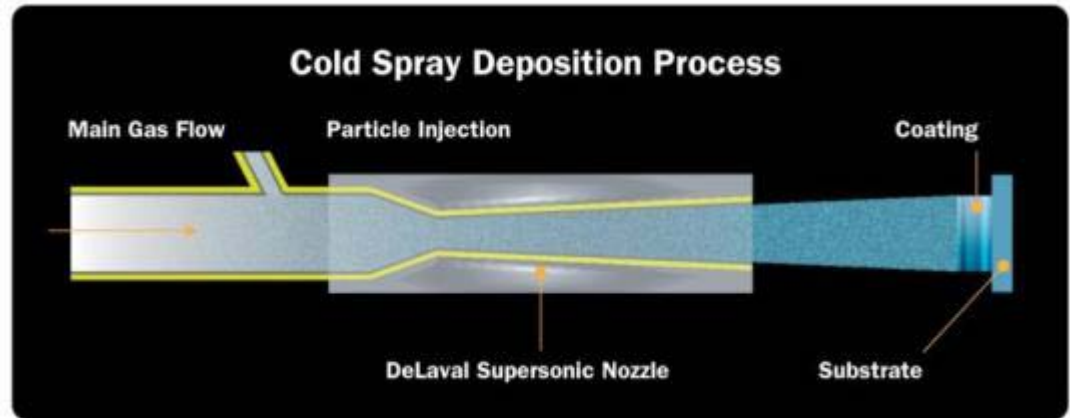




Cold Spray Repair of Aerospace Components

Jarrold Schell
Ben Hoiland
Paul Blunden
Isaac Izhaki
Bob Bierk

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.

