</tr>
<tr>
<td>Primer</td>
<td>Coating</td>
<td>Exterior</td>
<td>Al, SS, Mg, Ti, Composite</td>
<td>PR-2</td>
<td>Deft 02GN083, 02GN084</td>
<td>Conventional</td>
<td>1.12</td>
</tr>
<tr>
<td>Primer</td>
<td>Coating</td>
<td>Exterior</td>
<td>Al, SS, Mg, Ti, Composite</td>
<td>PR-2</td>
<td>Inhibitors: RE diphenyl phosphate, IO salt/BTTSA,</td>
<td>Conventional</td>
<td>1.42</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>hydrotalcite-organidisulfide</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primer</td>
<td>Coating</td>
<td>Exterior</td>
<td>Al, SS, Mg, Ti, Composite</td>
<td>PR-2</td>
<td>Epoxy-silane</td>
<td>Conventional</td>
<td>1.3</td>
</tr>
<tr>
<td>Primer</td>
<td>Coating</td>
<td>Exterior</td>
<td>Aluminum</td>
<td>PR-2</td>
<td>TCP+</td>
<td>Conventional</td>
<td>1.12</td>
</tr>
<tr>
<td>Primer</td>
<td>Coating</td>
<td>Exterior</td>
<td>Aluminum</td>
<td>PR-2</td>
<td>Akzo 10PW22-8; Deft 44GN098</td>
<td>Conventional</td>
<td>1.1</td>
</tr>
<tr>
<td>Primer</td>
<td>Coating</td>
<td>Exterior</td>
<td>Al, SS, Mg, Ti, Composite</td>
<td>PR-2</td>
<td>Magnesium-rich</td>
<td>Conventional</td>
<td>1.61, 1.62, 1.63</td>
</tr>
<tr>
<td>Primer</td>
<td>Coating</td>
<td>Munitions</td>
<td>Al, SS, Mg, Ti, Composite</td>
<td>PR-3</td>
<td></td>
<td>Conventional</td>
<td></td>
</tr>
<tr>
<td>Primer</td>
<td>Removal</td>
<td>All</td>
<td>All</td>
<td>PR-4</td>
<td></td>
<td>Laser</td>
<td></td>
</tr>
</tbody>
</table>
Sealants

• Roadmap identified 4 sealant applications
  • Used mainly to prevent dissimilar metal contact
    – Faying surfaces
    – Installation of fasteners
• Requires a different solution than primers in a typical coating system
  – No topcoat
  – Inaccessible areas of the aircraft
• Few prospective alternatives identified to date
## Sealants

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>PROCESS</th>
<th>SUBSYSTEM</th>
<th>SUBSTRATE</th>
<th>CODE</th>
<th>ALT MATERIAL</th>
<th>ALT PROCESS</th>
<th>DOC #S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sealant/Primer</td>
<td>Assembly/Post-Assy</td>
<td>Faying Surfaces</td>
<td>Al, Mg, Ti, Steel</td>
<td>SE-1</td>
<td>AC131sol-gel/23377N, Alodine5700/53022I, PreKote/AquaSur HS, PreKote/Akzo Mg-rich, Alodine5700/Akzo Mg-rich, AC-730, CS 5500CI</td>
<td>Conventional</td>
<td>1.22</td>
</tr>
<tr>
<td>Sealants</td>
<td>Assembly/Post-Assy</td>
<td>Faying Surfaces</td>
<td>Al, Mg, Ti, Steel</td>
<td>SE-2</td>
<td>Various PRC/DeSoto Bases/Accelerators</td>
<td>Conventional</td>
<td>1.33, 1.39</td>
</tr>
<tr>
<td>Sealants</td>
<td>Assembly/Post-Assy</td>
<td>Fastener interface</td>
<td>SS, Ti, Cad plating</td>
<td>SE-3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sealants</td>
<td>Assembly/Post-Assy</td>
<td>Fuel Tanks</td>
<td>Aluminum</td>
<td>SE-4</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Bonding and Wash Primers

• **Bonding Primer**
  – Critical surface prep component in adhesive structural bonding
  – Stringent and challenging requirements
  – Basic research needed to define corrosion protection requirements

• **Wash Primer**
  – Another option for pretreatment/primer prior to topcoat
  – Specification requires zinc chromate
  – Some testing of alternatives has been performed, including TCP
## Bonding and Wash Primers

