Cold Spray Technology for DOD Applications

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Report Documentation Page

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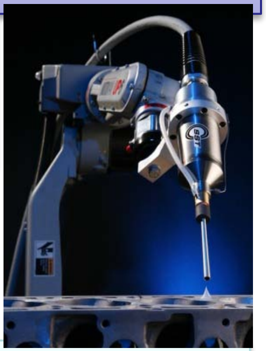
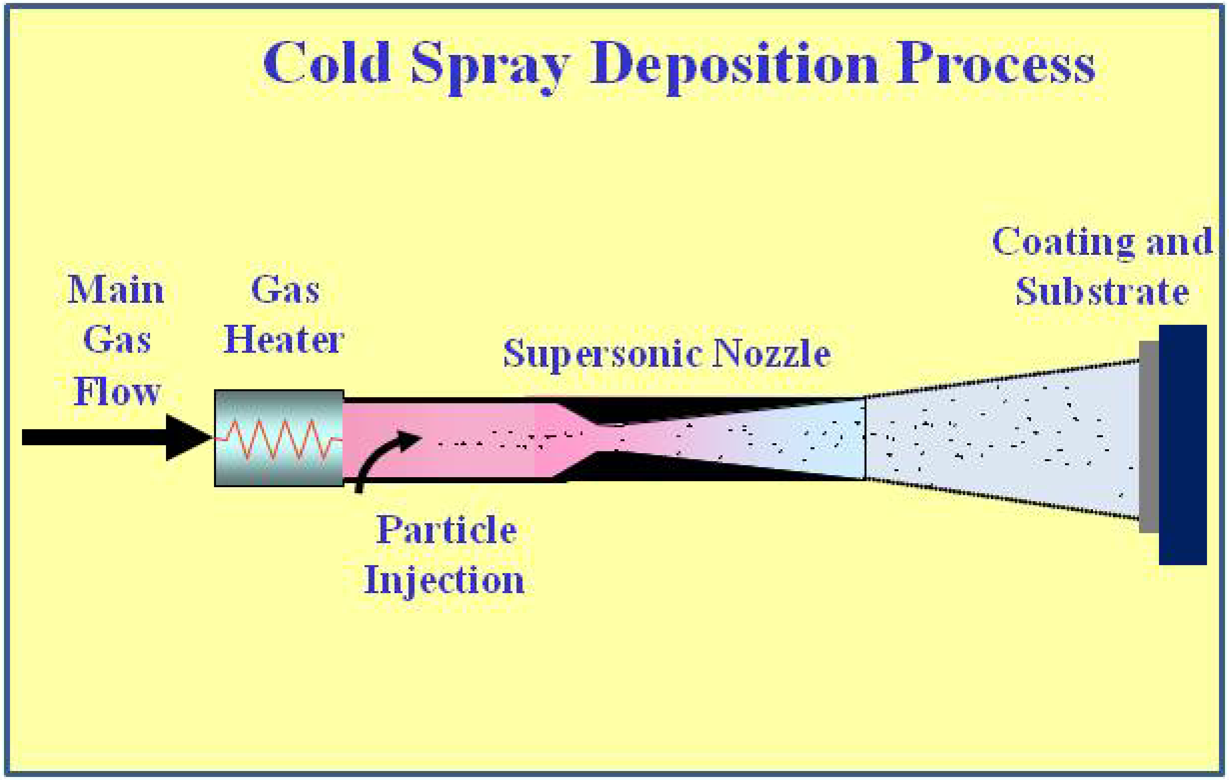
Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

The Cold Spray Process

➢ ***Unique solid-state materials consolidation process which utilizes high velocity particles impinging upon a substrate to build up coatings and/or free-standing structures without the use of combustion fuels.***

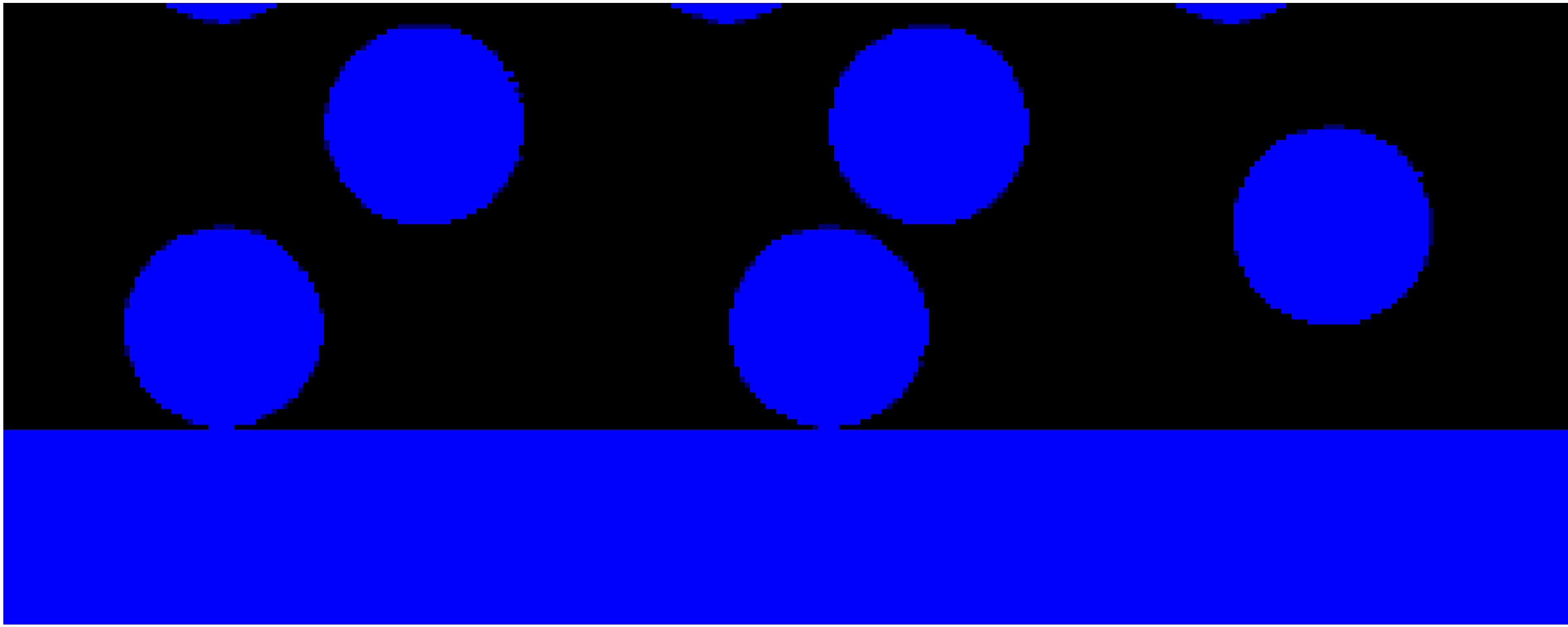
- *Stationary Robot Controlled Systems for precision and or high volume*
- *Portable Hand-held Systems for field repair and mobility*





- ***Feed stock typically ranges from 1 to 50 µm diameter***
- ***Gas temperature ranges from R.T. to 1,000°C and pressures from 300 - 725psi***
- ***No melting of particles***
- ***Negligible oxidation***
- ***No decomposition or phase changes of deposited particles or substrate***

