Cold Spray Materials Manufacturing Technology Research

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Outline

- The Case for Cold Spray: Nonthermal Additive Manufacturing
- ARL Center for Cold Spray Research & Technology Background
  - 1st Generation Cold Spray Repairs
- Beyond Nonstructural Repair
  - Holistic Modeling Approach and Results
  - Modeling-Enabled Performance and Applications
  - Future AM Efforts and Capabilities
### Traditional Process vs. Additive Process

<table>
<thead>
<tr>
<th>Traditional Process</th>
<th>Additive Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Casting, Welding</td>
<td>SLM, EBM, Wire-Arc Additive Manufacturing (WAAM)</td>
</tr>
<tr>
<td>Sintering</td>
<td>Powder Binder Jet, Single-Pass Jetting</td>
</tr>
<tr>
<td>Extrusion</td>
<td>Fused Deposition Modeling</td>
</tr>
<tr>
<td>Forging</td>
<td>Strain-Mediated Additive Manufacturing</td>
</tr>
</tbody>
</table>

**Architected Feedstocks**

- **Solid-State Deformation Processing**
- **Retained & Refined Microstructures for Enhanced Net & Near-Net Shape Materials**

The Nation’s Premier Laboratory for Land Forces
ARL is Recognized as International Leader in Cold Spray Technology

- Modeling & Simulation
- Powder Development
- Cold Spray Materials
- Characterization
- Advanced Processing
- Applications Development
- Equipment (VRC Gen III-JOA)
- Specifications, Stds. & Training
- Transition & Implementation

ARL Center for Cold Spray

**Advantages**
- Low Temperature Process
- Below Melting Point of Metals
- No Combustion Fuels, Gases
- Results in Highly Conductive Deposits
- Solid State Bonding
- Mechanical Mixing of Particles and Substrate
- Similar to Explosive Bonding
- Plastic Deformation of Particles
- Disrupt Internal Films
- Compressive Residual Stresses
- High Density Deposits
- Form Thin Coatings at High Deposition Rates
- Low Oxide and Porosity Content (<1%)
- Form Free-Standing Structures

**Applications**
- Corrosion Resistant Coatings (Zr, Al)
- Dimensional Restoration and Repair (Ni, Stainless Steel, Titanium, Aluminum)
- Wear Resistant Coatings (CrN, WC-Co, WC)
- EMI Shielding
- Portable Units for Field Repair

**Technology Driven. Warfighter Focused.**
Cold Spray Technology Evolution

VISION: Non-structural Repair

- Industry
  - AF & Army RIF
  - RDECOM TMR
- OSD & Army Mantech
- NAVAIR
- AFRL
- Navy-TIPS
- ESTCP
- DLA
- SBIR
- SERDP
- ARL, ONR

PRODUCTION SCALE-UP

- UH-60 Sump Repair
  - MEO B1671
  - TD-63 Actuator

First Approved Army-Navy & Air Force Applications

- B-1
- FEB Panels & Hydro

Characterization & Testing

Near Net Shape Spray Form Components

UTS = to wrought

Powder

Process Development

VISION: Non-structural Repair              Structural Repair               Near-net Parts

POWDER SYNTHESIS

MODELING & SIMULATION

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Cold Spray Background

- Main Gas Stagnation Pressure 0.5-5 MPa
- Gas Temperature 0-1000°C
- Main Gas Flow Rate 30-200 m³/hr
- Powder Feed Rate 1 to 15 kg/hr
- Particle Velocity 300-1500 m/sec.
- Particle Size 1-50um diameter
Cold Spray Demonstration
**ROI for the UH-60 Sump**

- **Unit Cost:** $11K
- **Annual Demand Rate:** 85
- **Repair Cost:** $880
- **Investment:** $60K
- **Annual Savings:** $860K

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**Official Approval Documents and Commitment**

1. **Maintenance Engineering Order (MEO) T7631 UH-60 Sump Repair**
   - Army Aviation & Missile Research, Development & Engineering Center (AMRDEC)
   - Program Office – UH-60 Blackhawk
   - Corpus Christi Army Depot-SAFR Program Office

