Thermal Spray Coating of 5xxx Aluminum

National Shipbuilding Research Program (NSRP)
PPPF Panel Project

CG Structural IPT Meeting
17 January 2017

Public: Approved for public release; distribution is unlimited (including to foreign countries).
Agenda

• Problem Statement
• Proposed Solution
• Project Overview
• Accomplishments vs Work Breakdown Structure (WBS)
• Next Steps
Problem Statement

• Aluminum is part of the Navy’s $3B ship corrosion problem
  – Mg-Al 5000 series (5086, 5083, 5059, 5456) alloys will sensitize over time, which becomes exfoliation or worse, stress corrosion cracking (SCC)

• Sensitization and SCC are already a huge repair problems on CG 47 superstructure, and are already emerging on LCS

• 50% of USN ships under contract or construction use aluminum significantly – LCS, LHA, JHSV, SSC, CVN
  – It’s not limited to an in-service repair problem

• Aside from Low Solar Absorption (LSA) paint, there is no preventative treatment for 5xxx alloys short of replacement!
Proposed Solution - Thermal Spray

• Example – electric arc thermal spray - Two wires melted in arc and propelled onto surface by compressed air
• Particles ‘pancake’ onto surface, solidify, and contract
• Subsequent passes build additional thickness at ~90% densification, 10% voids, typ. to 0.010 inch thickness
• Mature, inexpensive, rapidly deposited metallic coating (but voids are concern)

NMC R2519 Rapid Response project

• For CVN application, Thermal Sprayed Commercially Pure (CP) aluminum applied to sensitized Al substrate
• Worst case: NO paint applied
• While untreated samples failed, Thermal Spray passed both 1000 hour scribed, acidified salt fog test (no indications) and 6 month SCC U-bend tests (no failures)
• Voids STILL concern for 35 yr life

Proposed Solution - Thermal Spray + Paint Can Work As a System

Even without paint, Thermal Sprayed CP Aluminum is an effective barrier to environment for substrate (R2519, 6 month SCC and 1000 hour acidified salt fog)

With no magnesium in the alloy, CP Aluminum coating is NOT SUSCEPTIBLE to sensitization

Combined with an LSA paint, this will also preclude further sensitization of the substrate

WITH paint, the combination should provide an extremely durable composite environmental barrier

Thermal sprayed CP Aluminum, 90% densified

Corrosive Environment

Susceptible Material

Tensile Stress At Surface

Top coat, LSA or non-skid LSA

Low viscosity tie coat

Substrate aluminum
Project Overview

• National Shipbuilding Research Program (NSRP) Planning, Production Processes and Facilities (PPPF) Panel Project
  – Mr. Ken Fast, PPPF Chair

• Scope / Statement of Work
  – This project will evaluate the use of thermal spray commercially pure (CP) aluminum (Al) coatings as an effective preventative measure for SCC in Al ship structures.
  – Potential application scenarios, technical performance data, cost information, and a roadmap for implementation will be generated.

• Period of Performance: 1 Jan 2016 – 30 Dec 2016
• $149,986 total funding
Project Overview – Project Team

- Concurrent Technologies Corporation (CTC) – PI and PM
- Huntington Ingalls Industries – Newport News Shipbuilding (NNS)
- Fincantieri – Marinette Marine Corporation (MMC)
- General Dynamics – Bath Iron Works (BIW)
- Ingalls Shipbuilding
- Naval Surface Warfare Center Carderock Division (NSWCCD)
- Naval Sea Systems Command (NAVSEA) 05P
- NAVSEA 21
- NSRP PPPF Panel
- NSRP Surface Preparation and Coatings (SPC) Panel
- SCRA – Prime contractor for NSRP
Project Accomplishments vs. WBS

• Task 1 – Application Scenarios
  – **COMPLETED**
  – Confirmed key application areas, target sizes, and configurations
  – Selected optimal thermal spray method for targeted application
  – **Drafted and submitted Use Case Scenarios Report (D)**

• Task 2 – Develop Test Matrix
  – **COMPLETED**
  – Developed test matrix to conduct testing
  – Testing to quantify sensitization, SCC corrosion resistance, and durability of selected thermal spray CP coatings, both with and without LSA paint
  – **Drafted and submitted Test Matrix (D)**

(D) = contract deliverable
Project Accomplishments vs. WBS (cont.)