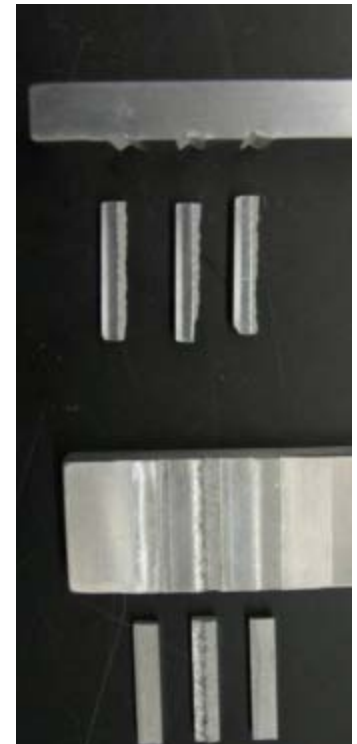
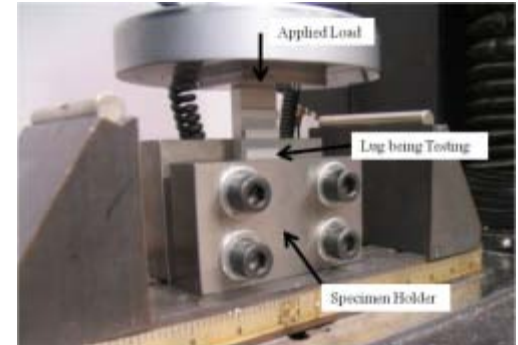
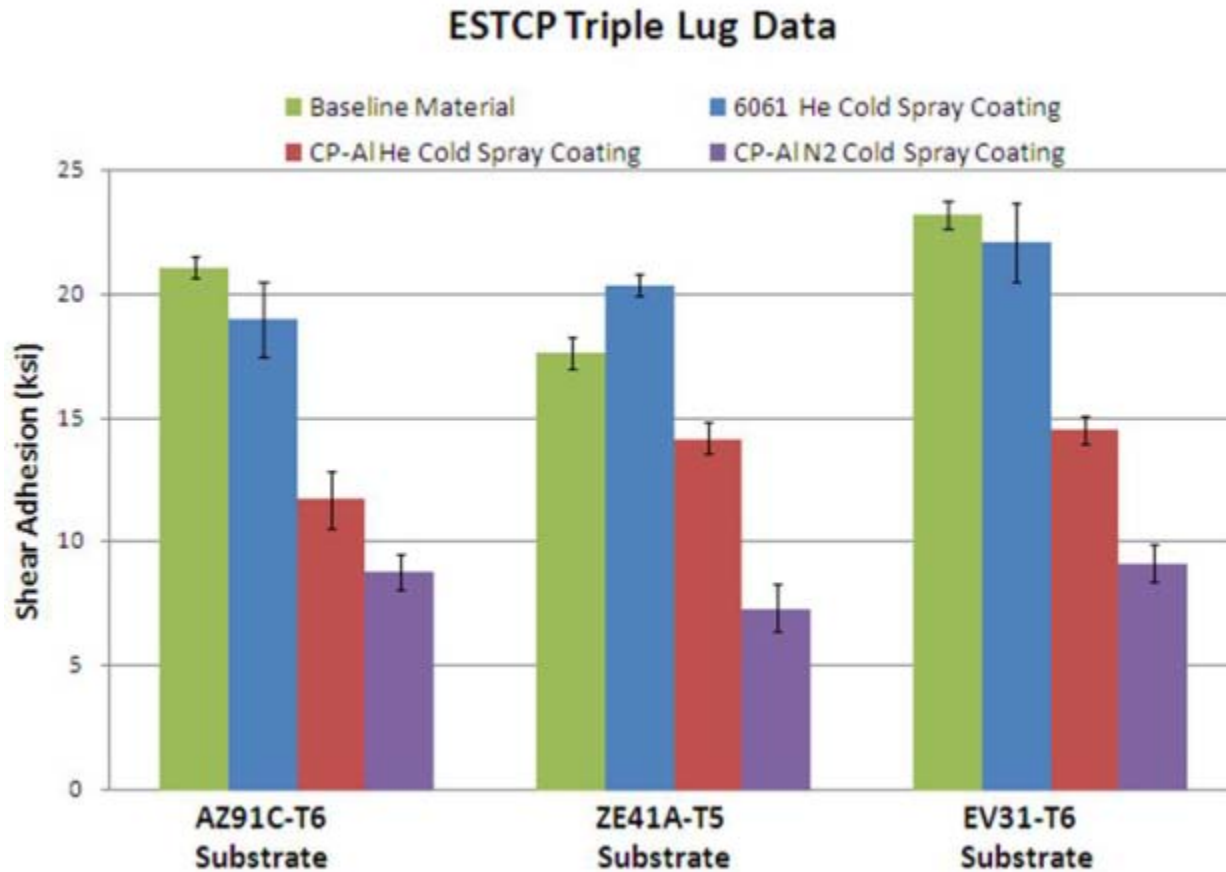
- Lowest operational temperature in thermal spray family
- Capable of highest particle velocity in thermal spray family
- Does not rely on melting/solidification of feedstock for adhesion

Cold Spray – Characteristics and Benefits

- HP Bond strengths ~ 80-100 MPa (12-15ksi)
- 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 <120C (250F)
- Variety of substrates (Al, Mg, Cu, Ti, Steel, Glass)

