Cold Spray Repair of Aerospace Components

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Cold Spray – Technology

Cold spray is an additive manufacturing method where micron sized, metallic powder material is driven to high speed by a compressed carrier gas through a nozzle and directed at a substrate material. The resulting impact and associated particle/substrate’s plastic deformation build a coating of the feedstock material onto the substrate. The resultant coating can be machined, heat treated or otherwise handled like stock material.

- Lowest operational temperature in thermal spray family
- Capable of highest particle velocity in thermal spray family
- Does not rely on melting/solidification of feedstock for adhesion
Cold Spray – Characteristics and Benefits

- HP Bond strengths ~ 80-100 MPa (12-15 ksi)
- No oxidation
- Compressive residual stress
- Strain hardening
- High density – low porosity (<1%)
- Thick coatings
- Heat treatable free forms
- Minimal surface preparation
- No distortion of substrate
- Limited masking
- Low substrate temperatures heating <120°C (250°F)
- Variety of substrates (Al, Mg, Cu, Ti, Steel, Glass)
Cold Spray – Shear Adhesion

ESTCP Triple Lug Data

Cold Spray – Ultimate Tensile and Yield Strength (Bulk)

UTS, YS, and percent elongation at failure for as-deposited 6061 Helium Cold Spray (yellow), in process annealed 6061 Helium Cold Spray (orange) versus wrought 6061.

Cold Spray – System Layout
Cold Spray – Compared

- Lowest operational temperature in thermal spray family
- Capable of highest particle velocity in thermal spray family
- Does not rely on melting/solidification of feedstock for adhesion

Cold Spray – Common Applications

- Recover wear/damage areas
- Enhance wear resistance
- Repair corrosion damage
- Prevent corrosion damage
- Recover mis-machined parts/manufacturing defects
- Surface build up
- Conductivity
- Dielectrics
- Thermal management
Cold Spray – Titanium Wear Area Recovery

Cross section of Cold Spray coated Hydraulic Tubing

Cold Spray Ti-6Al-4V
Titanium Tubing
Interface

Courtesy of: ARL
Moog Proprietary and/or Confidential
Cold Spray – Titanium Wear Area Recovery

Courtsey of: ARL
Cold Spray – Titanium Wear Area Recovery

Etched with Kellers

Courtesy of: ARL

Moog Proprietary and/or Confidential
Cold Spray Repair Demonstrated – Casting Defect

- Casting defect in Magnesium Housing, New Part
Cold Spray Repair Demonstrated – Casting Defect

Pre-machined

Masked

As Sprayed

Finished Machined
Cold Spray Repair Demonstrated – Casting Defect

Photomicrograph of coating/substrate interface (400X).

<table>
<thead>
<tr>
<th>Coating Property</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interface contamination (embedded grit)</td>
<td>Abrasive particles per linear inch---: Zero</td>
</tr>
<tr>
<td></td>
<td>Length examined: 0.400”</td>
</tr>
<tr>
<td>Porosity</td>
<td>Average value: 0.234%</td>
</tr>
<tr>
<td></td>
<td>Standard deviation: 0.113%</td>
</tr>
<tr>
<td></td>
<td>Minimum: 0.10% / Maximum: 0.51%</td>
</tr>
<tr>
<td>Cracks or interface zone separation</td>
<td>Non observed</td>
</tr>
<tr>
<td>Bond Strength</td>
<td>Average: 11925 psi (82.2 MPa)</td>
</tr>
<tr>
<td>Micro-hardness</td>
<td>Average value: 108.0 HV(0.2kg)</td>
</tr>
</tbody>
</table>

Substrate Temperature Log
Cold Spray Repair Demonstrated
Rotorcraft Accessory Cover

Cold Spray deposited on two areas of the as-cast surface and one (1) snap ring groove.
Cold Spray Repair Demonstrated – Corrosion

Cold Spray on As-Cast surface to be smoothed down to original surface by sanding or other accepted method.
Cold Spray Repair Demonstrated – Corrosion