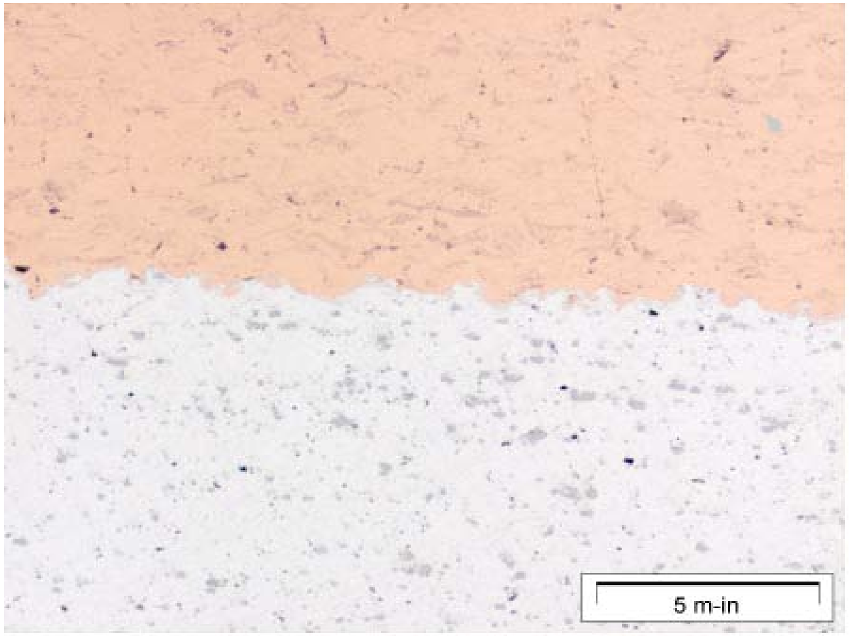
*Particle/Substrate Interaction**

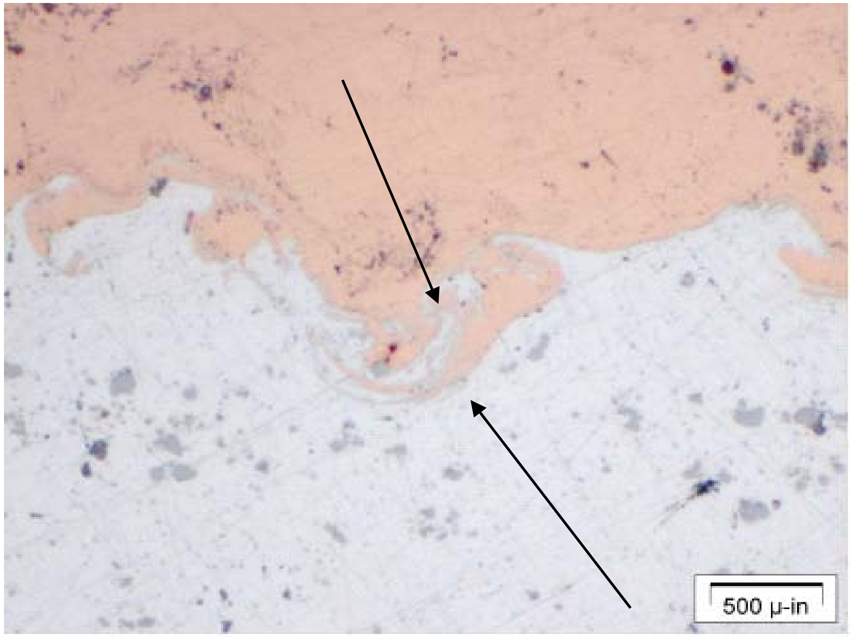


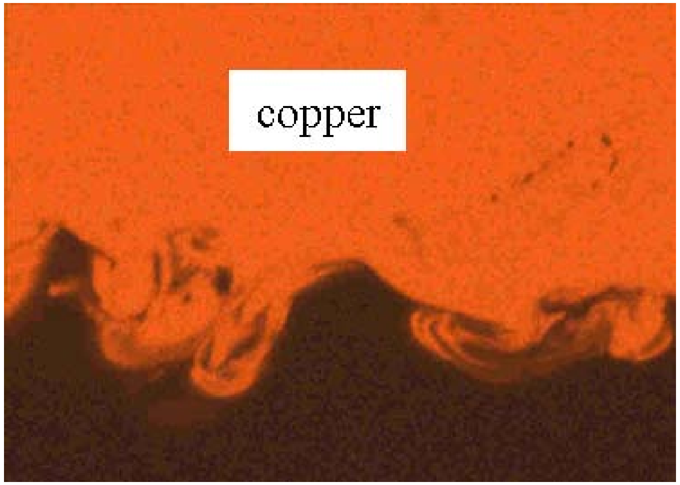
Color changes denote temperature gradients. Higher temperatures are at splat boundaries.

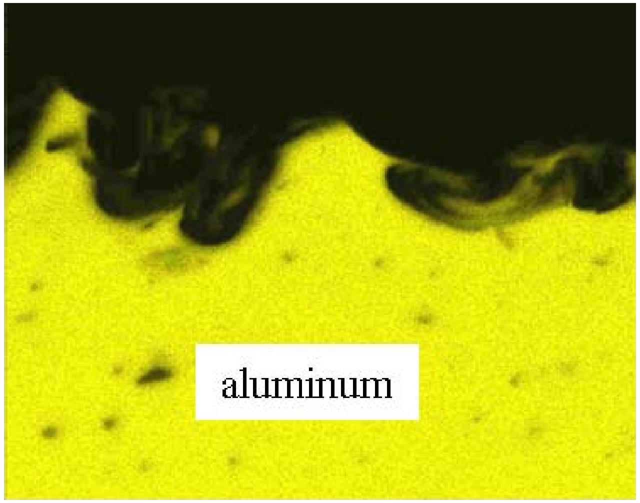
**from H. Assadi, www.modares.ac.ir/eng/ha10003/CGS.htm*

Mechanical Mixing at Interface









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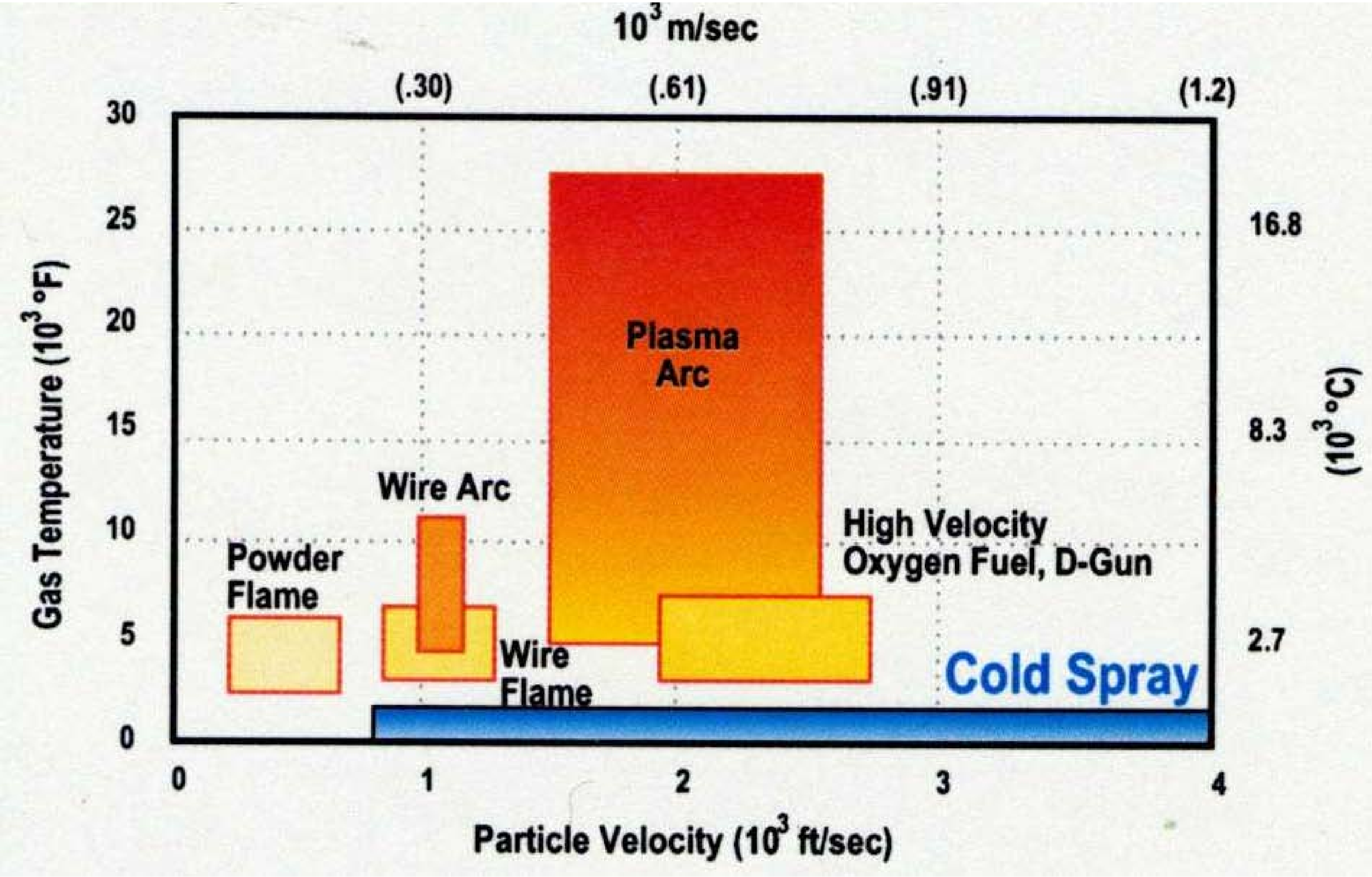
Cold Spray vs. Thermal Spray



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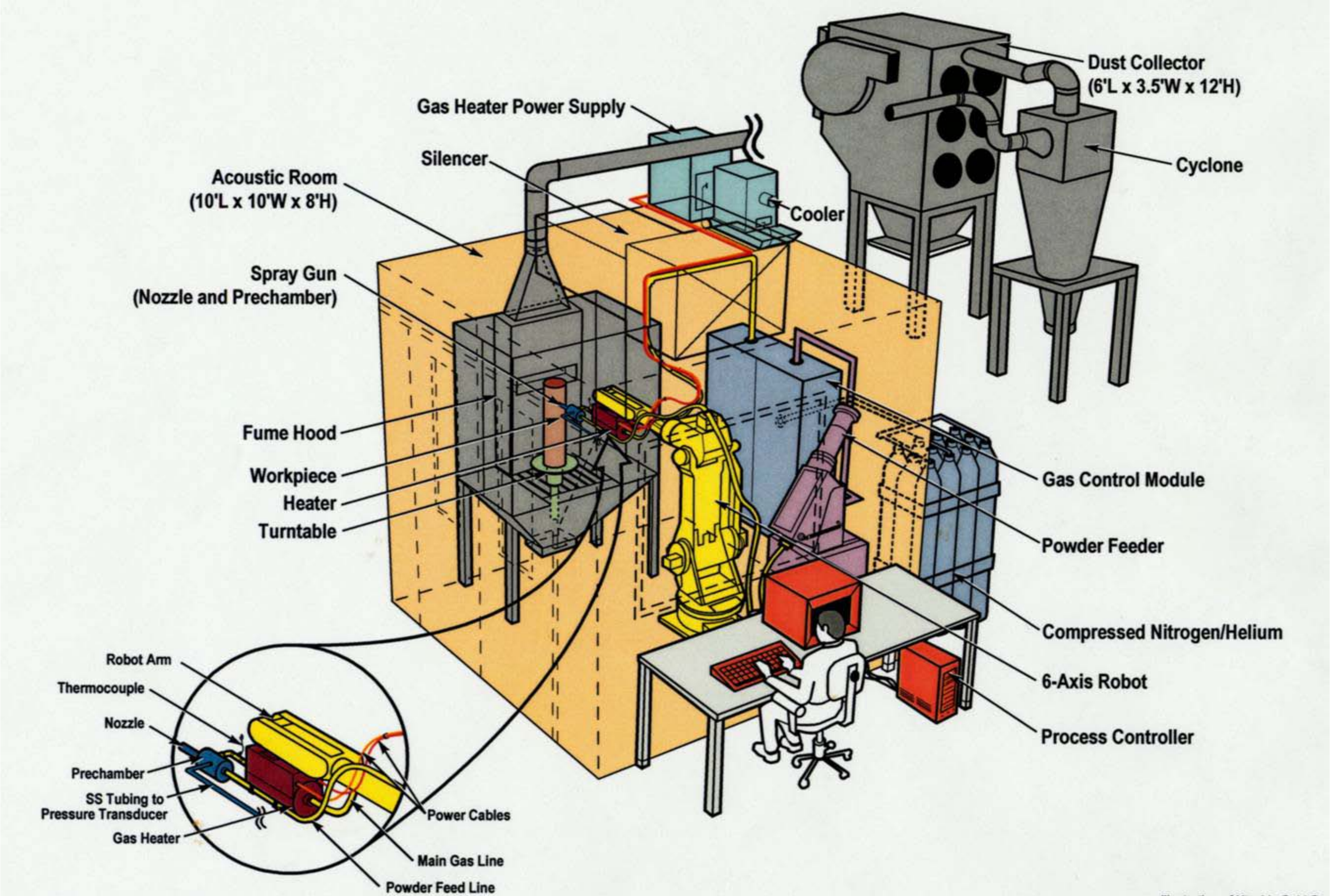
Schematic of the Cold Spray Process