2. **Overhaul Repair Instruction (ORI) SS8491 UH-60 Sump Repair**
   - Sikorsky Aircraft Company-Technology Integration
Holistic Approach to Cold Spray AM  Integrated Computational Materials Engineering (ICME)

Powder Production → Powder Processing

Output from Powder Production & Powder Pre-Processing models are used as input to the Particle Impact Model

Predictive models to complement experimental approach

Process Parameters → Particle Impact → Bulk Material → Prediction of Properties

Cold Spray Process

User-input Parameters
### Technical Results - CS Al Alloys

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Parameters</th>
<th>Specimen ID</th>
<th>HRB</th>
<th>%IACS</th>
<th>UTS MPa (ksi)</th>
<th>%El</th>
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<tbody>
<tr>
<td></td>
<td>Press.</td>
<td>Temp</td>
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<td></td>
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<tr>
<td>6061</td>
<td>20 bar</td>
<td>400°C</td>
<td>CS-12-275</td>
<td>31.0</td>
<td>44.03</td>
<td>239 (34.6)</td>
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<tr>
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<td>25 bar</td>
<td>450°C</td>
<td>CS-13-096</td>
<td>40.4</td>
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<td>400°C</td>
<td>CS-14-150</td>
<td>64.6</td>
<td>30.18</td>
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<td>500°C</td>
<td>CS-14-152</td>
<td>57.3</td>
<td>31.96</td>
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<td>CS-14-128</td>
<td>65.2</td>
<td>31.08</td>
<td>387 (56.2)</td>
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<td>400°C</td>
<td>CS-14-120</td>
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<td>35.92</td>
<td>326 (47.3)</td>
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<tr>
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<td>30 bar</td>
<td>500°C</td>
<td>CS-14-125</td>
<td>62.7</td>
<td>31.11</td>
<td>394 (57.2)</td>
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<tr>
<td>5056</td>
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<td>500°C</td>
<td>CS-14-101</td>
<td>63</td>
<td>26.25</td>
<td>406 (58.9)</td>
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</tbody>
</table>
Fielded Applications of Cold Spray

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

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

Three Fielded Blackhawk Medvac Units with Cold Spray Al Repair
Operating Since August, 2009
ARL/AMCOM/Ft. Hood 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
Fielded Applications (Cont’d)

Submarine TD 63 Actuator with Cold Spray Al Repair
Operating Since May, 2014
PSNSY/ARL/VRC/MOOG/PSU Collaboration

Apache Intermediate Gear Support-Al Repair
Production Part-Casting Defect Repair-Fielded in 2014
Boeing/MOOG/ARL Collaboration

Cold Spray Refractory Gun Barrel Coating

3 ¾ inch dia.
ARMS

- AH-64 Intermediate Gear Support (EYAB: 12-153 top & outer land repair)
- UH-60 Sump (MEO T7631B → MEO B1671 packing seal surface repair)
- MEO-B1718 T-700 Turbine Engine Front Frame –FY15
- UH-60 Intermediate Gearbox (MEO B1089 center, input, output housings)
- UH-60 Tail Rotor Gearbox (MEO B1090 center, input, output housings)
- UH-60 Accessory Gearbox (MEO B1091 cover and housing)
- UH-60 Input Module (MEO B1092 center, input, output housings)

NAVY

- F/A-18E/F AMAD Main Housing (hydraulic pad restoration)
- F/A-18E/F AMAD Main Housing (gear failure repair)
- F/A-18E/F AMAD Hydraulic Gear Shaft seal surface repair
- H-1 Mixer Gearbox (external chafing repair)

AIR FORCE

- B-1 Forward Equipment Bay (FEB) Panels (ETAR) E12-00248
- B-1 Hydraulic Tube Repair (ETAR) E09-00065

MOOG has been approved by Boeing, Sikorsky and Bell Helicopters as a Qualified Cold Spray Vendor.
Axisymmetric Near-Net Shape Components

Cold Spray Donor Tube-50 Caliber
ARL Installation Spring 2018

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