<table>
<thead>
<tr>
<th>APPLICATION</th>
<th>PROCESS</th>
<th>SUBSYSTEM</th>
<th>SUBSTRATE</th>
<th>CODE</th>
<th>ALT MATERIAL</th>
<th>ALT PROCESS</th>
<th>DOC #S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bonding</td>
<td>Wipe/Brush-on/Spray</td>
<td>Surface Prep</td>
<td>Metal Surfaces</td>
<td>BD-1</td>
<td></td>
<td>Conventional</td>
<td>1.66</td>
</tr>
<tr>
<td>Wash Primer</td>
<td>Immersion/Spray</td>
<td></td>
<td>Aluminum</td>
<td>WP-1</td>
<td>TCP+</td>
<td>Conventional</td>
<td>1.6,1.40</td>
</tr>
<tr>
<td>Wash Primer</td>
<td>Immersion/Spray</td>
<td></td>
<td>Magnesium</td>
<td>WP-2</td>
<td></td>
<td>Conventional</td>
<td></td>
</tr>
<tr>
<td>Wash Primer</td>
<td>Immersion/Spray</td>
<td></td>
<td>Stainless Steel</td>
<td>WP-3</td>
<td></td>
<td>Conventional</td>
<td></td>
</tr>
</tbody>
</table>
AFRL S&T Related Technologies

• Cr+6 Reduction Plan

• Inorganic Coatings
  – Chrome Replacement
    • Next Generation Non-Line of Sight Coatings
    • Dichromate Sealer Replacement

• Organic Coatings
  – Cr Free Paint Systems
    • Sicopoxy
    • Mg Rich Primer
  – UV Curable Coatings
    • Topcoats; Primer; One Coat
    • Explosion Proof UV Lamp
    • UV Paint Booth
  – Paint / Depaint Life Cycle Extension
AFRL Chrome Reduction Plan

Description
• Reduce hexavalent chromium use and waste

Approach
• Review hexavalent chromium usage in DoD to identify applications.
• Develop Strategic Implementation Plan for hexavalent chromium reduction throughout AF

Benefits
• Reduce hexavalent chromium applications in order to improve compliance to EPA, DoD, and other federal, state, and local directives.
• Addresses Executive Order 11514, CAA, CWA, RCRA, NESHAP, AFI32-7040, and AFI 32-7042, and State hazardous reduction plans

Weapon Systems
• Various aircraft components - especially landing gear, wheels, hydraulic components, fasteners; vehicles; ground support equipment

Stakeholders
• USAF (e.g., B-1, F-16, F-18, F-22, F-35, C-5, C-17 POs, Space); ANG; Army aircraft, TACOM; NAVAIR; Coast Guard, NASA, DSCC, OEMs
No qualified, completely chromium-free system yet ...

- Some individual chromium-free components cannot be combined with some MIL SPEC or other components; e.g., PreKote with Deft 02-GN-084
- AFRL currently testing two chromium-free coating systems that show most promise based on screening/performance testing
PreKote / Mg Rich (AeroDur 2100)

- Pretreatment Manufacturer – Pantheon Chemical
  - Approved for use in T.O. 1-1-8 with a chrome primer
  - PreKote used on F-16, T- Jets (AETC) since mid ‘90s, Hill AFB since ‘05, C-5 & C-130’s @ Robins AFB

- Primer Manufacturer – Akzo Nobel
  - Corrosion Inhibitor – Mg particles
    - Galvanic Corrosion protection
  - New formulation best lab corrosion test performance to date

- System Performs as well as chrome in outdoor exposure on corrosion sensors on aircraft
  - Parts flying on CG HH-60 rescue aircraft

- Field testing on full aircraft in planning stages (HH-60, C-130, F-16)
- System in testing for qualification to MIL-PRF-32239
- CTIO’s choice to meet USD, Mr. Young letter
The Road Ahead…Phase 2

• Phase 1 has:
  – Established the applications to use as a starting point
  – Identified much of the existing RDT&E data

• Phase 2 will:
  – Develop technology roadmaps
    • Identify technology gaps for each application
    • Identify intermediate steps needed
    • Identify RDT&E projects
    • Estimate funding levels and timeframes needed
  – Document Cr(VI) use and alternative implementation by weapon system