Ktech Cold Spray System at ARL

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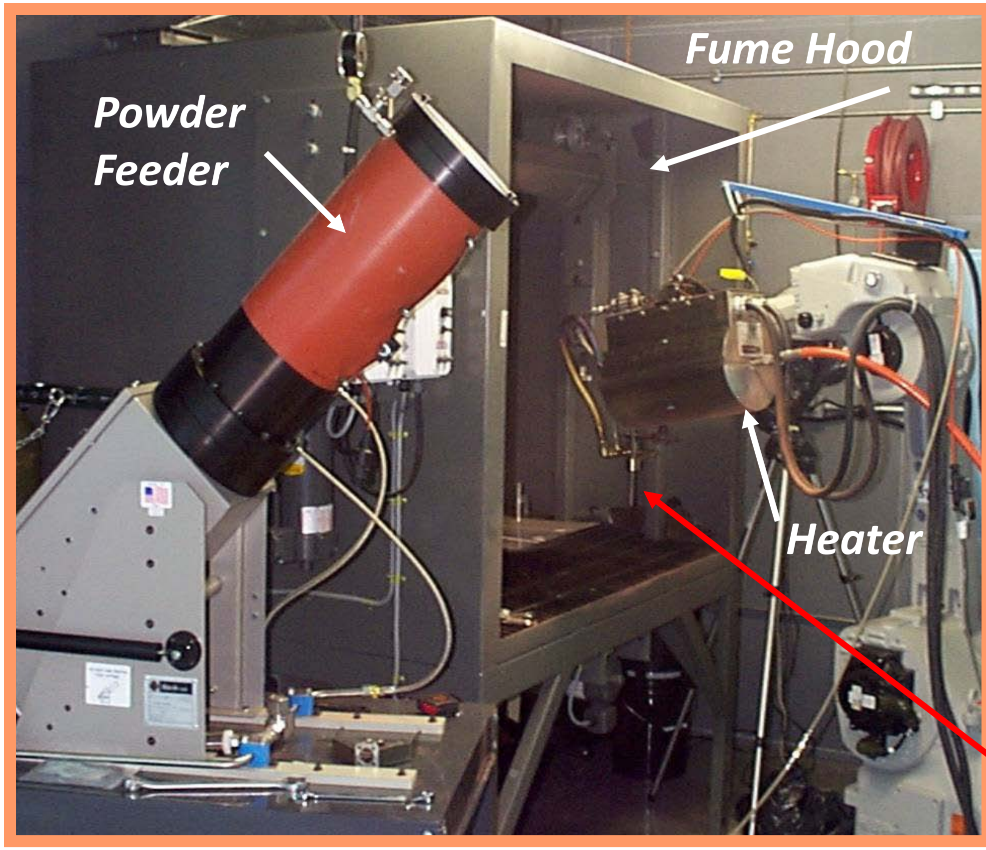
Cold Spray System Components



Robotically Controlled Spray Gun

Spray Nozzle

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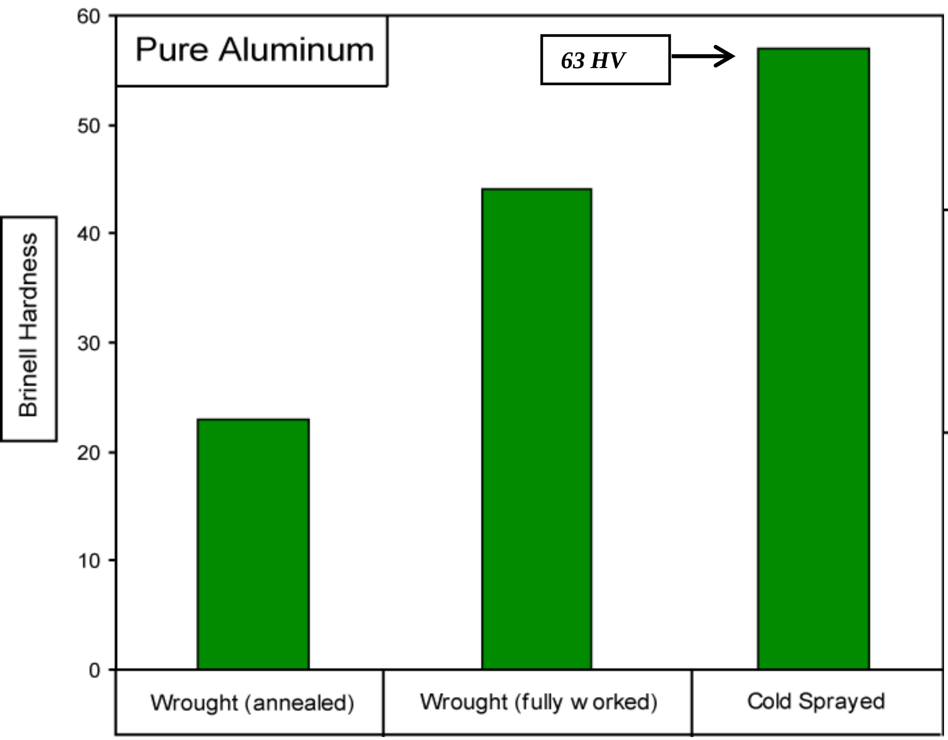
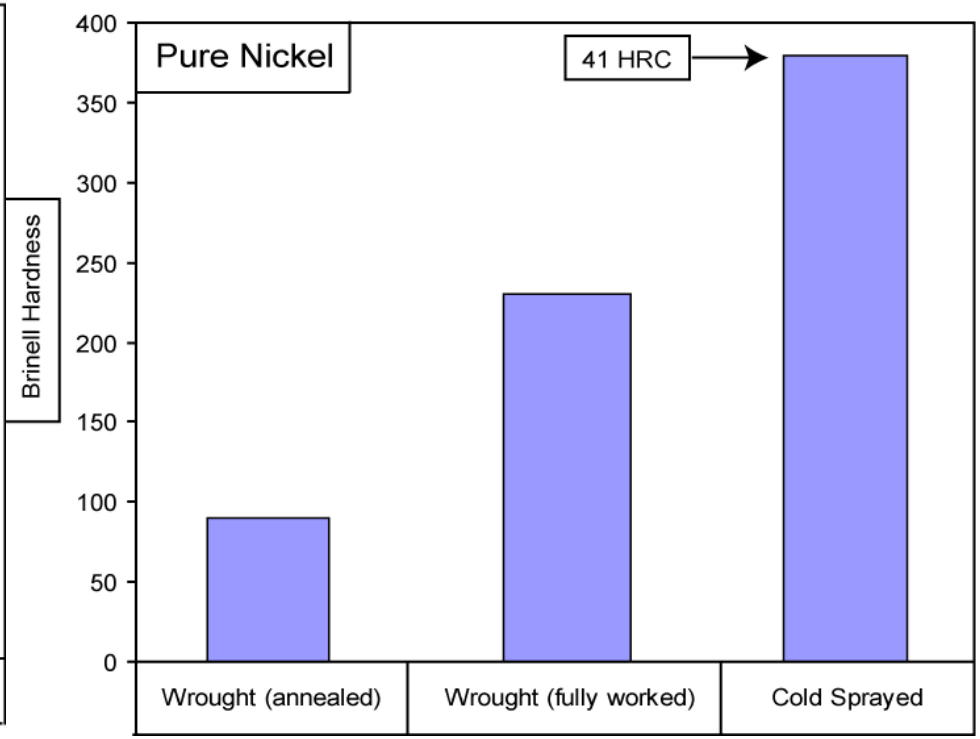
Advantages of Cold Spray

- Low Temperature Process
  - Particles "peen" the surface and develop compressive stresses (beneficial for fatigue)
  - Bonding mechanism similar to explosive cladding (mechanical mixing & metallurgical bond)
  - Conducive for thermally sensitive substrates (i.e. magnesium, composites)
- Strength/Hardness
  - High strength/hardness (often greater than comparable wrought materials)
- Density
  - 100% consolidation possible with many materials, equal to theoretical
  - Little to no porosity or inherent defects(i.e. oxides), good electrical/thermal conductivity
- Wide Selection of Commercially Available Powders/Materials
  - Metals, oxides, hydrides, polymers, nanostructured materials
- Versatility
  - Graded structures and coatings (lengthwise and/or through thickness)
  - Complex geometries
  - Free-form fabrication of parts
- Ease of Production
  - Fully automated/robotically controlled turnkey system
  - No harmful fuels or extraordinary safety equipment
  - Minimal material waste-high deposit efficiency (i.e. 80W-20Cu 94%, 6061 Al 100%)
  - Deposition rates reported up to 40 kg/hr and higher (CP Titanium)

Cold Sprayed vs. Wrought Materials Hardness Comparison





ARL Portable Cold Spray System

Overview of Accomplishments

- ***Cold Spray Coating Parameters Optimized at ARL for CP-Al & 6061Al***
- ***FRC-East cold spray system is installed, set up and processing parts***
- ***All training sessions and quality control sample production completed at FRC-East.***
- ***DEMVAL successfully completed at FRE-East, June 2011***

2008 Defense Standardization Program Achievement Award

•Presented to members of the Cold Spray Team for the development of a military process specification, "MIL-STD-3021, titled Materials Deposition, Cold Spray" (2008)

Sikorsky is proceeding with the sump repair for the H-60 platform

•Approval obtained for Overhaul Repair Instruction (ORI) SS8491 (2011)

Cold Spray has been approved through MAB, AED and PO-UH-60 for UH-60 Sump Repair

•Maintenance Engineering Order (MEO)T-7631 (2012)

Transition Plan:

FLEET READINESS CENTER EAST

DOD VERTICAL LIFT CENTER OF EXCELLENCE

IN SERVICE SUPPORT CENTER

POC: Carl Sauer
Materials Engineer

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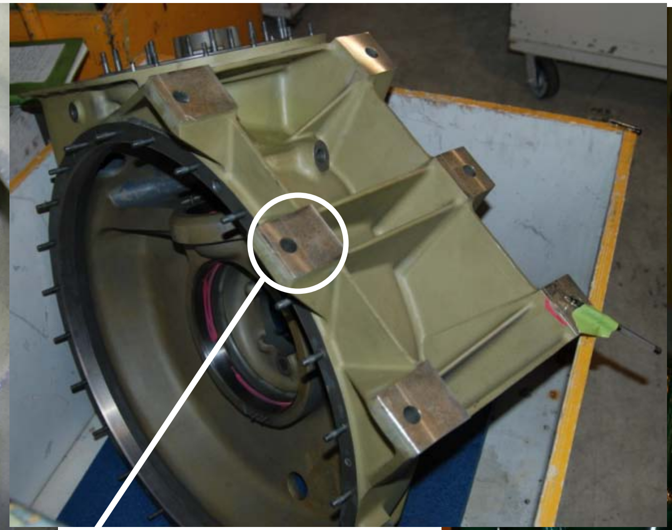
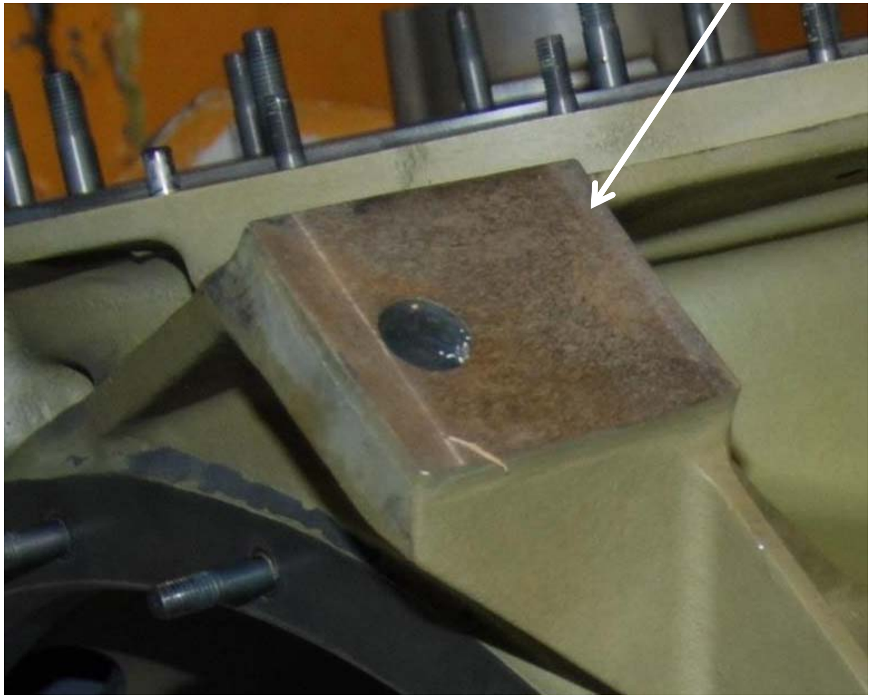
Transition Plan at FRC- East



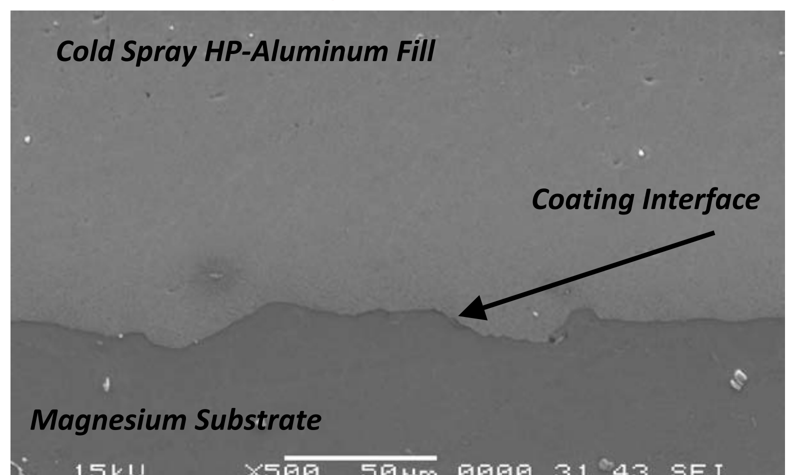


Cold Spray Shim Replacement for Mounting Feet on H-53 Main Gearbox

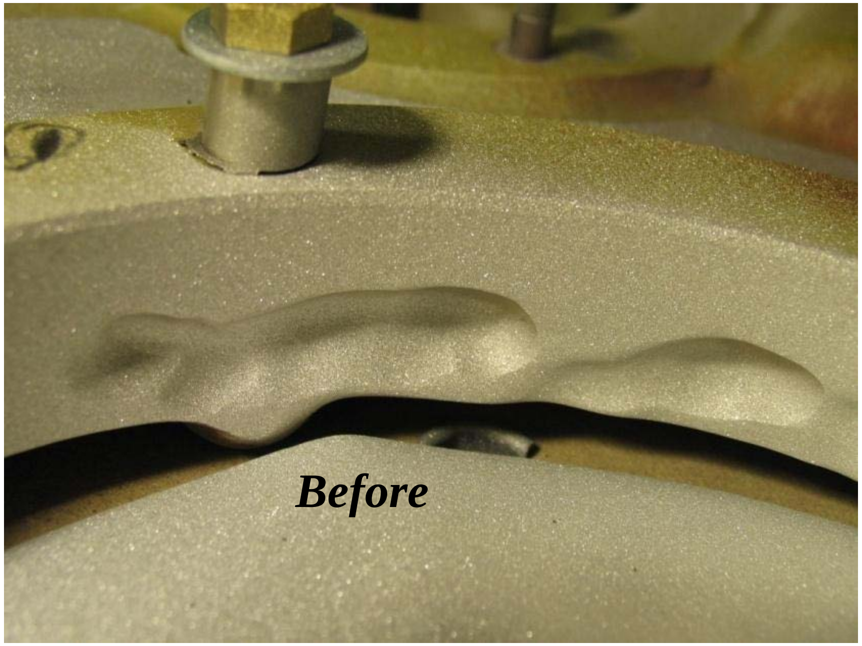
Examples of Corrosion Damage on Fielded Parts and Subsequent to Cold Spray Repair

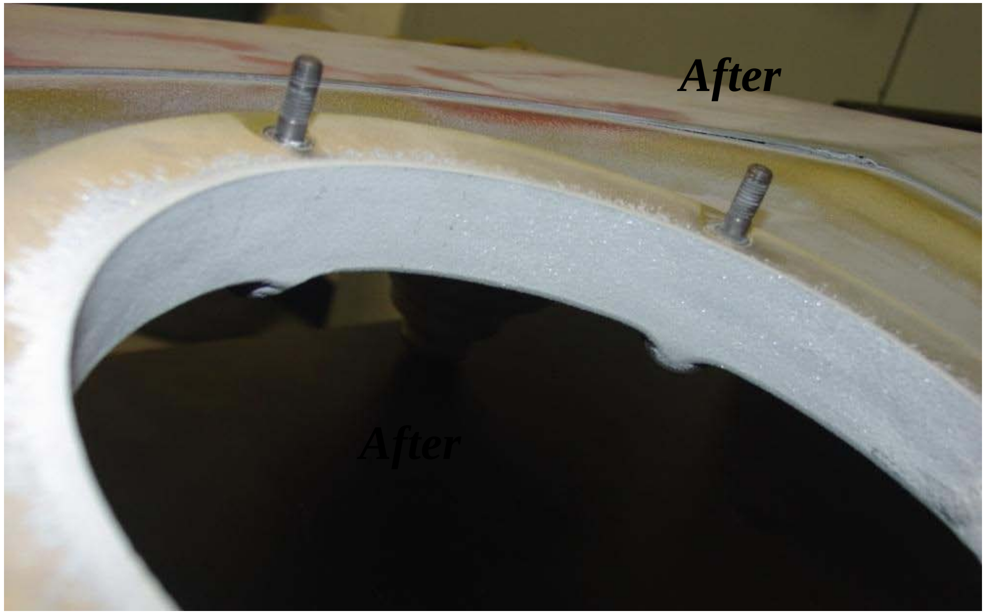
UH-60 Main Rotor Transmission

Cross-section of a Cold Spray Repair



Development and Implementation of Commercially Pure (CP) Aluminum and 6061 Aluminum Alloy Cold Spray Coatings for the Repair of Magnesium Helicopter Gearbox Components





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COLD SPRAY at Tinker Air Force Base Candidate Engine Parts

Materials

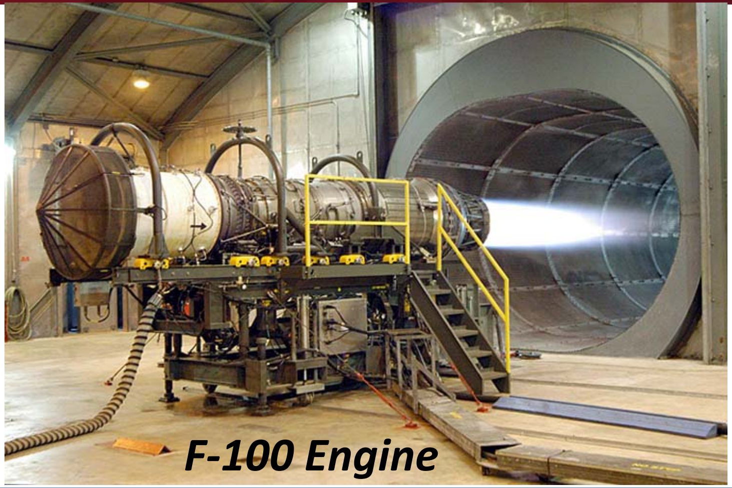
- Ti6Al-4V
- Inconel
- Waspalloy
- Aluminum

Candidate Parts

- Pump Housing
- Fan Case
- Exhaust Case
- Augmenter Duct Support
- Fan Ducts
- Bleed Valve
- Intermediate

Problems

- Cavitation
- Wear
- Corrosion


F-100 Engine

F-15 Eagle

Cold Spray Applications Development at ARL

- *Corrosion Damage Repair and Dimensional Restoration*
- *High Conductive and Wear Resistant Coatings*
- *Production of Exotic Materials Not Capable By Conventional Ingot Metallurgy*
- *Erosion Resistant Coatings*
- *Near Net Fabrication of Components*
- *Aerospace Specialty Coatings*
- *Conformable Antennas*
- *Selective Galvanization*
- *Aircraft Skin Repair*
- *Heat Sinks and Power Modules*
- *Cladding*

from Prototype to the Field

Fielded SH-60 Seahawk with Cold Spray Mg Repair Operating Since August, 2009-Australian Navy
ARL/JSF/DSTO Collaboration