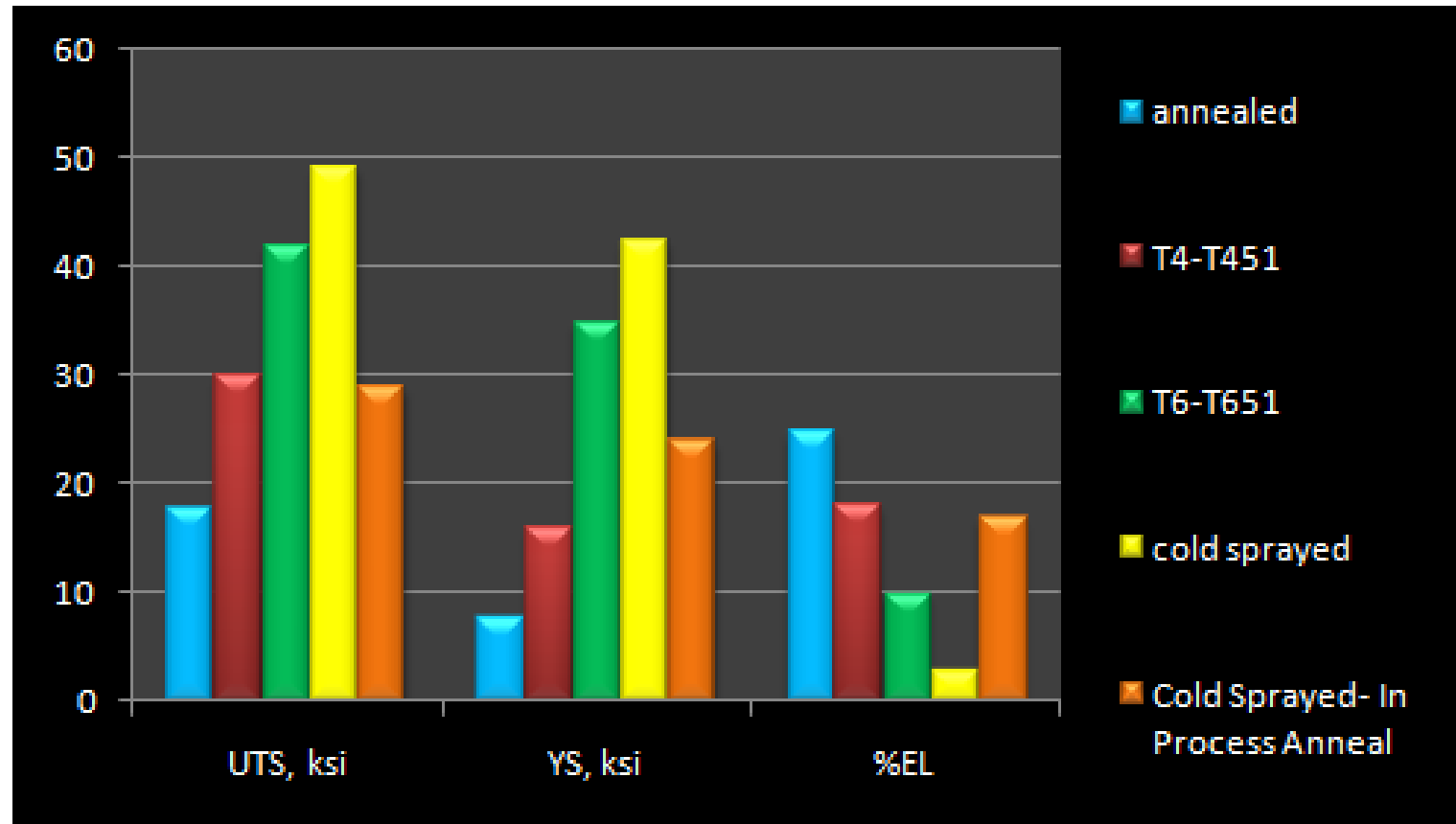
Powders	HP	LP
Aluminum	●	●
Copper	●	●
Nickel	●	●
Zinc	●	●
Tin	●	●
Metal Matrix	●	●
Composites		
Brass	●	
Bronze	●	
Silver	●	
Alum Alloys	●	
Titanium	●	
Tantalum	●	
Niobium	●	
Ti-6Al-4V	●	
Inconel 625, 718	●	
SS 316L	●	
SS 403	●	
SS 430	●	
Monel	●	
Ni-Cr	●	
Ni-Al	●	

