Applied Research Laboratory
The Pennsylvania State University

Navy ManTech Cold Spray Programs The Institute for Manufacturing and Sustainment Technologies

A Navy Manufacturing Technology Center of Excellence

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Applied Research Laboratory
Institute for Manufacturing and Sustainment Technologies

manufacturing technology program

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Background / Core Competencies

- U.S. Navy established the Applied Research Laboratory at Penn State in 1945
- In 1996, DoD reaffirmed its strategic relationship and commitment by designating ARL as a University Affiliated Research Center (UARC)
- Trusted agent for the DoD
- Train next generation of Engineers
    - ARL is primarily a science and technology based laboratory with leadership in the following core competencies:
    - Materials and Manufacturing
    - Acoustics
    - Guidance and control
    - Thermal energy systems
    - Hydrodynamics, hydroacoustics, and propulsor design
    - Navigation and GPS
    - Communications and information
    - Graduate education

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Manufacturing Technology Program

- **The Navy ManTech Program develops and implements enabling manufacturing technology in the form of new equipment and processes**
  - **Supplements industry's ability to support DoD acquisition, weight reduction or Life Cycle Cost reduction efforts**
  - **Funded by ONR and associated stakeholders (program offices, directly related OEM's)**
  - **Leverage funding to support larger programs**
  - **Funding may include subcontracts to industry, government or other ManTech COE's**
  - **Requirements**
    - **Approval from Stakeholder**
    - **Clear Transition Path**
    - **One to three years duration**

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iMAST Overview

- **iMAST established February 1995**
- **Address advanced weapon system issues**
- **Development & transition of new manufacturing processes & equipment supporting Navy acquisition and sustainment programs**
- **Projects contribute to affordability, life cycle cost reduction and sustainment**
- **Repair Technology (REPTECH) Projects: Repair, overhaul and sustainment**
- **Target fielded weapon systems and provide the process and equipment technology needed to repair and maintain fleet assets**
- **Implementation at naval depots, shipyards, Marine Corps logistics bases, intermediate maintenance activities and contractor facilities**

Introduction

- **Presentation Outline**
- **Portable Cold Spray Repair and Restoration**
- **Corrosion Resistant Coatings for Magnesium Transmission Gearboxes for SH60**
- **AAV Enhanced Appliqué Armor Kit Product Improvement**

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Portable Cold Spray Repair

Objective:

- **Develop portable processes for repair and restoration of Aluminum and Magnesium Components**

Approach:

- **Survey available portable Cold Spray Systems**
  - **Perform test to evaluate Cold Spray Systems**
  - **Select Cold Spray System – Compliment NAVAIR**
    - **Cherry Point – CGT Portable**
- **NAVAIR components**
  - **AMAD Transmission Housing Cover**
  - **IVD Aluminum Repair**
  - **AH-1 and UH-1N Support Case Mount Foot**
  - **H-60 Tail Cone Bulkhead**
- **Develop process to repair components**
- **Perform qualification testing**
- **Develop implementation requirements (safety, personal protection, etc.)**
- **Transition technology**

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Portable Cold Spray Repair

- **Develop Cold Spray Repair – Transmission Housing**
  - **Dimensional restoration**
  - **High adhesion strength**
  - **Hardness comparable to A357**
  - **Good Machinability**
  - **Rapid Response**
- **Approach**
  - **Process Development**
  - **Repair Validation**
  - **Repair Housing**
- **Compare Results to HP Systems**

A357.0-T61
Hardness of 113 VHN (41 Rockwell A)
Ultimate Tensile= >45ksi
Tensile = >36ksi
Composition
Al-7%Si
Ti = 0.04-0.20%

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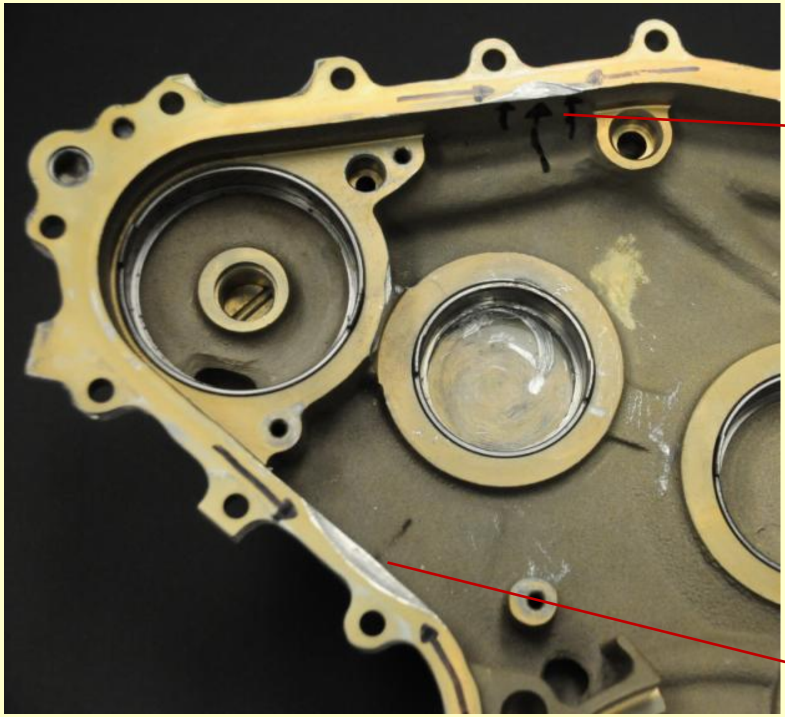
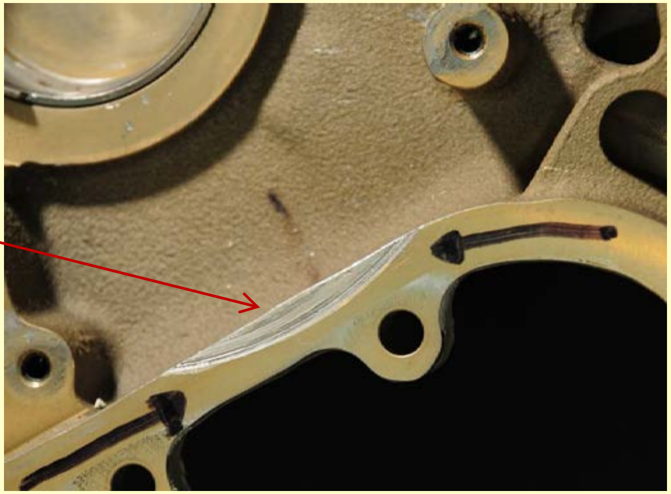
Portable Cold Spray Repair





