Elimination of Chromium Electrodeposition from Large Caliber Launch Systems

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part of the US Army Armaments Research, Development and Engineering Center
Elimination of Chromium Electrodeposition from Large Caliber Launch Systems

Army Benet Laboratories, Picatinny Arsenal, NJ, 07806

Approved for public release; distribution unlimited

LARGE CALIBER GUN EROSION

Direct Fire

INCREASING MUZZLE ENERGIES REQUIRE:
Improved Bore Protection
Less Erosive Energetics

FCS-Mounted Combat System Goal

Executive Order 13148 “Greening The Government …..
Reduction of Toxic Chemical Releases by 40% by 31 Dec 2006
Reduction of Toxic Chemical Usage by 50% by 31 Dec 2006
120mm GUN BARREL DEGRADATION
Classic Erosion Defined

- HC Chrome is produced in an “as cracked” condition offering path to substrate
- HC Cr contaminants off-gas causing further material volume shrinkage and stress-relief cracking
- Combustion products:
  - Penetrate cracks
  - Alter steel substrate phase
  - Convert substrate surface to carbides & oxides
  - Lowers MP of substrate surface
- Gas wash:
  - Removes lower MP substrate surface
  - Erodes Cr foundation (compromised adherence)
- Departing Cr exposes more substrate to high velocity gas wash and further erosion
120mm GUN BARREL MANUFACTURING PROCESS

- Billet
- Rotary Forge
- Heat Treat
- Rough Machining
- Autofrettage
- Finish Machining
- Post-Autofrettage Thermal Soak
- Chrome Plate
- Inspection
- Ship
- Machining
- Fielding
- Chrome Plating

Rotary Forging

Machining

Fielding

Chrome Plating
# LARGE CALIBER GUN COATING REQUIREMENTS

**Material & Deposition Process Requirements**

## Material Characteristic

<table>
<thead>
<tr>
<th>Material Characteristic</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting Point</td>
<td>Cr (1875 C) or better</td>
</tr>
<tr>
<td>Elastic Modulus</td>
<td>Compatible with substrate <em>(facilitates low surface crack densities)</em></td>
</tr>
<tr>
<td>YS at Elevated Temps</td>
<td>High</td>
</tr>
<tr>
<td>Fracture Toughness</td>
<td>High</td>
</tr>
<tr>
<td>Hot Hardness</td>
<td>High (appropriate)</td>
</tr>
<tr>
<td>Chemical Resistance</td>
<td>High</td>
</tr>
<tr>
<td>Coefficient of Thermal Exp.</td>
<td>Compatible with substrate</td>
</tr>
<tr>
<td>Thermal Conductivity</td>
<td>Low</td>
</tr>
<tr>
<td>Reaction w/ Rotating Band</td>
<td>Inert</td>
</tr>
<tr>
<td>Phase Transformations</td>
<td>None</td>
</tr>
</tbody>
</table>

## Process Characteristic

<table>
<thead>
<tr>
<th>Process Characteristic</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deposition Temperature</td>
<td>Less than 357C <em>(post autofrettage thermal soak limit)</em></td>
</tr>
<tr>
<td>Deposit Rate</td>
<td>1 mil of coating material per hour</td>
</tr>
<tr>
<td>Surface Finish</td>
<td>Equal or better than 32 RMS at deposition</td>
</tr>
<tr>
<td>Deposition Length</td>
<td>58 Calibers or greater</td>
</tr>
<tr>
<td>Hazardous Impacts</td>
<td>None or limited</td>
</tr>
</tbody>
</table>
# COATING DEPOSITION PROCESS SELECTION for Large Caliber Guns

## Functional Requirements

<table>
<thead>
<tr>
<th></th>
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<th></th>
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</thead>
<tbody>
<tr>
<td>Autofrettage Stresses Protected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No Post-process Surface Finish Req</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Acceptable Deposition Rate</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Proper Process Aspect Ratio</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Accept Dim. and Densities over 50 cal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Acceptable Adhesion</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Dry Process</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Eliminate Hazardious Materials</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Eliminate Air / Water Contamination</td>
<td></td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

- **TECHNICAL PANEL EXPERTS (1997)**

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**U.S. Army Benet Laboratories**

**ARDEC**
TECHNICAL APPROACH
Technology Maturation Methodology

Coupons & 12" Sections

Full-Length Gun Barrels

40" Sections

TEST ASSET FIRING
An Army patent pending manufacturing technology to provide “atomically clean” surfaces for CMS deposition onto full length gun barrels.
CMS Cr Coating Morphology

- SEM images of tensile fractured chromium specimens:
  a: dense fibrous grain structure (zone T per Thornton)
  b: small amount of columnar growths
- XRD residual stress study: compressive stress of ~ 30 Ksi
Cr Coating Comparison

Electropladed vs sputtered

Microhardness:
- HC Cr: 800-1000 HK
- CMS Cr: 220 - 400 HK
Cr Coating Composition

Bulk impurity concentration:
- CMS Cr: all non-Cr elements < 0.1 at %
- HC Cr: carbon concentration ~ 10 at %, oxygen concentration ~ 2 at %
Laser Pulse Heating (LPH) method

