Thermal Spray Coating of 5xxx Aluminum

National Shipbuilding Research Program (NSRP)
PPPF Panel Project

CG Structural IPT Meeting
17 January 2017

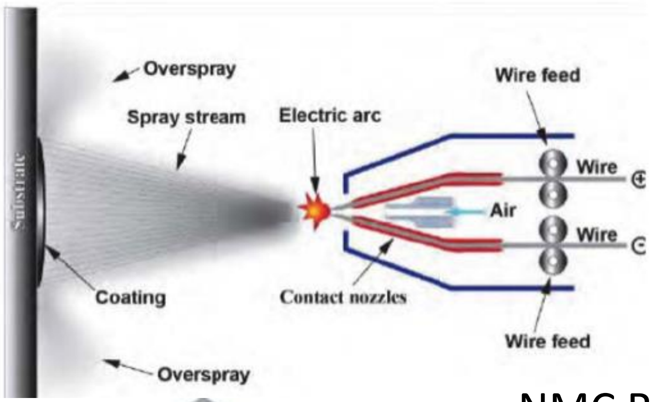
Agenda

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

Problem Statement

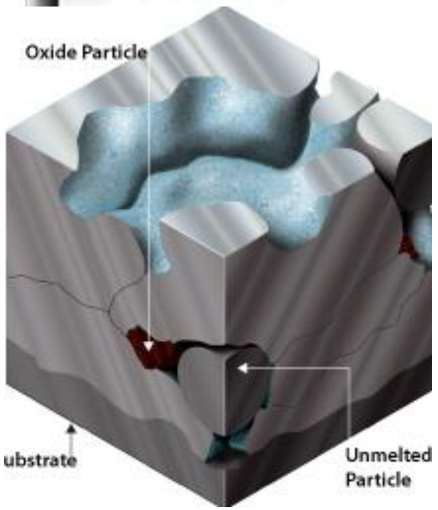
- Aluminum is part of the Navy’s $3B ship corrosion problem
  - Mg-Al 5000 series (5086, 5083, 5059, 5456) alloys will sensitize over time, which becomes exfoliation or worse, stress corrosion cracking (SCC)
- Sensitization and SCC are already a huge repair problems on CG 47 superstructure, and are already 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



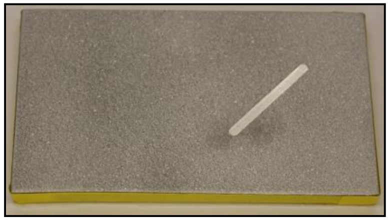
- Example – electric arc thermal spray - Two wires melted in arc and propelled onto surface by compressed air
- Particles 'pancake' onto surface, solidify, and contract
- Subsequent passes build additional thickness at ~90% densification, 10% voids, typ. to 0.010 inch thickness
- Mature, i9nexpensive, rapidly deposited metallic coating (but voids are concern)

*NSRP NASSCO/DTRC "Procedure Handbook for Shipboard Thermal Sprayed Coating Applications" 3/92



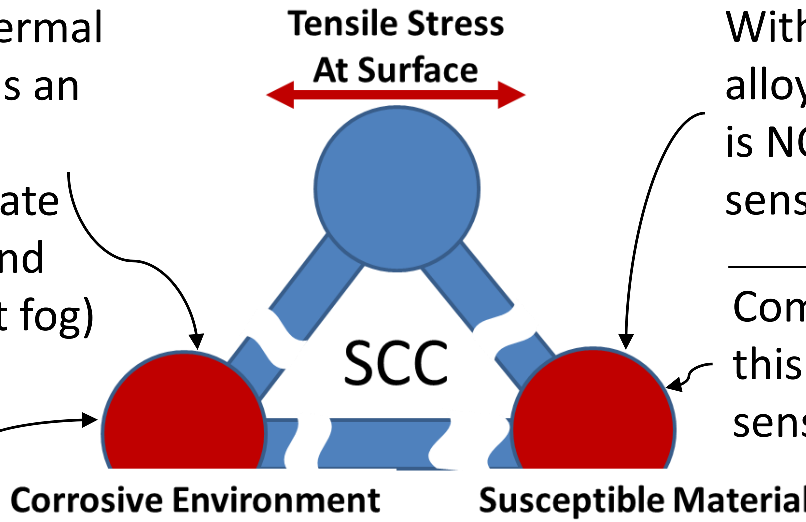
<u>NMC R2519 Rapid Response project</u>

- 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

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

Project Accomplishments vs. WBS (cont.)