Damaged areas

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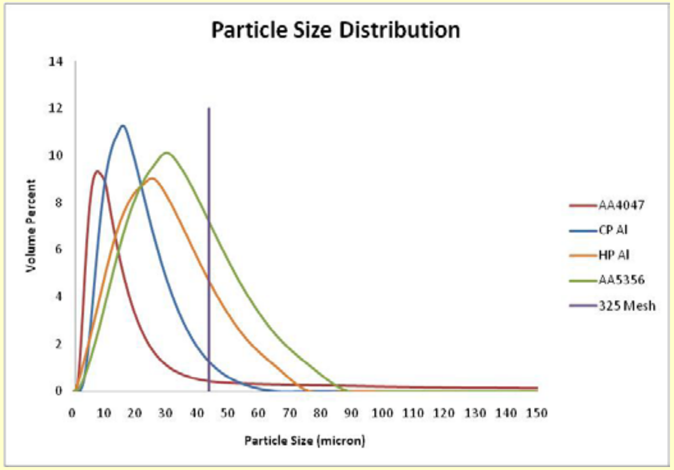
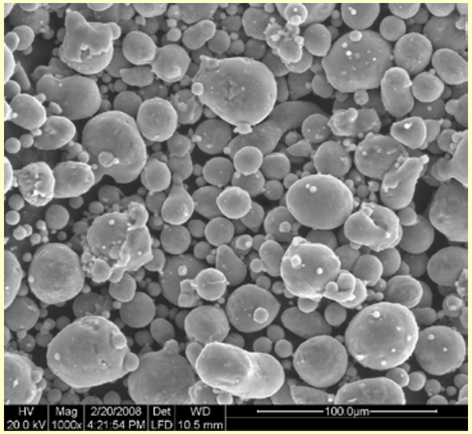
Portable Cold Spray Repair

Initial Set-up

- **Type of repair**
  - **Dimensional**
  - **Structural**
- **Powder Selection**
  - **Material Compatibility**
  - **Hardness**
  - **CTE Match**
  - **Size and morphology**
- **Surface Preparation**
  - **Material removal**
  - **Bead blasting**
  - **Surface roughness**
- **Cold Spray System**
- **Process parameters**
  - **Modeling – initial parameters**
  - **Process Gas – Type, Pressure, Temperature**
  - **Nozzle**
  - **Traverse rate**
- **Powder testing**
  - **Size Distribution**
  - **Morphology**





SEM of Al-12Si

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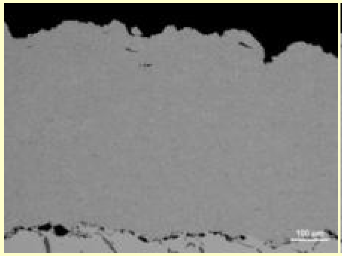
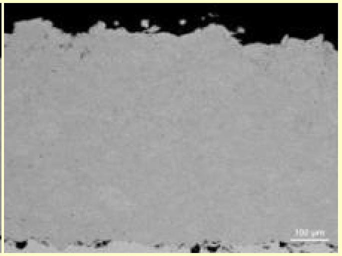
Portable Cold Spray Repair

- **Powders**
  - **CP-Al, AA6061 and AA4047**
- **Systems**
  - **High Pressure**
    - **CGT 4000/47 with He, N2**
    - **Ktech He, N2**
  - **Low Pressure**
    - **Centerline SST with He, N2 and Compressed Air**
- **Surface Prep – Glass Bead (G3) Media Blasting**
- **Microstructure Results AA4047**
  - **Porosity <0.1%**
- **Galvanic Corrosion AA4047**

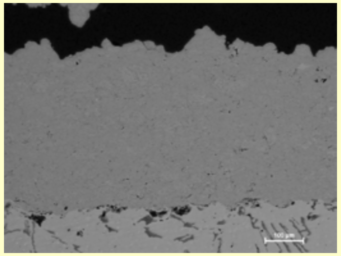
Al 12-Si – A357



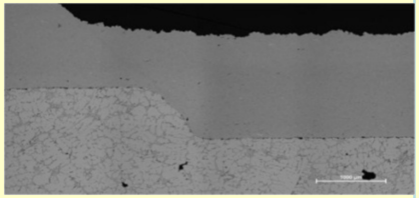
CGT (He) - 100x



CGT (N2) - 100x



SST (He) - 100x



CGT (N2) - 100x

Initial System Repair Results

Initial System Comparison Results			
System	Main Process Gas	Hardness (VHN)	Bond Strength (ksi)
CGT-HP	N2	106	12.1*
CGT-HP	He	117-137	8.5-11.2*
CGT- Portable	HE		
SST - Portable	HE	141	6
* glue failures			