- **Task 1 Completed – Use Case Scenarios report drafted and submitted**
- **Specific areas of interest for application of thermal sprayed CP Al**
  - Hitch girders on CVN aircraft elevators
  - CG deck houses
  - 5083 material on LCS
  - Al extrusions on CGs
- **CG deck houses very promising application**
- **No specific LCS components cited (but some areas of interest)**
  - Evaluating general specimen configurations made from 5083 Al alloy
- **Hitch girders may be more related to material conditions than sensitization**
  - Currently being addressed (somewhat) by weld buttering
  - Will be considered as secondary application
- **Al extrusions also considered as secondary application**
- **Two additional areas on CGs – one under flight deck and another in radio central**
  - Specific parts and components could not be identified
  - Consider as secondary applications
• Evaluated available thermal spray processes

<table>
<thead>
<tr>
<th>PROCESS</th>
<th>CAPABILITY</th>
<th>AVAILABILITY</th>
<th>APPLICABILITY</th>
<th>TOTAL SCORE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wire Arc</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>HVOF</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>Flame Spray</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Cold Spray</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Plasma Spray</td>
<td>3</td>
<td>1</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>D-Gun</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

• Wire arc, HVOF, and flame spray were found to be most promising thermal spray processes for further study
  – Cold spray may also be considered if time and funding permits
# Task 2 Test Matrix (final)

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Type</th>
<th>Accompanying test specification</th>
<th>No. of Replicates</th>
<th>Thermal Spray Only</th>
<th>LSA Coated Replicates</th>
<th>Baseline Material</th>
<th>In-Service Material</th>
<th>Lab Sensitized Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distortion</td>
<td>Visual</td>
<td>Visual</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Adhesion</td>
<td>Bends</td>
<td>ASTM E290 [2]</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Adhesion</td>
<td>Adhesion</td>
<td>ASTM D4541 [3]</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Coating Integrity</td>
<td>Metallographic Inspection</td>
<td>MIL-STD-1687A</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
<tr>
<td>Thermal Transfer / Intercoat Thermal Profile</td>
<td>QUVA (thermal)</td>
<td>ATM G154 [7]/ ASTM D4587 [8]</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>Susceptibility</td>
<td>NAMLT</td>
<td>ASTM G67 [9]</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>
Project Accomplishments vs. WBS (cont.)

• Updated Applicable Specifications
  – MIL-STD-2138A, Military Standard, Metal Sprayed Coatings for Corrosion Protection Aboard Naval Ships
    • Cancelled as of 19 February 2009
  – MIL-C-81751B, Military Specification, Coating, Metallic-Ceramic
    • Inactive for new design as of 28 August 1996
  – NACE No. 12/AWS C2.23M/SSPC-CS 23.00, Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel
    • Active, relevant, but focused primarily on steel
    • Active, preferred by NSWCCD
  – Procedure Handbook for Shipboard Thermal Sprayed Coating Applications
    • Active, relevant to NSRP
• Task 3 – Test Specimen Fabrication and Coating
  – In process
  – TEST PLAN COMPLETED
  – Fabricated 5xxx Al alloy test specimens of selected configuration
  – Selected spray facility
  – Baseline NAMLT testing completed
  – Panels being coated with thermal spray CP Al (flame spray, electric arc, and HVOF)

(D) = contract deliverable
## Test Plan Evaluation Matrix (final)