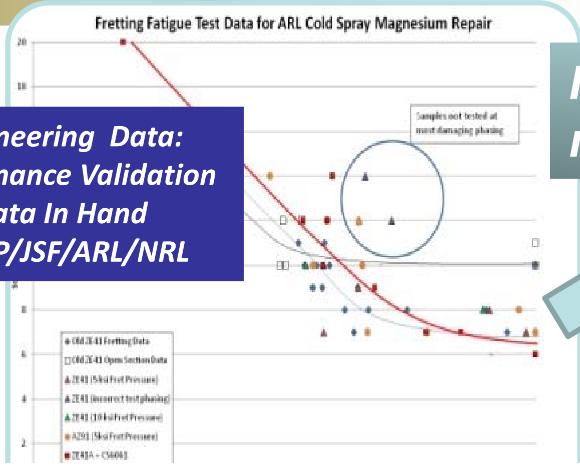
Three Fielded Blackhawk Medvac Units with Cold Spray Al Repair Operating Since August, 2009
ARL/AMCOM/Ft. Hood Collaboration

Fielded B-1 Bomber with Cold Spray Ti Repair Operating Since September 2009- Tinker AFB
ARL/Tinker AFB/HF Webster Collaboration

Two Expeditionary Fighting Vehicles with Cold Spray Mg Repair Fielded and Operating Since September, 2008

- *Power Transfer Module - PTM*
  - *10 Magnesium Castings*
- *Transmission*
  - *13 Magnesium Castings*

From Prototype to Production
OSD Mantech Program FY12-FY14



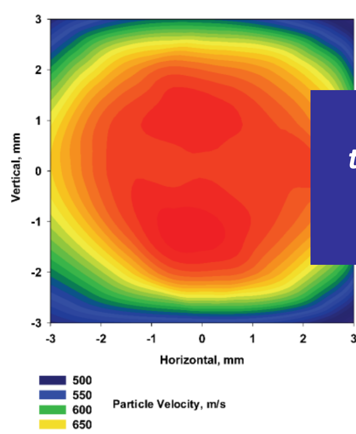
Engineering Data: Performance Validation Data In Hand ESTCP/JSF/ARL/NRL

Integrate laboratory, coupon and prototype data to make the technology successful for production

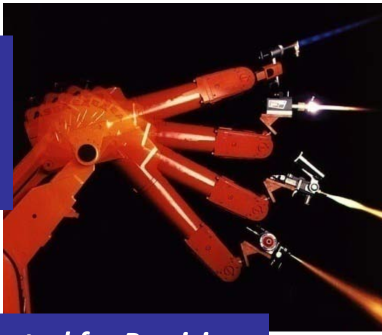
Integrate CAD/CAM to Produce Complex Geometries, Minimize Machining and Eliminate Material Waste

Production Engineering: Couple with Cold Spray Production Facility at Mid-America, Webster, MA

Real-Time Process Mapping



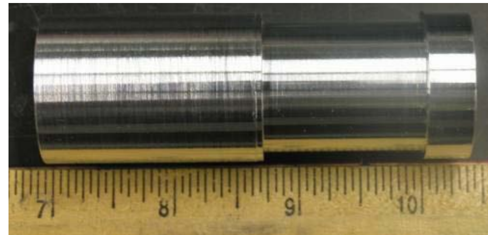
In-flight particle temperature, velocity, and particle size measurement

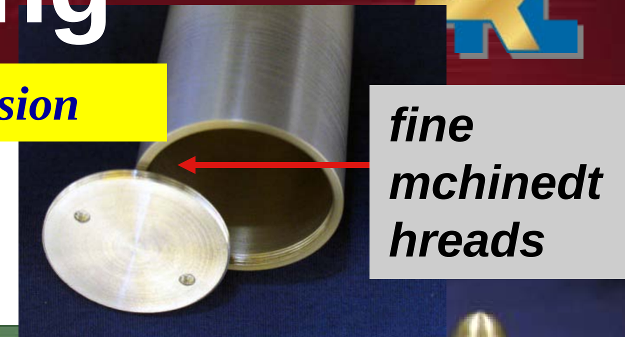


Robotic Control for Precision and Repeatability

Near Net Forming

Current state of the art: parts require machining to final dimension





- *Cold spray is a proven technology*
- *Has demonstrated potential as a means of producing near-net shape complex components.*
- *Upgrade conventional CS systems for near-net fabrication.*
- *New powders and processes are required.*

Future goals

Integrate CAD/CAM to produce complex geometries, minimize machining and eliminate material waste

Using CAD/CAM reproduce a shaped charge line (above) eliminating dimensional machining

CAD\CAM

- *Demonstrate production of a 6061 Al part*

Technical Objectives

Demonstrate and qualify cold spray aluminum alloy coatings which provide surface protection and a repair/rebuild methodology for Mg alloy components on Army and Navy helicopters and advanced fixed-wing aircraft such as the Joint Strike Fighter

1. **Cost-effective**
2. **ESOH-acceptable technology**

MOUNTING FEET LOCATION

MAIN GEARBOX

TECHNICAL APPROACH

Joint Test Protocol

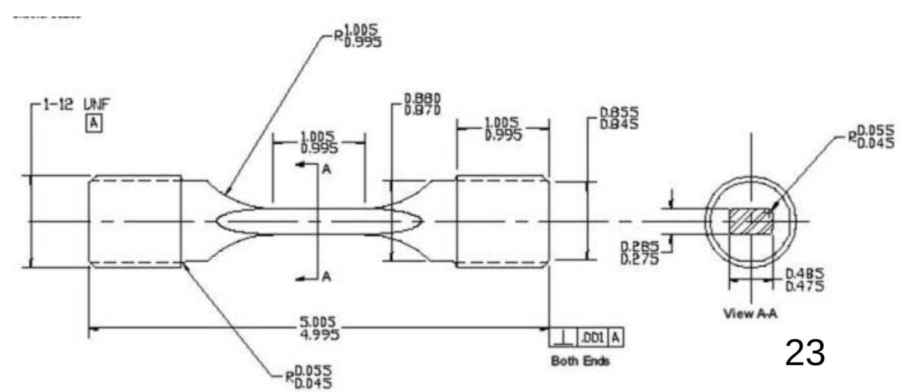
Mechanical Tests

- Adhesion Tensile Bond Test (ASTM C633)
- XRD Residual Stress
- R.R. Moore RB Fatigue
  - surface finished 125 R_A
- Fretting Fatigue – UTRC
- Impact - ASTM D5420
- Hardness
- Porosity
- Triple Lug Shear

Corrosion Tests

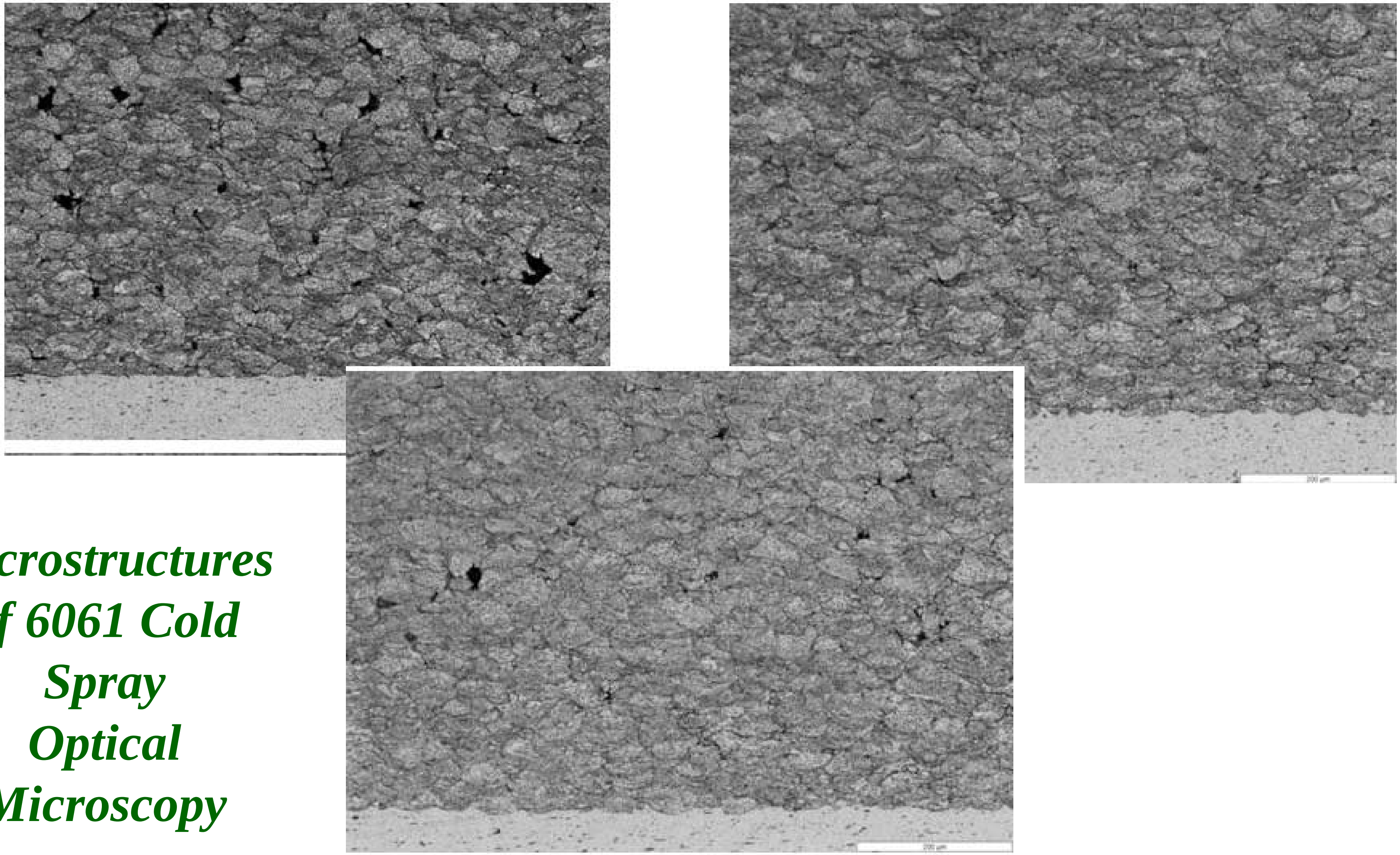
- *Un-scribed ASTM B117*
- *Scribed ASTM B117*
- *GM9540 Scribed*
- *Galvanic Corrosion (G71)*
- *Crevice Corrosion (G78)*
- *Beach Corrosion*
- *G85 Annex 4-SO_2*