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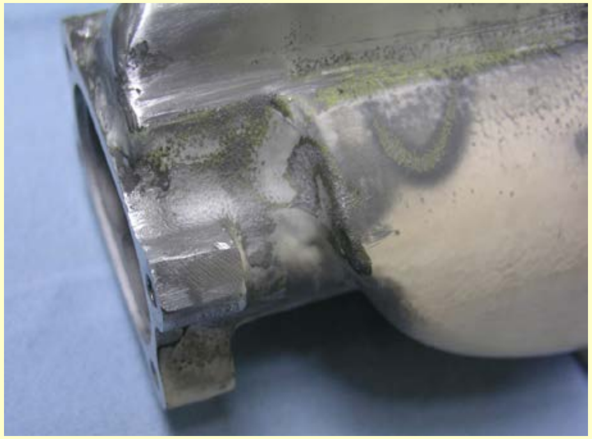
Initial System Repair Results





A357 Casting – Al-12 Si repair with Centreline Portable System

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Initial System Repair Results

A357 Casting – Al-12 Si repair with Centreline Portable System

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Initial System Repair Results

A357 Casting – Al-12 Si repair with Centreline Portable System

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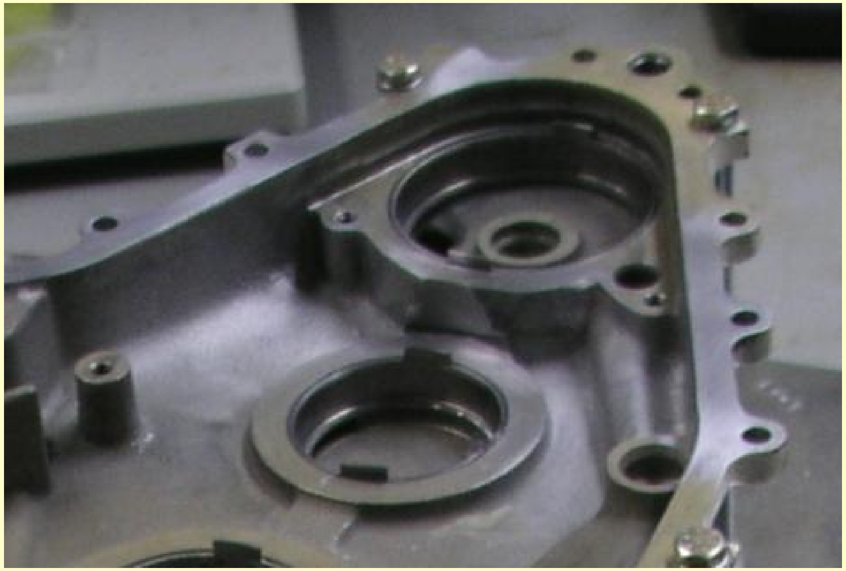
Cold Spray Repair HP System

Repair

- **Surface Preparation**
- **Masking**
- **Coating Application**
- **Final Machining**
- **Dimensional Measurements**
- **Visual Inspection**
- **Acceptance Testing**
  - **Requirements/Specification**
  - **NDE**
  - **Thermal Cycling**
- **Technology Transfer**
- **Documentation**

Damaged Housing



Repaired Housing

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Cold Spray Transition

Transition Locations

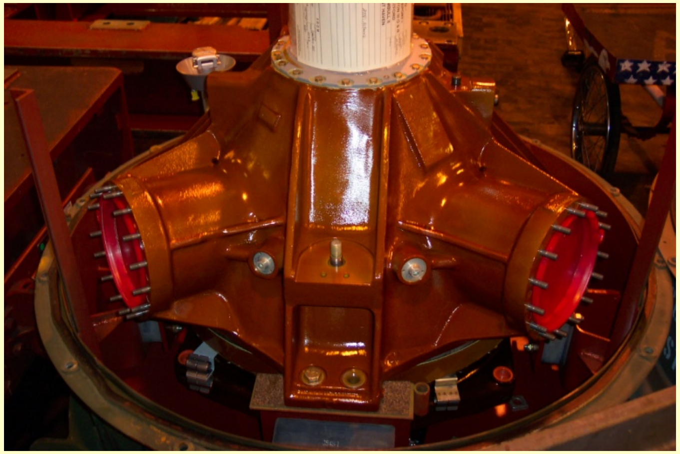
- **US Naval Aviation Depot, Cherry Point, NC (FRC-E)**
- **North Island, CA (FRC-SW)**
- **Jacksonville, FL (FRC-SE)**

- **Program will be completed in 18 months**

Cold Spray Aluminum for the Corrosion Protection of Mg Gearbox: Aluminum-Magnesium Galvanic Corrosion

Project Objective

- **Apply a corrosion resistant barrier coating of Al to Mg using Cold Spray**
- **Leverage Project with ESTCP Supersonic Particle Deposition Technology for Repair of Magnesium Aircraft Components**
- **Powder Development and Evaluation**
- **Corrosion Testing**
- **Supporting Transition**



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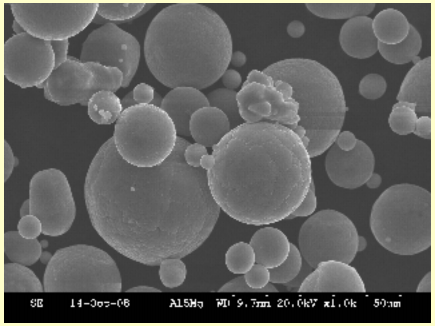
SH-60 Gearbox Repair

Magnesium highly susceptible to galvanic corrosion

- Most electrochemically negative structural metal
- Thermodynamic driving force to corrode when coupled to any metal