Cold Spray – Shear Adhesion



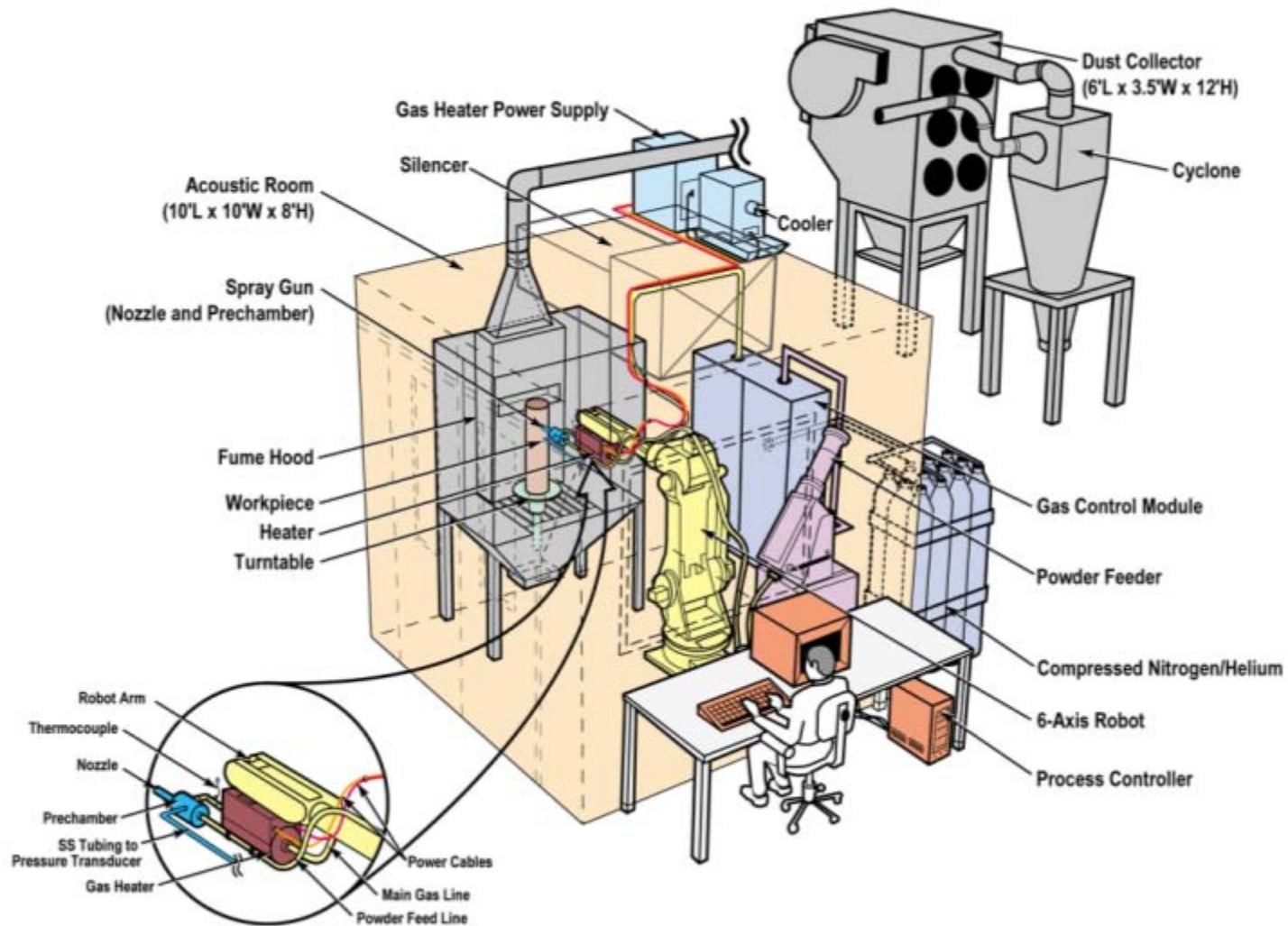
Cold Spray Repair of Magnesium Components. 2011. [report] US Department of Defense, p. 85, 92.