Stack Up: RockHard, 23377, and 85285



UTRC Fretting Fatigue Specimen

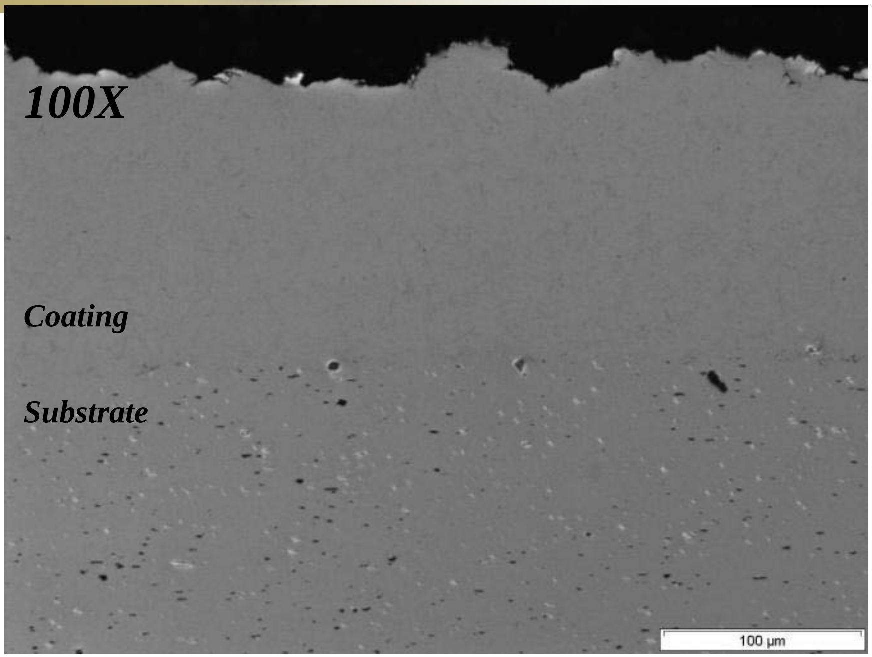
Technical Progress

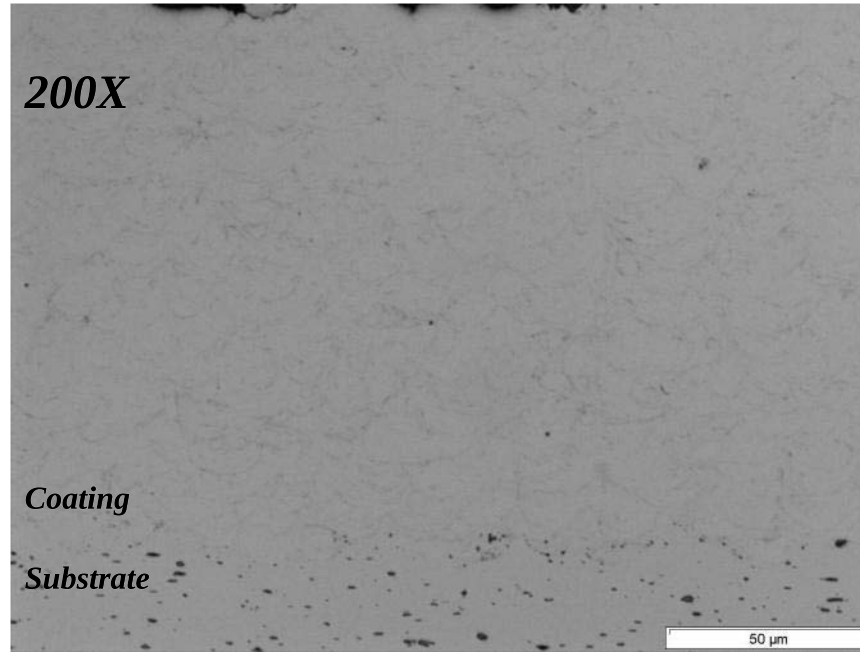


Microstructures of 6061 Cold Spray Optical Microscopy

Increasing Gas Pressure

Technical Progress





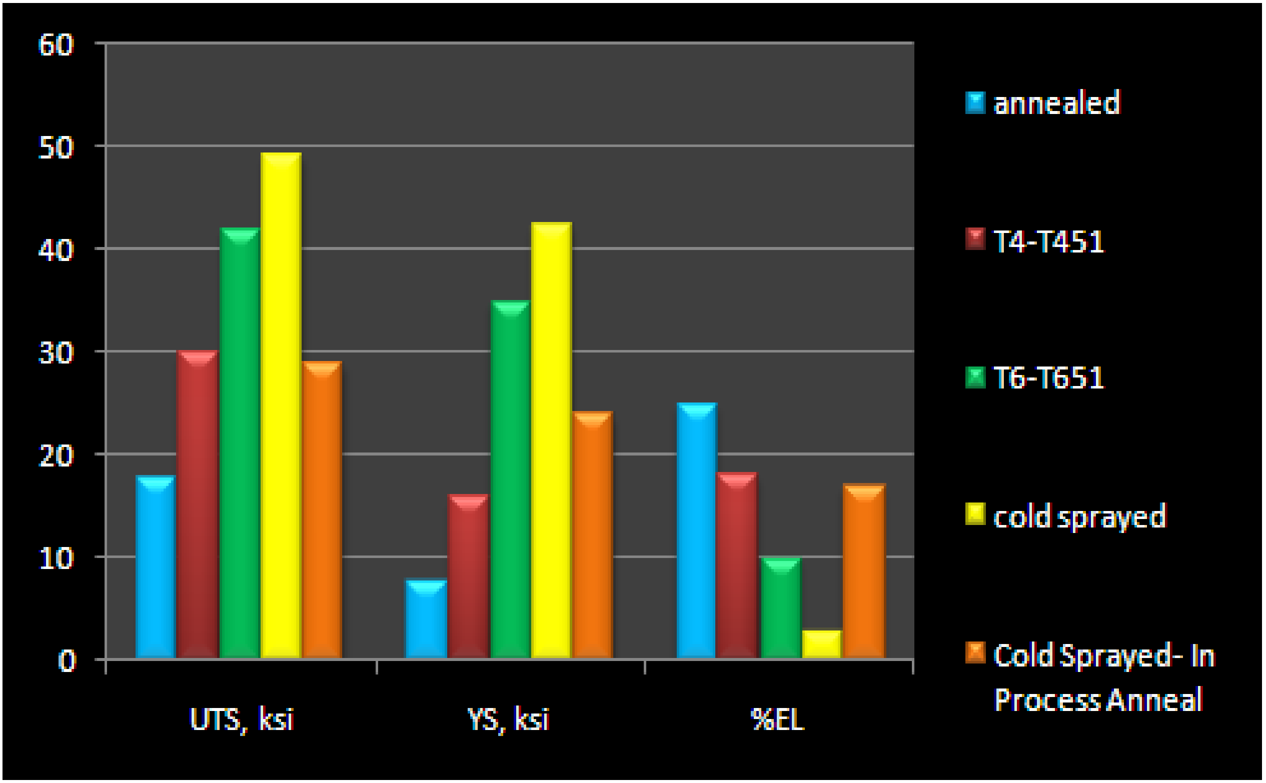
Alloy	Condition	Aging Temp (°F)	Time (Hrs)	Solutionizing Temp (°F)	Aging after Solutionizing Temp (°F)	Time (Hrs)
AZ91C	T5	335	16	---	---	---
AZ91C	T6	---	---	775	335	16
					420	5-6
AZ92A	T5	500	---	---	---	---
AZ92A	T6	---	---	765	425	5
ZE41A	T5	625	2	---	---	---

ZE41A-T5 Substrate Temperature Recorded at 326.1° F (163.4° C)

M. M. Avedesian, Hugh Baker,"Magnesium and magnesium alloys", Edition: 2 - 1999,ASM International, pgs 78-79.

Technical Progress

Wrought versus Cold Spray 6061



6061 Condition	Source	UTS, ksi	YS, ksi	%EL
annealed	1	18	8	25
T4, T451	2	30	16	18
T6, T651	2	42	35	10
cold sprayed (CS)	3	49.3	42.5	3
CS- In process anneal	3	29.0	24.0	17

Key

T4, T451- Solution heat-treated and naturally aged to a substantially stable condition. Temper -T451 applies to products stress-relieved by stretching.[2]

T6, T651- Solution heat-treated and then artificially aged, Temper -T651 applies to products stress-relieved by stretching.[2]

In Process Anneal- 640°F for 10 to 12 Hours

[1]Matweb
[2]Alcoa.com
[3]**Microtensile Test by Aaron Nardi at UTRC of ARL Cold Spray Block**