Galvanic corrosion possible on Al-coated gearbox

- Edge of coating (Al-Mg interface)
- Scratched/damaged coating (Mg exposed)



Powder Development and Evaluation

- Commercially Pure Al (CP) (99.5% Al)
- High Purity (HP) Al (99.95% Al)
- High Purity (HP) Al-5 wt.% Mg (95% Al) – Produced at PSU
- Al 5356 (5 wt.% Mg)
- Al 4047 (12 wt.% Si)
- Al 6061

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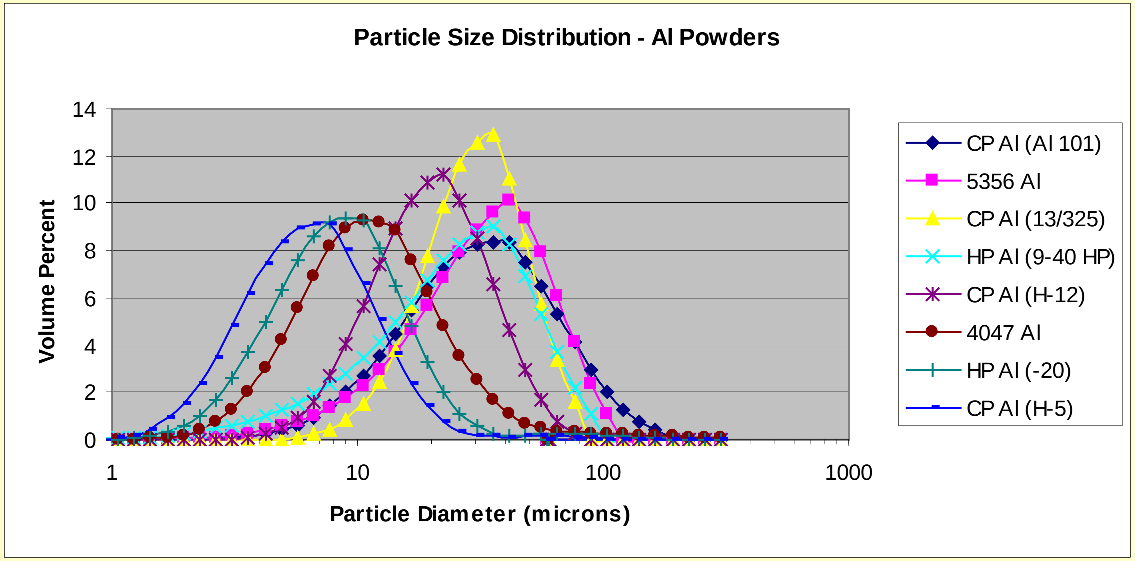
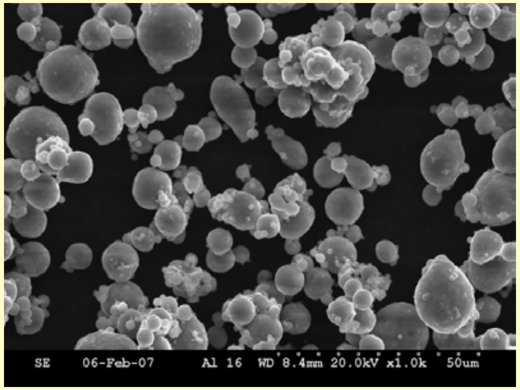
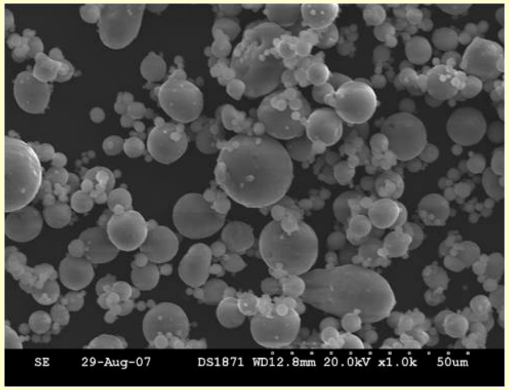
SH-60 Gearbox Repair