Cold Spray – Ultimate Tensile and Yield Strength (Bulk)



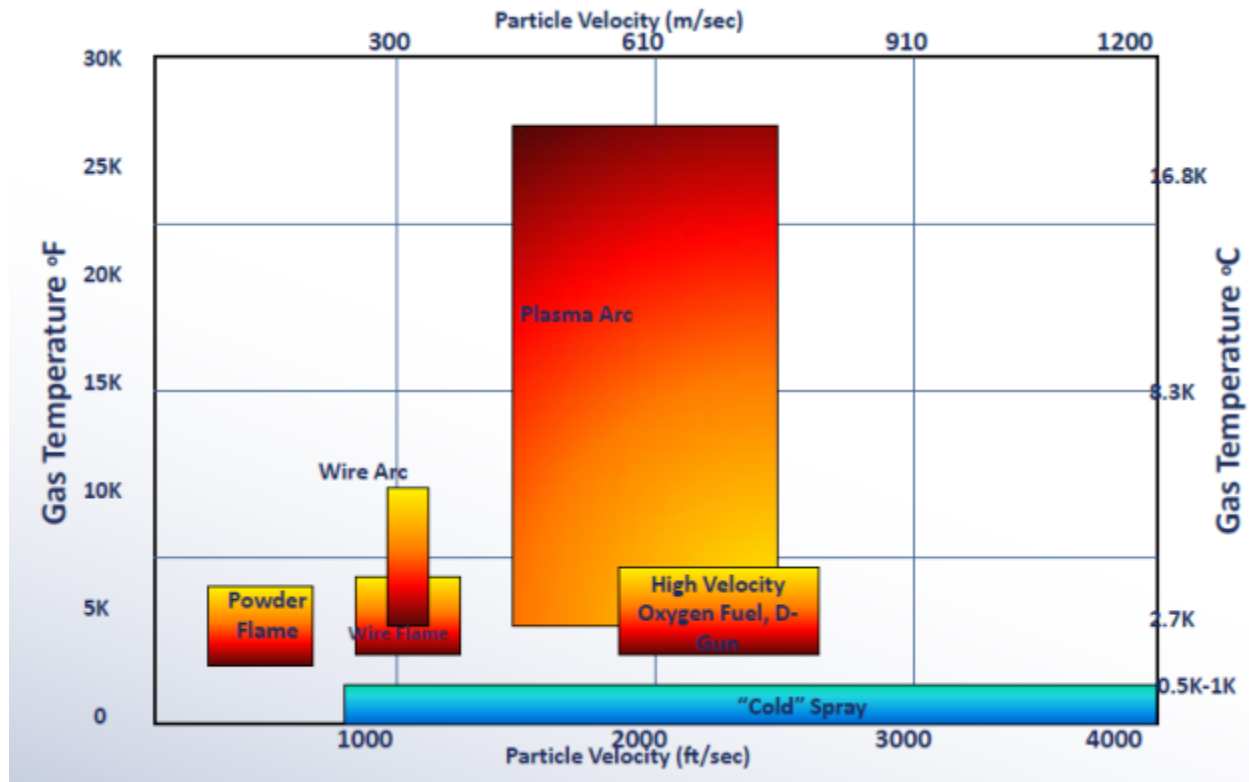
UTS, YS, and percent elongation at failure for as-deposited 6061 Helium Cold Spray (yellow), in process annealed 6061 Helium Cold Spray (orange) versus wrought 6061.