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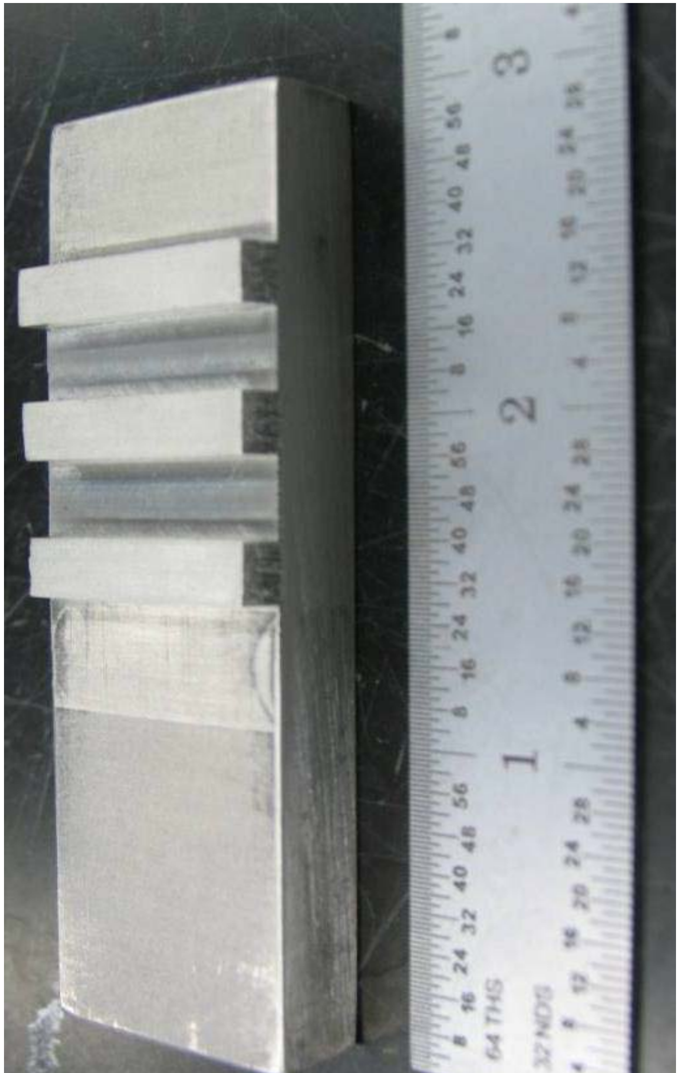
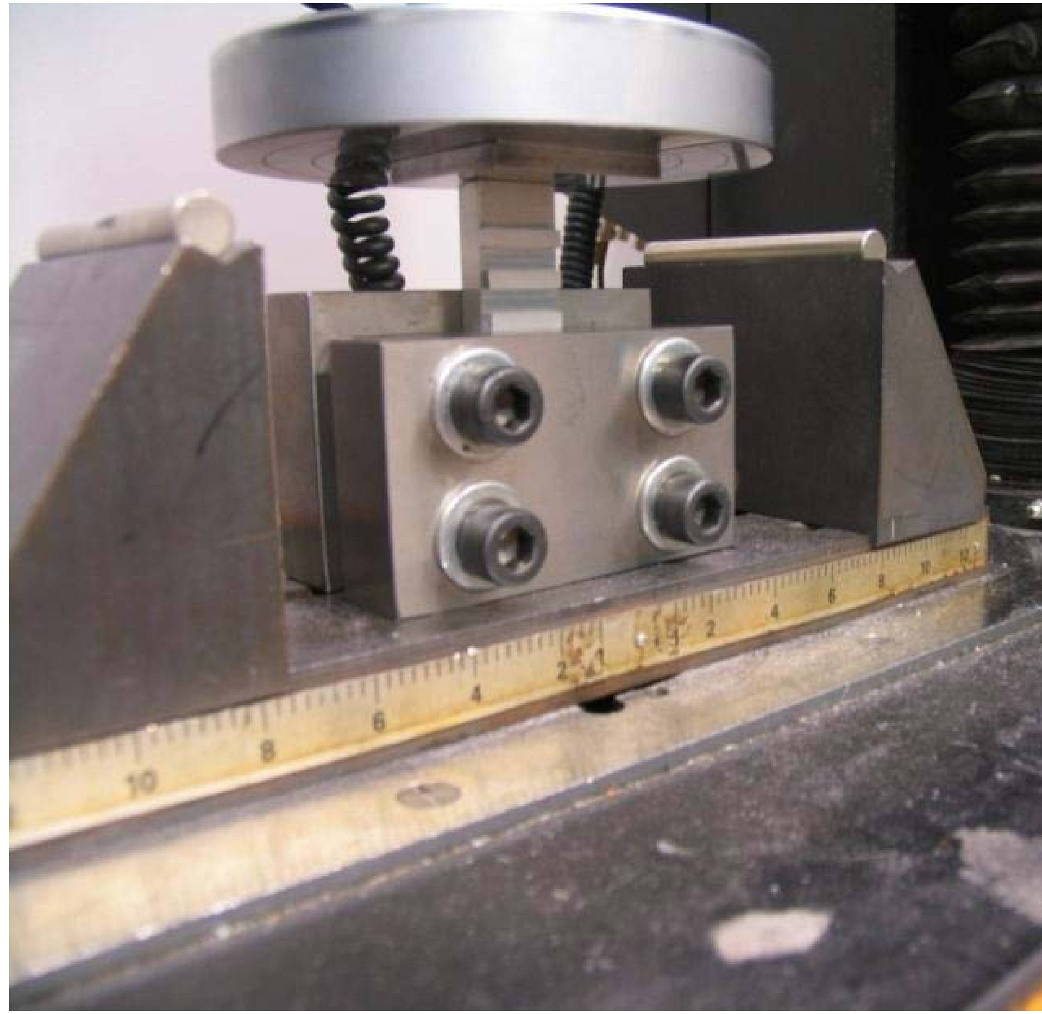
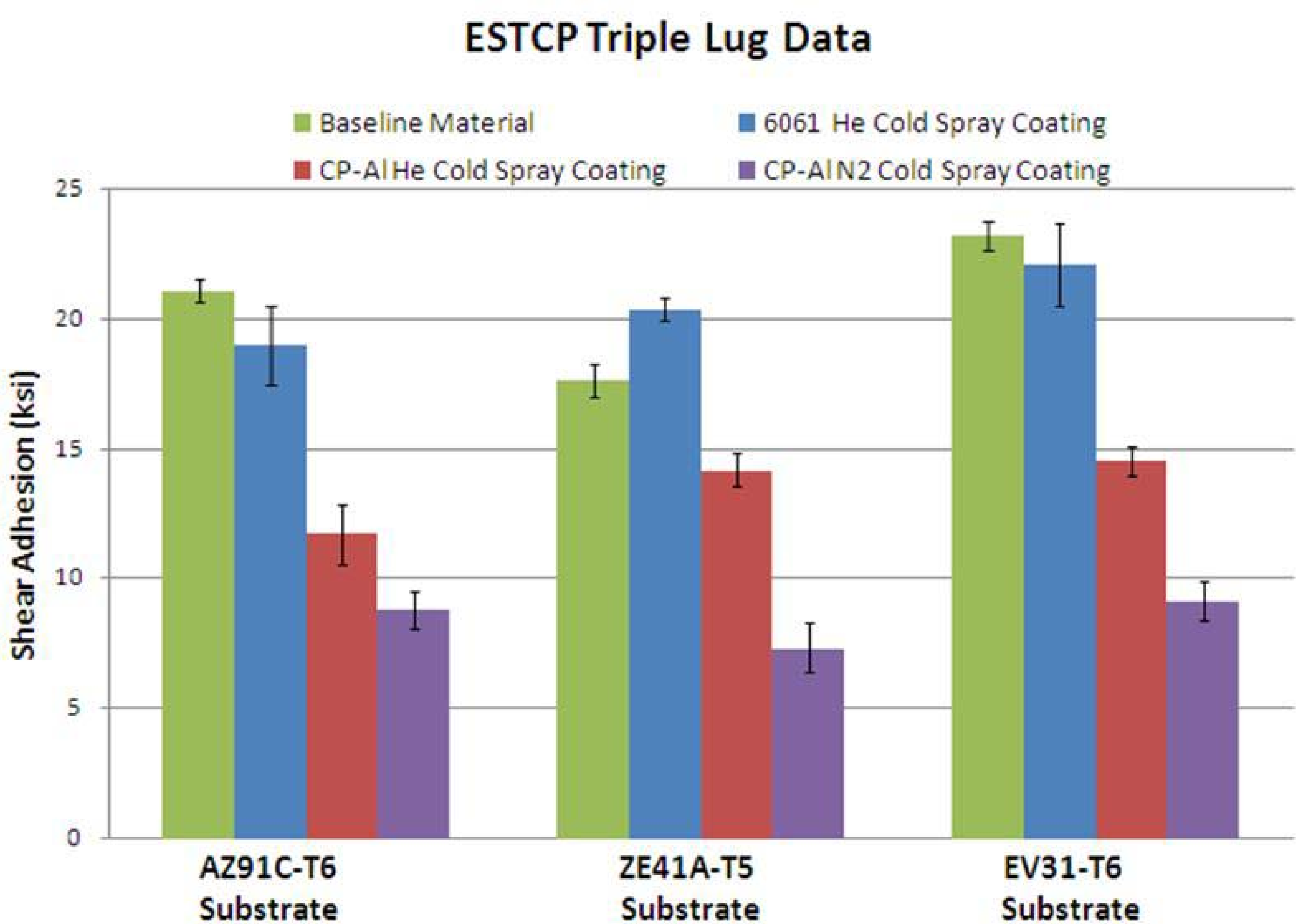
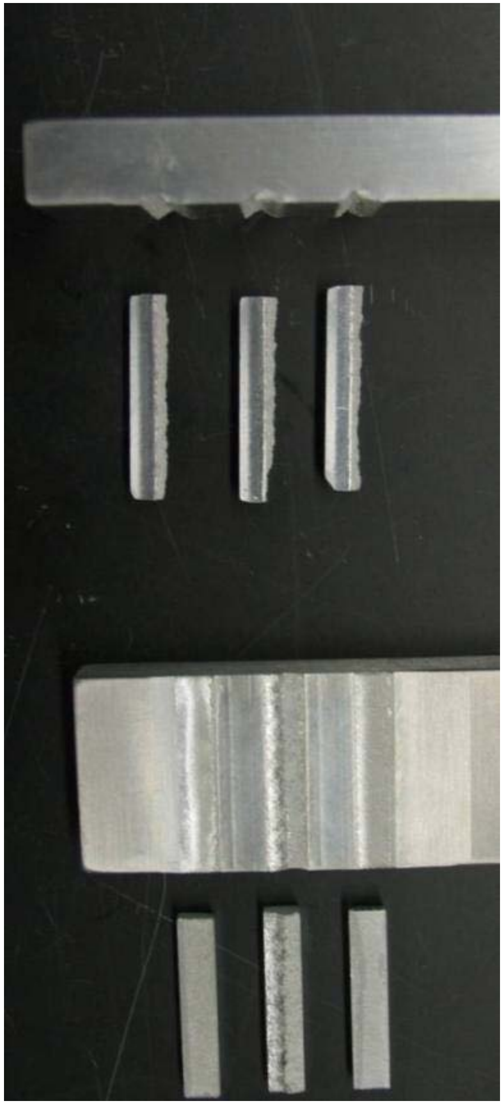
Triple Lug Shear Test