- Evaluated available thermal spray processes

PROCESS	CAPABILITY	AVAILABILITY	APPLICABILITY	TOTAL SCORE
Criteria	*4 = best, 1 = worst*	*4 = best, 1 = worst*	*4 = best, 1 = worst*	
Wire Arc	3	2	3	8
HVOF	3	2	3	8
Flame Spray	2	2	3	7
Cold Spray	3	1	1	5
Plasma Spray	3	1	1	5
D-Gun	2	1	1	4

- 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)

Property	Test Type	Accompanying test specification	No. of Replicates	Thermal Spray Only	LSA Coated Replicates	Baseline [1]Material	In-Service Material	Lab Sensitized Material
Distortion	Visual	Visual	1	1	0	yes	yes	no
Adhesion	Bends	ASTM E290 [2]	3	3	3	yes	yes	no
Adhesion	Adhesion	ASTM D4541 [3]	2	2	2	yes	yes	no
Coating Integrity	Visual Inspection	MIL-STD-1687A [4]	2	2	2	yes	yes	no
Coating Integrity	Metallographic Inspection	MIL-STD-1687A	2	2	2	yes	yes	no
Coating Integrity	Corrosion	ASTM B117 [5] OR ASTM G30/38/44/47/49 [6]	3	2	3	yes	yes	no
Thermal Transfer / Intercoat Thermal Profile	QUVA (thermal)	ATM G154 [7]/ ASTM D4587 [8]	3	3	3	yes	yes	yes
Susceptibility	NAMLT	ASTM G67 [9]	2	2	0	yes	yes	yes

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*
  - *MIL-STD-1687A, Department of Defense Manufacturing Process Standard, Thermal Spray Processes for Naval Ship Machinery Applications*
    - *Active, preferred by NSWCCD*
  - *Procedure Handbook for Shipboard Thermal Sprayed Coating Applications*
    - *Active, relevant to NSRP*

Project Accomplishments vs. WBS (cont.)

- 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)

Property	Test Type	Accompanying test specification	Testing Stage
Coating Quality	Visual Inspection	MIL-STD-1687	1
Distortion	Visual Inspection	Visual	1
Adhesion	Bends	ASTM E290	1
Adhesion	Pull-off	ASTM D4541	1
Coating Integrity	Metallographic Inspection	MIL-STD-1687	1
Coating Integrity	Corrosion	ASTM B117	1
Coating Integrity	Alternate Immersion SCC	ASTM G47	2
Susceptibility	NAMLT	ASTM G67	2
Thermal Transfer / Intercoat Thermal Profile	QUVA (thermal)	ATM G154 / ASTM D4587	2
Coating Wear	Taber Abrasion	ASTM D4060	2

CTC Concurrent Technologies Corporation

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

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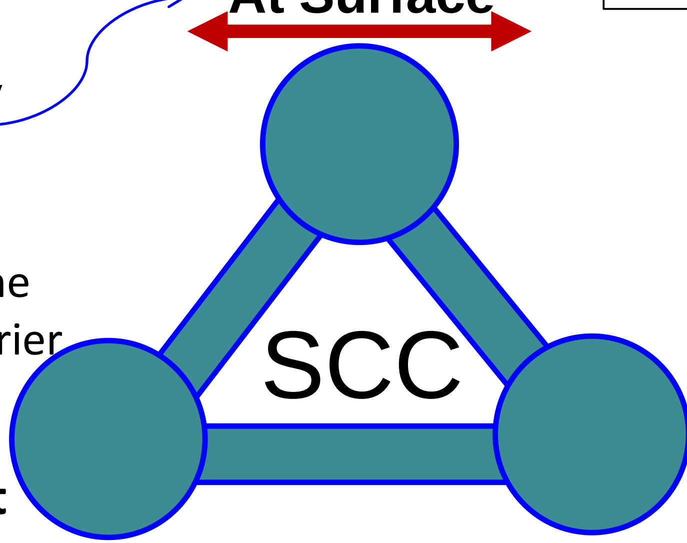
BACKUP SLIDES

Sensitization and SCC

Sensitization: Mg_2Al_3 'β phase' forms at higher temp and migrates to grain boundary

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

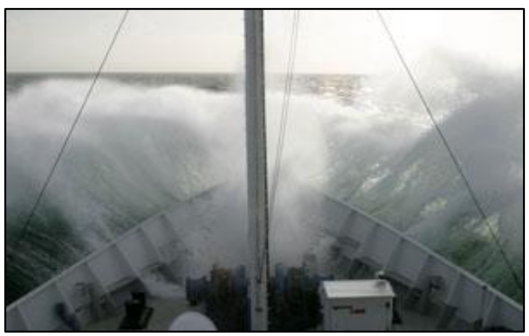
Tensile Stress At Surface



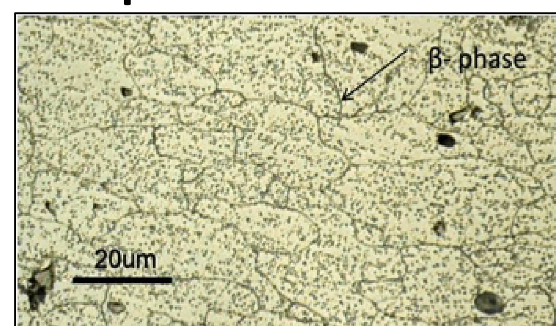
Painted aluminum alone is NOT an effective barrier

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

Corrosive Environment



Susceptible Material



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

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