Particle Characterization

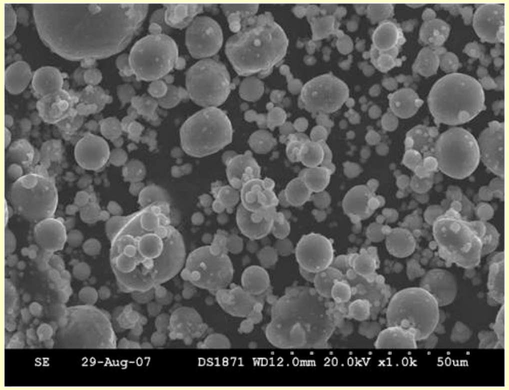




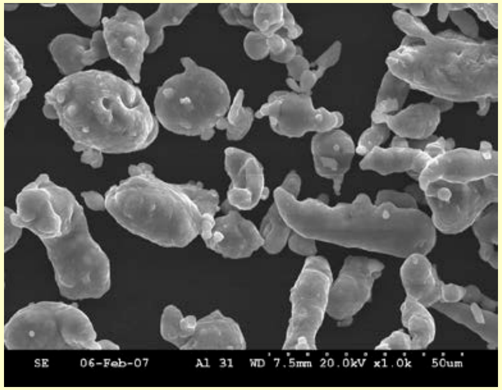
CP Al - 18 µm



4047 Al - 13 µm



HP Al - 23 µm



CP Al - 42 µm

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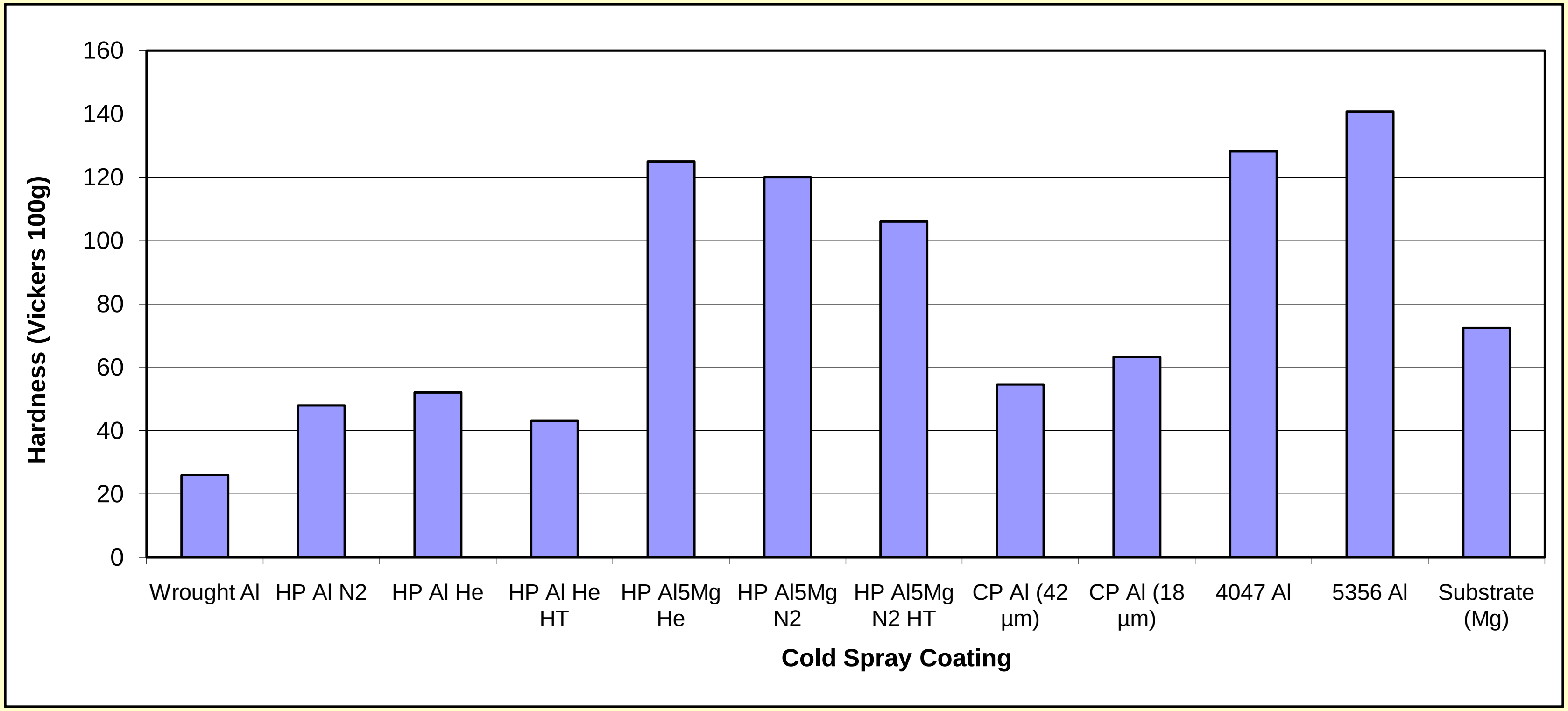
SH-60 Gearbox Repair



Hardness of Aluminum Powders applied by Cold Spray

Galvanic Couple – ASTM G71

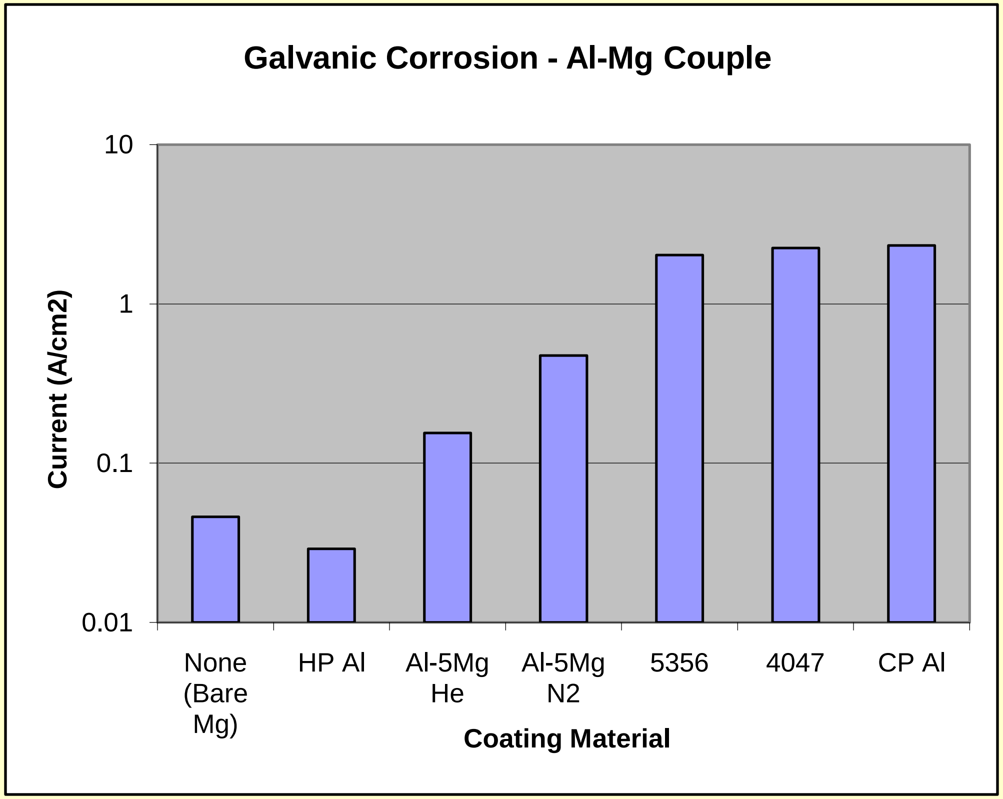
Experimental:

- Mg and Al-coated Mg coupons electrically coupled by ZRA in 3.5% NaCl
- Current measured

Results:

- HP Al yielded no galvanic current (similar to Mg-Mg couple)
- Al-5Mg shows higher current due to contamination from crucible

Coating	Mean	Std Dev	95% CI
None (Bare Mg)	0.046	0.03	0.00, 0.09
HP Al	0.029	0.01	0.00, 0.04
Al-5Mg He	0.155	0.04	.11, .20
Al-5Mg N2	0.473	0.06	.37, .57
5356	2.03	0.34	1.61, 2.46
4047	2.24	0.14	1.89, 2.58
CP Al	2.33	0.38	1.86, 2.81



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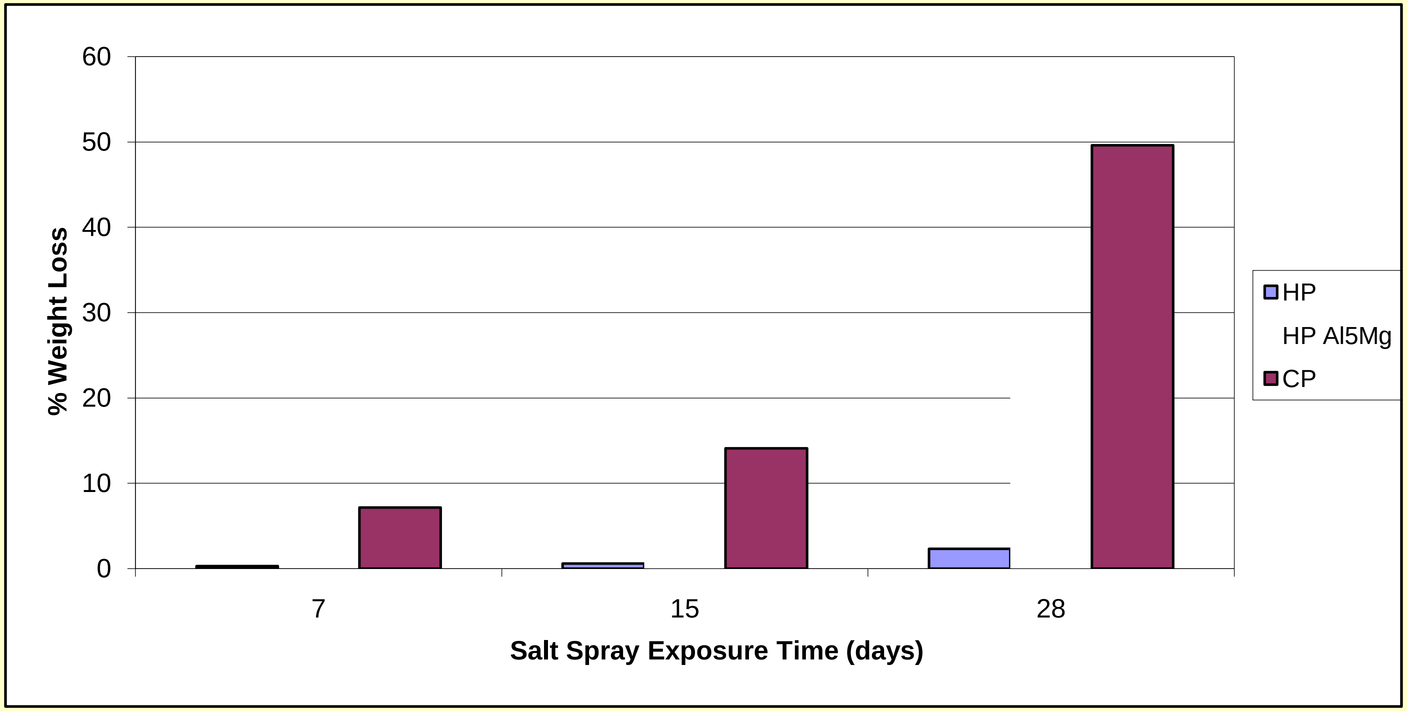
Galvanic Couple – Salt Spray

Experimental

- Mg panel coated with Al on both faces with Mg edges uncoated (sandwich)
- Weight loss determined (2 samples per condition)

Results

- HP Al coated panel showed little material loss
- CP Al subject to enhanced galvanic corrosion and cathodic corrosion