Technical Progress





6061/ZE41A-T6

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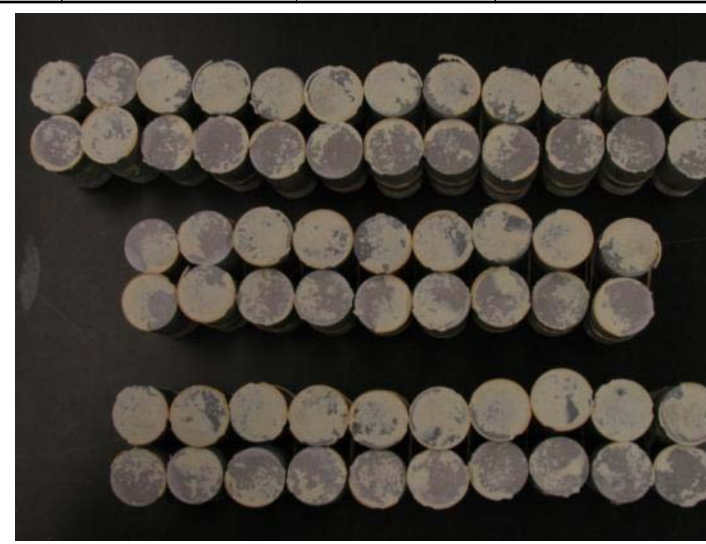
Bond Bar Adhesion (ASTM C633)

Substrate	Coating System	Averge Thickness (in)	Average Max Tensile Stress (PSI)	Stdev. Tensile Stress (PSI)	95% Confidence Tensile (PSI)	Observed Failure Mechanism
ZE41A-T5	6061 He	0.0134	11052	808	560	100% Glue
	CP-Al He	0.0197	12069	597	370	100% Coating Adhesion
	CP-Al N_2	0.0228	10400	846	677	100% Coating Adhesion

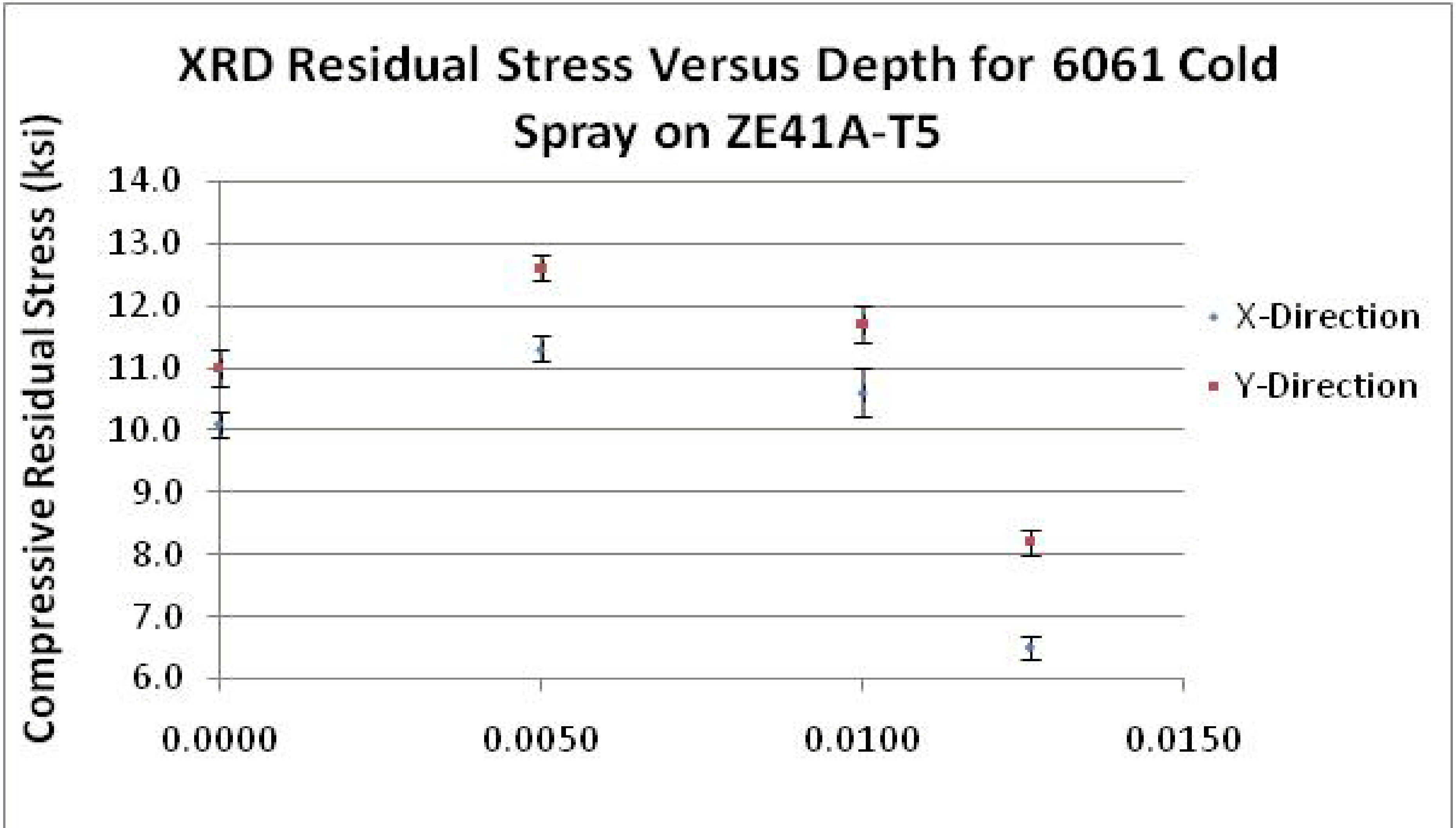
ZE41A-T5

AZ91C-T6

EV31-T6

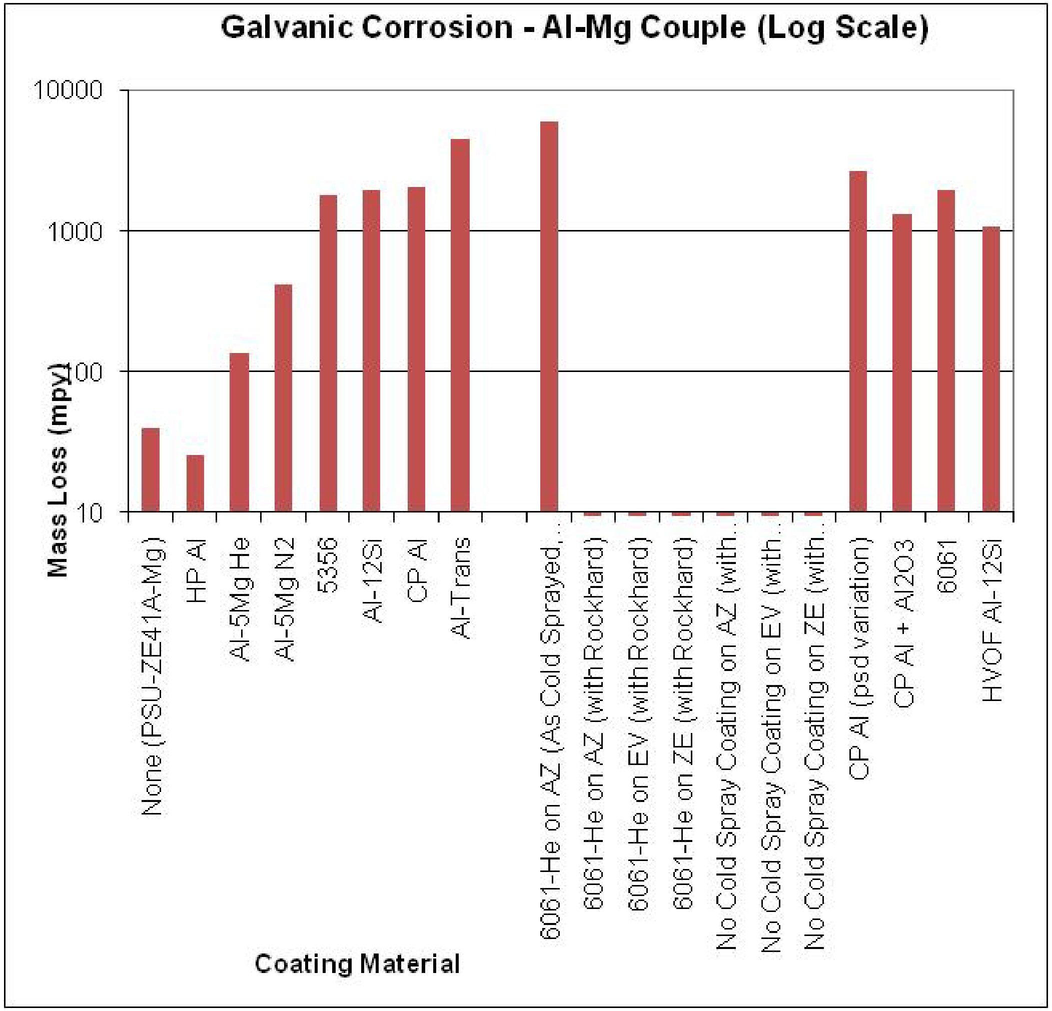


Technical Progress



Technical Progress

- Un-scribed ASTM B117
  - CP-Al went well (7000 hours at Army and 1000 hours at PSU)
  - 6061 went 7000 hours at Army and will be retested at PSU due to thin spots
- Scribed ASTM B117
  - 1000 hours through top coat but 24 hours through to substrate. On par with HVOF Al-12Si
- GM9540 Scribed- Sprayed
- Galvanic Corrosion (G71)
- Crevice Corrosion (G78)- No Crevice mechanism
- Beach Corrosion- Undergoing testing



*vs uncoated ZE41

-Cd plated steel specimens are currently being fabricated for comparison

Sump Qualification

Sump Assembly Main Module-Main Gearbox Repair

Substrates: ZE41A & AZ91C Magnesium

Coating Material: CP-Aluminum and/or 6061 Al

Total Replacement Cost Savings estimated to be $935,000.00/ year

Acknowledgments

- Victor Champagne
- ARL Cold Spray Team
- Oak Ridge Institute for Science and Education
  - This research was supported in part by an appointment to the Postgraduate Research Participation Program at the U.S. Army Research Laboratory administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the US Department of Energy and USARL