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

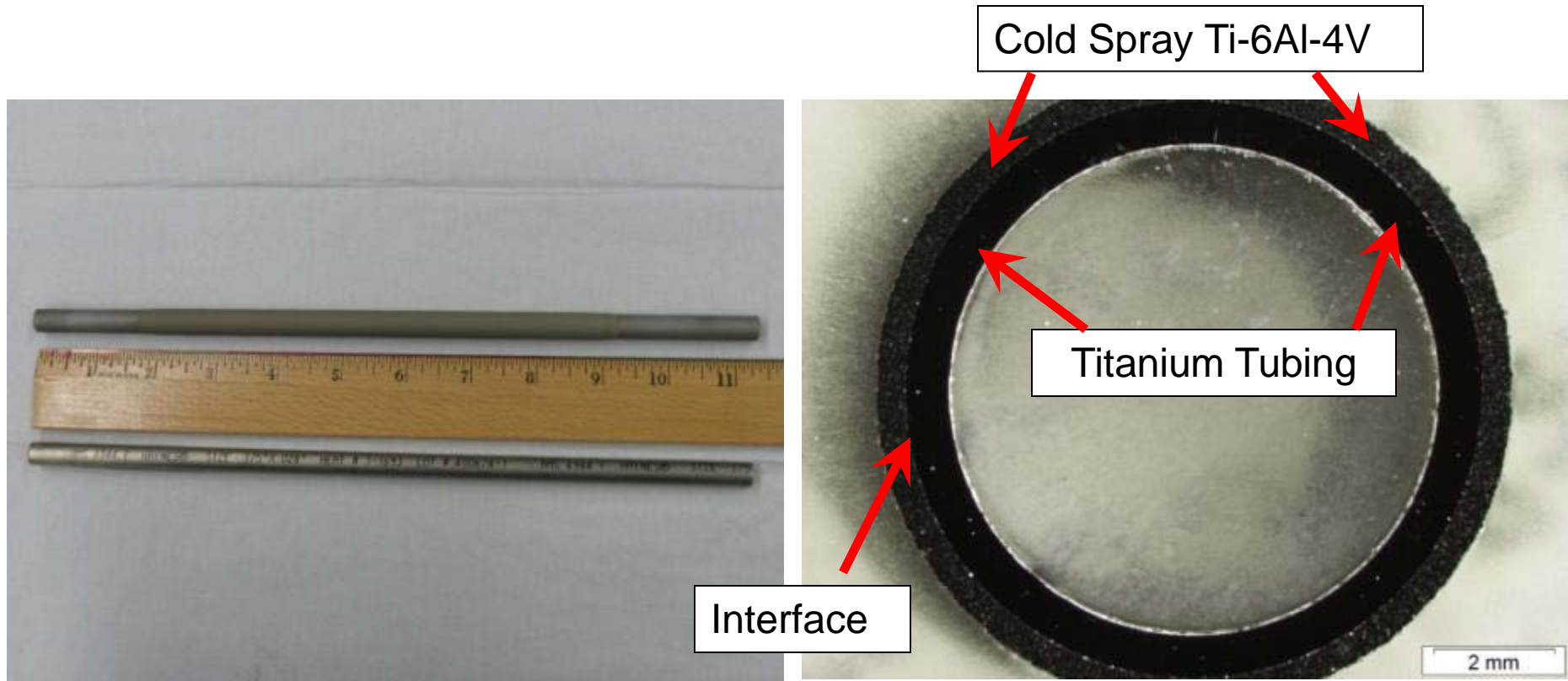


Ref R.C. McCune, A.N. Papyrin, J.N. Hall, W.L. Riggs and P.H. Zajchowski, An exploration of the Cold Gas-Dynamic Spray Method for Several Materials Systems, Advances in Thermal Spray Technology, ASM International, 1995, p1-6