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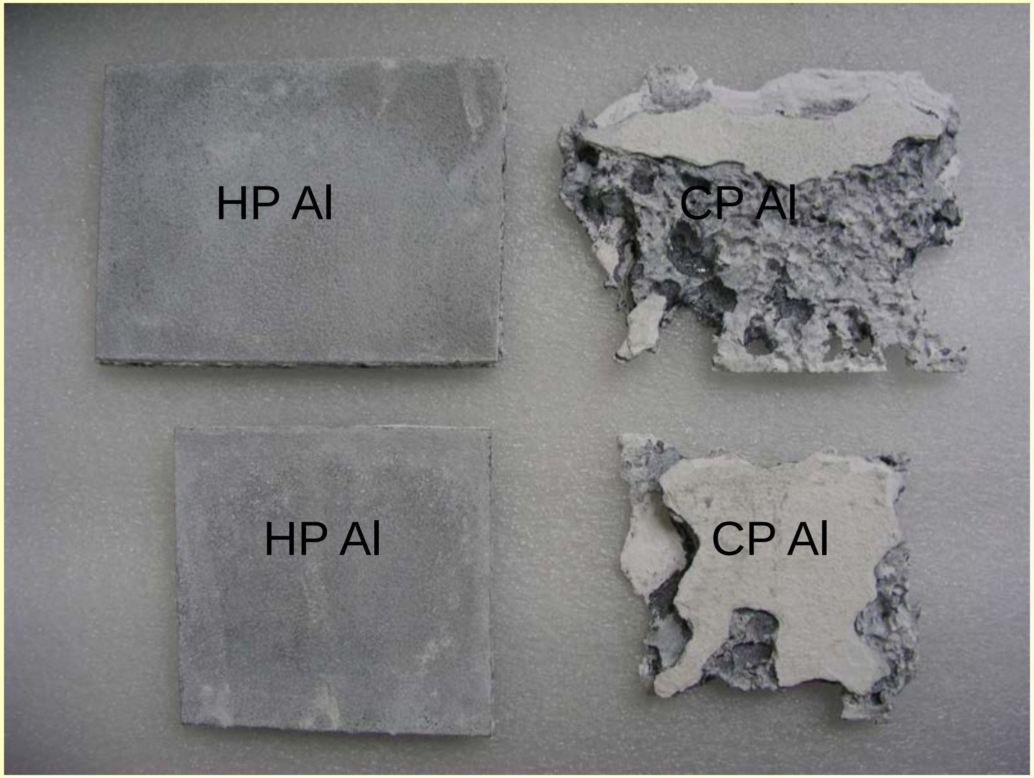
Galvanic Couple – Salt Spray

Corrosion Testing – Galvanic Couple (ASTM B-117)

- **HP Al showed little material loss**
- **CP Al subject to enhanced galvanic corrosion and cathodic corrosion**



Comparison galvanic coupling of high purity and commercially pure Cold Spray aluminum coatings with ZE41A-T5 Mg panel (0.25” thick) after two weeks in salt spray chamber (ASTM B117). Coating applied to front and back of Mg (Edges of Mg exposed). Left – high purity Al. Right – commercially pure Al.

SH-60 Gearbox Repair

- **Summary**
  - **Leveraged ESTCP Program**
  - **Performed Corrosion and Materials Evaluation**
  - **Developed Powders for improved corrosion**
  - **Provided input for selection of powders with optimal combination of properties**

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AAV Problem Statement

- **Appliqué Armor was corroding at a very high rate**
  - **Damage to CARC Paint**
    - **Handling – installation and removal**
    - **Shipping**
    - **Storage**
    - **Operation**
  - **Maintenance Procedures**
- **Cadmium coatings on bolts and washers were an environmental hazard**



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AAV Program Overview

- Visit Camp LeJeune to understand installation, removal, operating conditions, and storage
- Indentified corrosion mechanisms and initiation path
- Evaluated steel, rubber, binder and CARC coating
- Evaluated CP Al, Zn and Zn-Al coatings
- Coatings applied with Cold Spray and thermal spray and sealed with mil spec paint.
- Preformed alternate Immersion tests at ARL and at LaQue Corrosion Technology Center, environmental exposure, impact testing, galvanic testing
- Evaluated alternatives to cadmium plated bolts
- Coated four full sets of armor
- Field tested on two long term deployments
- Cost analysis

Mild Steel
Rubber
Hardened Steel

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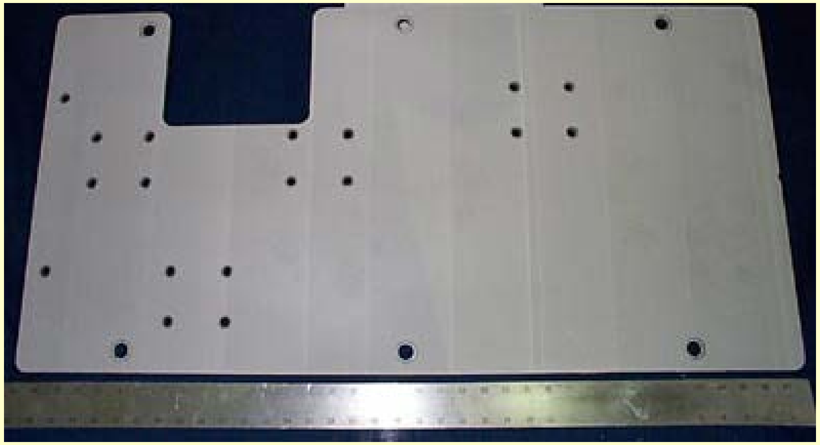
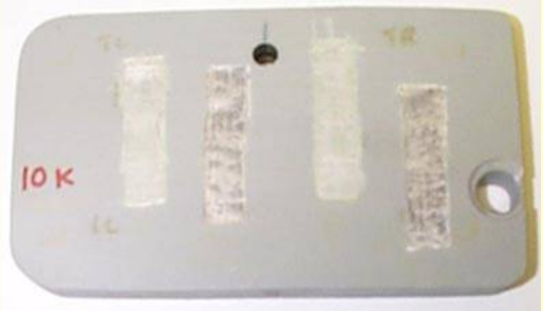
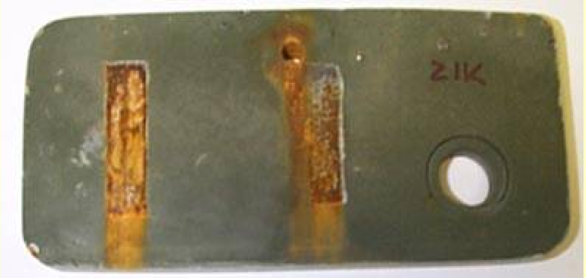
Cold Spray Coated Panels