<table>
<thead>
<tr>
<th>Property</th>
<th>Test Type</th>
<th>Accompanying test specification</th>
<th>Testing Stage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating Quality</td>
<td>Visual Inspection</td>
<td>MIL-STD-1687</td>
<td>1</td>
</tr>
<tr>
<td>Distortion</td>
<td>Visual Inspection</td>
<td>Visual</td>
<td>1</td>
</tr>
<tr>
<td>Adhesion</td>
<td>Bends</td>
<td>ASTM E290</td>
<td>1</td>
</tr>
<tr>
<td>Adhesion</td>
<td>Pull-off</td>
<td>ASTM D4541</td>
<td>1</td>
</tr>
<tr>
<td>Coating Integrity</td>
<td>Metallographic Inspection</td>
<td>MIL-STD-1687</td>
<td>1</td>
</tr>
<tr>
<td>Coating Integrity</td>
<td>Corrosion</td>
<td>ASTM B117</td>
<td>1</td>
</tr>
<tr>
<td>Coating Integrity</td>
<td>Alternate Immersion SCC</td>
<td>ASTM G47</td>
<td>2</td>
</tr>
<tr>
<td>Susceptibility</td>
<td>NAMLT</td>
<td>ASTM G67</td>
<td>2</td>
</tr>
<tr>
<td>Thermal Transfer / Intercoated</td>
<td>QUVA (thermal)</td>
<td>ATM G154 / ASTM D4587</td>
<td>2</td>
</tr>
<tr>
<td>Thermal Profile</td>
<td>Taber Abrasion</td>
<td>ASTM D4060</td>
<td>2</td>
</tr>
</tbody>
</table>
Next Steps

• Task 4 – Conduct Testing
  – Conduct testing to quantify performance of thermal spray CP Al (with and without LSA paint) as preventative for SCC
  – Draft and submit Final Report / Test Report (D)

• Task 5 – Analysis and Roadmap
  – Identify requirements and recommendations for shipyard application process and approximate notional costs for process requirements in hours/ft$^2$
  – Include cost of equipment and operating costs
  – Evaluate impacts of treatments in new construction
  – Draft and submit Final Report / Test Report (D)
Contact Information

Rob Mason, Principal Materials Scientist

Office: 814.269.6480
Cell: 727.743.4924
masonr@ctc.com
BACKUP SLIDES
Sensitization and SCC

Residual stress from forming or welding, or applied stress (e.g. ship motion in a seaway) - very difficult to avoid

Painted aluminum alone is NOT an effective barrier

Corrosive Environment

Susceptible Material

Sensitization: $\text{Mg}_2\text{Al}_3$ ‘β phase’ forms at higher temp and migrates to grain boundary

Even strain-hardened tempers H116 and H321 will form β phase after years of exposure at in-service temperatures <150F

Objective: Break one or more legs of the triangle to avoid SCC

Tensile Stress At Surface
Project Accomplishments vs. WBS (cont.)

• Thermal spray processes – so what’s the difference anyway?
  – **Wire arc** uses electric arc between two consumable wire electrodes which melt to form spray material
    • Allows for high productivity, can cover larger area per application cost
    • High coating bond strength, low porosity
    • Arc light, ozone, and fumes may cause difficulties in some situations BUT likely similar to existing welding operations
  – **HVOF** uses spray material (powder) and process gases (hydrogen, oxygen, air) injected into torch combustion chamber at high pressure and ignited
    • Already has widespread use in DoD (USAF)
    • Highly adherent, low porosity coatings
    • Higher cost
Project Accomplishments vs. WBS (cont.)

• Thermal spray processes – so what’s the difference anyway? (cont.)
  – **Flame spray** uses heat generated from combustion of fuel gas (acetylene, propylene, propane, hydrogen) and oxygen mixture to heat spray material
    • Either wire or powder
    • NNS already has this technology in house
    • Low bond strength, high porosity, high oxide content
    • Lower cost
Outreach

- Participating in both PPPF and SPC panel meetings
- Update(s) to 5xxx Aluminum Maintenance Working Group
- Paper and presentation on aluminum sensitization and control, including thermal spray, for Fleet Maintenance and Modernization Symposium (FMMS) 2016
- Presentation to Mid-Winter Finishers Conference 2016
- Poster to support ShipTech 2016
- Poster to support NSRP Day at NAVSEA
- Poster to support SNAME Maritime Convention 2016