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



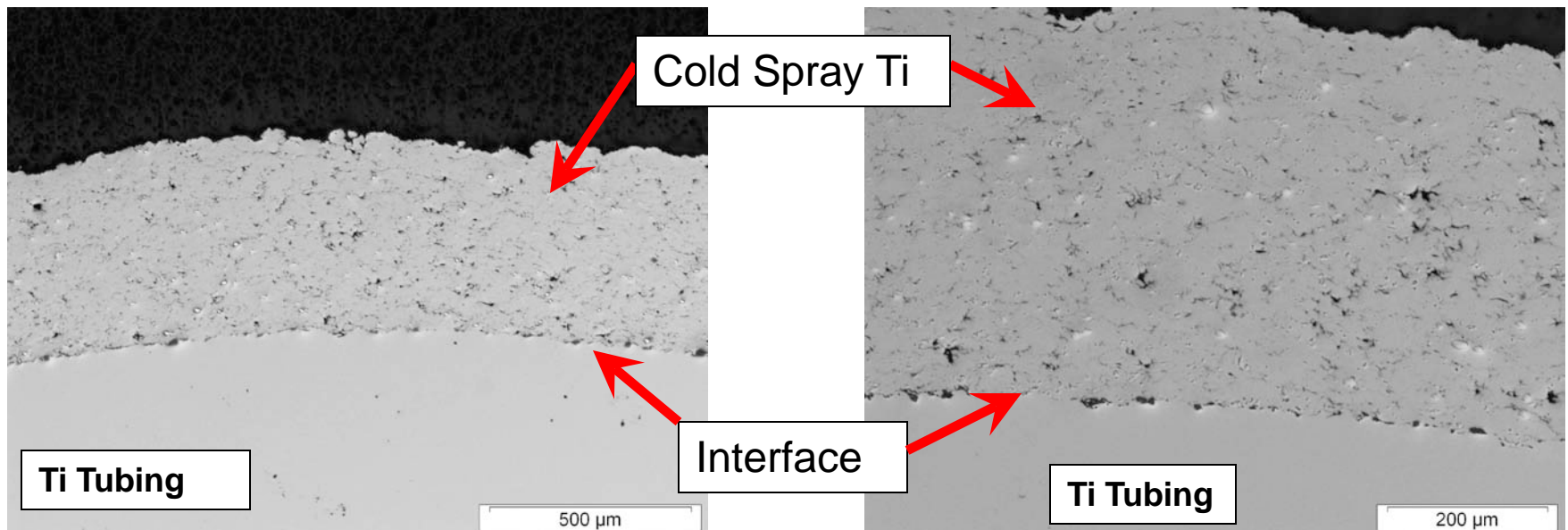
Cross section of Cold Spray coated Hydraulic Tubing

Courtesy of: ARL

Leyman, Phillip. Hrabe, Rob. James, Brian. Widener, Christian. "Titanium Repair Using Cold Spray." 2013. Microsoft PowerPoint Presentation.