6669255-C - APK Step



6669266 – APK Slope





Alternate Immersion Testing
Top- With CP-Al
Bottom – Uncoated

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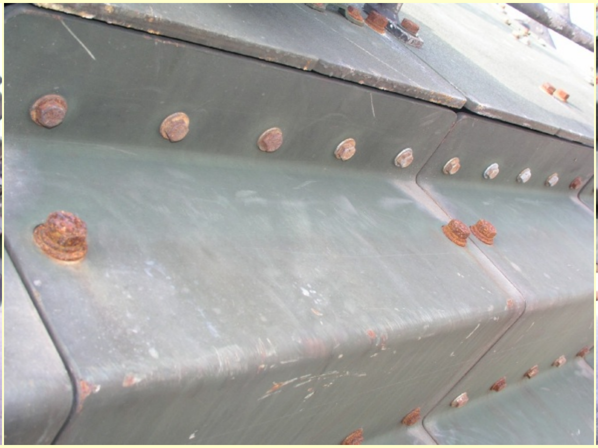
Deployment Results - Cold Spray

B212: Step - Cold Spray CP-Al Inside and outside



B205: Step - Thermal Spray CP-Al Inside and outside

B201: Thermal Spray CP- Al Inside Zn Primer outside

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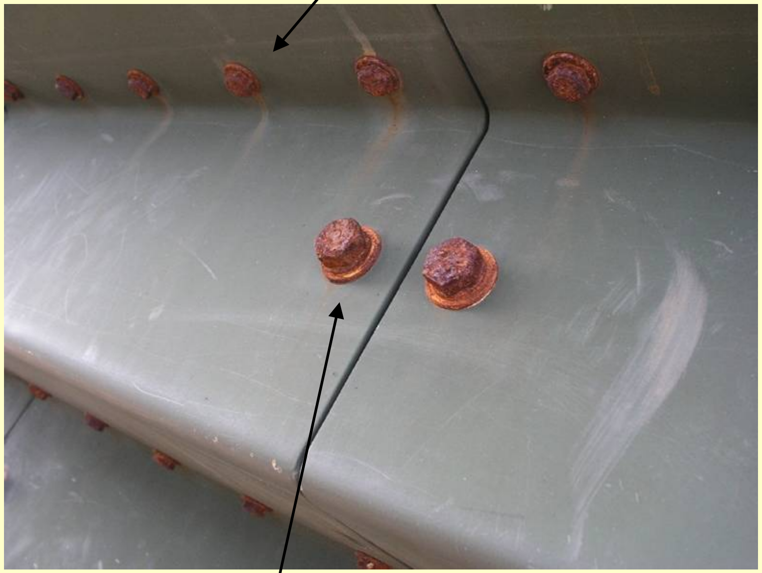
Deployment Results - Cold Spray

B205: Slope – Cold Spray CP-Al inside and outside
CARC damaged - Armor still protected

Deployment Results - Fasteners

Bolts with Al/Zn Plating (Dacromet 320)



Cadmium Plated Bolts

Cadmium and Dacromet 320 have similar performance – Dacromet 320 does not have the environmental hazard

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Deployment Summary

Field Test Coating Matrix				
Armor Set	**EAAK 1**	**EAAK 2**	**EAAK 3**	**EAAK 4**
Slope Inside	**TS CP-Al**	**TA CP-Al**	**CS CP-Al**	**CS CP-Al**
Slope Outside	**TS CP-Al**	**TA CP-Al**	**CS CP-Al**	**CS CP-Al**
Step Inside	**TS CP-Al**	**TA CP-Al**	**CS CP-Al**	**CS CP-Al**
Step Outside	**Zn – primer**	**TA CP-Al**	**Zn - primer**	**CS CP-Al**
Edge	**Polysulfide**	**Polysulfide**	**Polysulfide**	**Polysulfide**
Valley Bolts	**Al/Zn**	**Al/Zn**	**Al/Zn**	**Al/Zn**

Typical Deployment Activities April to Oct
Swim to transport ship
Swim to shore/return – training exercises
12 ship to shore-operations
Four different European locations

Deployment Results

Damage Mitigation

- **Panels coated with CP-Al performed better than panels with a thick zinc primer during deployment**
- **Panels coated with CP-Al using Cold Spray performed better than panels coated using thermal spray**
- **Edges damaged during installation and removal**
    - **Edge sealants protect edges**
- **Damage during shipping and handling**
    - **Al coating and sealant improves corrosion resistance**
- **Impact during use**
    - **Al coating and sealant improves corrosion resistance**
- **Application of CARC with large silicon carbide particles**
    - **Change application procedure and SiC particle size**
- **Cadmium plating is an environmental and health hazard**
- **Al/Zn (Dacromet 320) greatly reduced environmental and health hazards**
- **Cold Spray cost competitive with wire-arc thermal spray**
- **Developed Cost Software – verified coating large panels**

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Summary

iMAST/Navy ManTech

- **Bridge the technology transition valley of death**
- **Clear transition path**
- **Can be used to support existing program**
- **Excellent technology transfer/ implementation**
- **Can work with OEMs, government, and equipment manufacturers**

Acknowledgements

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