Corroded Snap Ring Groove
Cold Spray Repair Demonstrated – Corrosion

- Corroded Snap Ring Groove

As Received

Prepared for CS

As Sprayed

Finish Machined
Cold Spray Repair Demonstrated – Corrosion

- Cyclic Support Seat Bracket, Rotorcraft
- Multiple corrosion sites
- Removed, sprayed, blended
Cold Spray Repair Demonstrated – Corrosion

- Nose Wheel Steering Component
  - Refurbished with corrosion prevention coating.
Cold Spray Repair Demonstrated – Corrosion

Corrosion on all 3 feet
Corrosion removed

After Cold spray

Reworked to print
Cold Spray Repair Demonstrated – Corrosion

As-Received → Pre-Machined → Cold Sprayed → Finish Machined
Cold Spray Repair Demonstrated – Wear

- Air Inlet Housing – Recovery of Wear Area

As Received

As Cold Sprayed
Cold Spray Repair Demonstrated – Designed Wear

- Tantalum Dome

Damaged Dome  
As Sprayed
Cold Spray Repair Demonstrated – Designed Wear

- Tantalum Dome – Niobium Ring

![Damaged Ring](image1)

![As Sprayed](image2)
Cold Spray Repair Demonstrated – Designed Wear

- Tantalum Disc

Coupon  
Repaired Disc - As Sprayed
Cold Spray Repair Demonstrated – Non-Designed Wear

- Two Repair Areas
  - Mid Shaft
  - Wear Lugs
  - SS 316 Coating
Cold Spray Repair Demonstrated – Non-Designed Wear

- Titanium Fan Duct
Cold Spray Repair Demonstrated – In-Service Damage

- Bearing Support Cover

Damaged

Cold Spray Repaired
Cold Spray Repair Demonstrated – In-Service Damage

- Bearing Support Cover (reverse)
Cold Spray Repair Demonstrated – In-Service Damage

- Bearing Support Cover (reverse)

Damaged

Cold Spray Repaired
Cold Spray Repair Demonstrated – In-Service Damage

- Angle Gearbox

Damaged

Cold Spray Repaired
(Crack is Weld Repaired)
Cold Spray Repair Demonstrated – Complete Restoration

- Defective TBH
- Machined TBH
- Cold Sprayed TBH
- Finish ground TBH surfaces
- TBH protected by Tagnite
- TBH Finished w/Rockhard
Cold Spray Repair Demonstrated – IVD Replacement

Uniform thin coating.

Mean value  St. Deviation  Minimum  Maximum
109.40 µm   12.41 µm     80.46 µm   140.29 µm

Fully dense (1.2% porosity)
Cold Spray Manufacturing - Automotive

- New component manufacture – Cu solder zone with improved electrical and thermal conductivity over conventional plating process.
..And Others
Cold Spray Demonstrated – Evaluation

- Engine Gearbox for Commercial Client Test Evaluation

![Pre-Machined](image1)

![As Sprayed](image2)
Moog Cold Spray Repair Capabilities

- High, Med, Low Pressure Machines
- Machining
- Inspection
- Testing
Staff

- Product Line Engineering
  - FAA DER on Staff
  - FAA DER Major Repairs Systems/Equipment, Propulsion Accessories, Repair Specifications
  - Delegations for fixed wing and rotorcraft (Parts 23, 25, 27, 29)
- Experienced Cold Spray Engineers – all Degreed engineers with 5+ years cold spray specific experience
- Metallurgical Engineer Ph.D. on Staff
- AS9100 and AS9110 Certified
- FAA 145 Repair Station Certificate(s)
- Cold Spray Equipment - CGT HPCS, Plasma Giken HPCS, Centerline LPCS and MPCS
- Other – 5-Axis CNC, 3-Axis CNC’s, Tooling Fixtures, CNC Lathes, NDT Capability, Full Metallurgical Lab Facilities
Benefits of Cold Spray Repair

- Significant total cost savings
  - Save on inventory, lead time and labor costs
- Repair time reduction
  - Can be used in-situ
- Improved production yield
  - Salvage parts with manufacturing defects
- Versatile coating method
- Numerous Coating/Substrate combinations
- Engineered coating properties
- Moog has complete Cold Spray Repair capabilities
Acknowledgements

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