*Thermal shock resistance*

Nd:YAG laser
1064 nm, 5 msec

Optical fiber

2 - 3 mm diameter spot, approximately uniform energy density

~ 10 mm x 6 mm x 2.5 mm specimen

thermocouple

Vented Erosion Simulator (VES): For Interim Coatings Validation

- Flame T & chemistry similar to M829A2/M829A3
- Accepts Lg Cal coated coupons
- Extensively modeled
- Does not exceed critical T observed in current gun barrel erosion process
- Used to screen, evaluate, optimize, and validate Lg Cal gun bore coatings

Benet’s VES evaluates coatings in a simulated Lg Cal Gun Firing Environment

NOVEL SPIN-OFF TECHNOLOGY

Abrams M1A2 Main Battle Tank
INTERIM COATINGS VALIDATION

Vented Erosion Simulator (VES) Testing

- Flame T & chemistry similar to M829A2/M829A3
- Accepts Large Caliber coated coupons *(eliminates process scaling)*
- Ballistically modeled & validated
- Substrate transformed to same depth as Lg Cal Gun
- Maintains critical T observed in current gun barrel erosion process
VENTED EROSION SIMULATOR (VES)
an excellent simulation of Lg Cal gun firing

ACTUAL DAMAGE FROM M829A3 FIRINGS

X-Section – Cracking, HAZ, thermo-chemical attack

Top View – Thermal shock cracking

HC Cr coating

Gun steel

VENTED EROSION SIMULATOR DAMAGE

X-Section – Cracking, HAZ, thermo-chemical attack

Top View – Thermal shock cracking

HC Cr coating

Gun steel
COATING CRACK DENSITY

Substrate Exposure – Erosion Rate

As-Deposited Surface Appearance

- 2mm

Sputtered Cr
- As-deposited cracks
- Very small nodules

Sputtered Ta
- Extremely small surface features

HC Cr

Post-firing Crack Island Size (aka Crack Density)

Erosion Life

120mm Tank Gun Surfaces
### Summary of TECHNICAL METRICS

**Advanced Coatings for Large Caliber Guns**

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>Current state of HC CHROME PLATING</th>
<th>Desired end state for SPUTTERING</th>
<th>VERIFICATION TECHNIQUE</th>
<th>CURRENT STATUS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating Morphology</td>
<td>Zone 2</td>
<td>Zone 2</td>
<td>Microscopy</td>
<td>yes</td>
</tr>
<tr>
<td>Coating Phase</td>
<td>Single</td>
<td>100% Alpha (Ta)</td>
<td>Microscopy</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>bcc (Cr)</td>
<td>Microscopy</td>
<td>yes</td>
</tr>
<tr>
<td>Hardness</td>
<td>900 -1100 Knoop</td>
<td>200 - 300 Knoop</td>
<td>Microhardness (Ta)</td>
<td>yes</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Microhardness (Cr)</td>
<td>yes</td>
</tr>
<tr>
<td>Thermal Shock Resistance</td>
<td>Poor</td>
<td>Excellent</td>
<td>Pulsed Laser</td>
<td>yes</td>
</tr>
<tr>
<td>Adhesion / Cohesion</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Vented Erosion Sim</td>
<td>yes</td>
</tr>
<tr>
<td>Distribution over Length</td>
<td>.002 - .006 in.</td>
<td>Less than .0005</td>
<td>Microscopy</td>
<td>yes (80&quot;)</td>
</tr>
<tr>
<td>Distribution around ID</td>
<td>.002 - .006 in.</td>
<td>Less than .0005</td>
<td>Microscopy</td>
<td>yes</td>
</tr>
<tr>
<td>Deposition Rate</td>
<td>.001 inches/hr</td>
<td>.001 inches/hr</td>
<td>Microscopy</td>
<td>no (.00075)</td>
</tr>
<tr>
<td>Coating Thickness</td>
<td>.002 - .006 in.</td>
<td>.004 - .006 in.</td>
<td>Microscopy</td>
<td>yes</td>
</tr>
<tr>
<td>Surface Finish</td>
<td>63 finish</td>
<td>32 or better</td>
<td>Visual</td>
<td>yes (16)</td>
</tr>
<tr>
<td>Onset of Erosion</td>
<td>100 VES shots</td>
<td>better</td>
<td>Visual / Microscopy</td>
<td>yes</td>
</tr>
<tr>
<td>Weapon Service Erosion Life</td>
<td>260 Rnds (M829A3)</td>
<td>400 Rnds (M829A3)</td>
<td>Firing Tests</td>
<td>TBD</td>
</tr>
</tbody>
</table>
UPCOMING FIRING DEMONSTRATIONS

Advanced Sputtered Coatings

120mm XM36 Firing Test #1
- 120mm coated, shrink-fit liner
- July 04

120mm XM36 Firing Test #2
- 120mm coated, shrink-fit liner
- Oct-Nov 04

120mm XM36 Sub-Scale Development & Testing
- Full-length monoblock coating test
- Mid FY05
LARGE CALIBER Pre-PRODUCTION Demonstration Platform at Watervliet Arsenal – Initial Testing - Sep 04
SUMMARY

- Cylindrical Magnetron Sputtering is a viable alternative to electrodeposition

- Cylindrical Magnetron Sputtering results encouraging for large caliber systems
  - Increased adhesion and bulk properties
  - All laboratory metrics achieved (still improving deposition rate)

- Current 120mm XM36 tests should be insightful

- Large Caliber Full-length Pre-Production Platform Initial Testing by Sep 2004

- Will one coating technology address all platforms ???
  - Large Cal vs. Med Cal
  - Autofrettaged vs. Non-Autofrettaged
  - Smoothbore vs. Rifled bore