Moog Proprietary and/or Confidential

Cold Spray – Titanium Wear Area Recovery

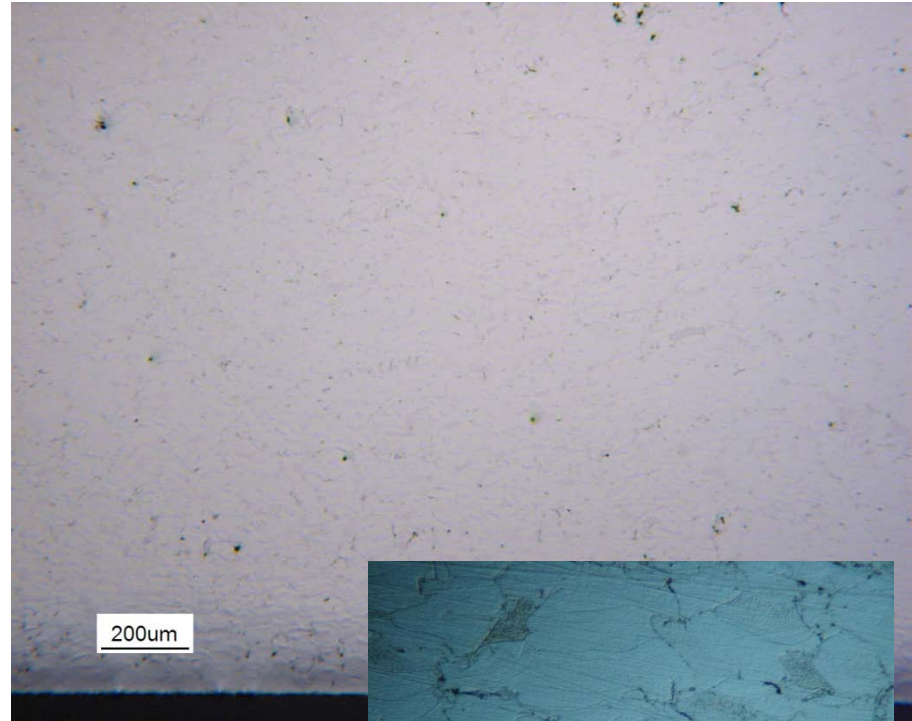
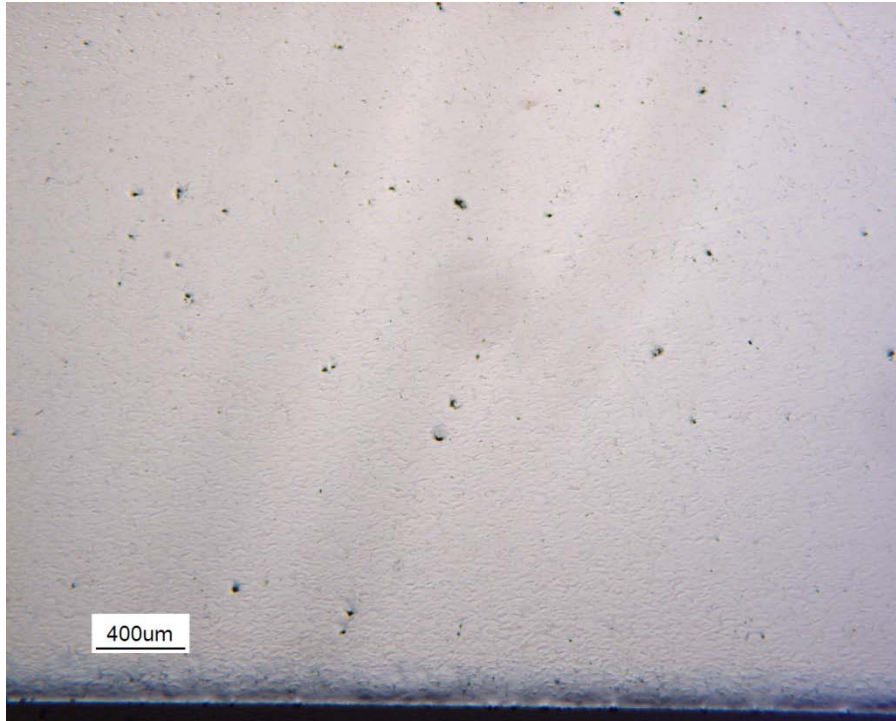


Courtesy of: ARL

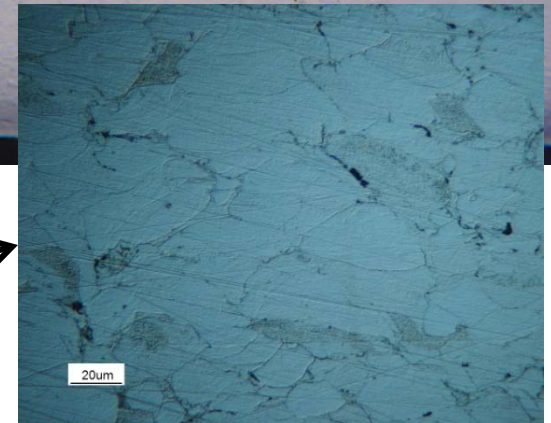
Leyman, Phillip. Hrabe, Rob. James, Brian. Widener, Christian. "Titanium Repair Using Cold Spray." 2013. Microsoft PowerPoint Presentation.

Moog Proprietary and/or Confidential

Cold Spray – Titanium Wear Area Recovery



Etched with Kellers



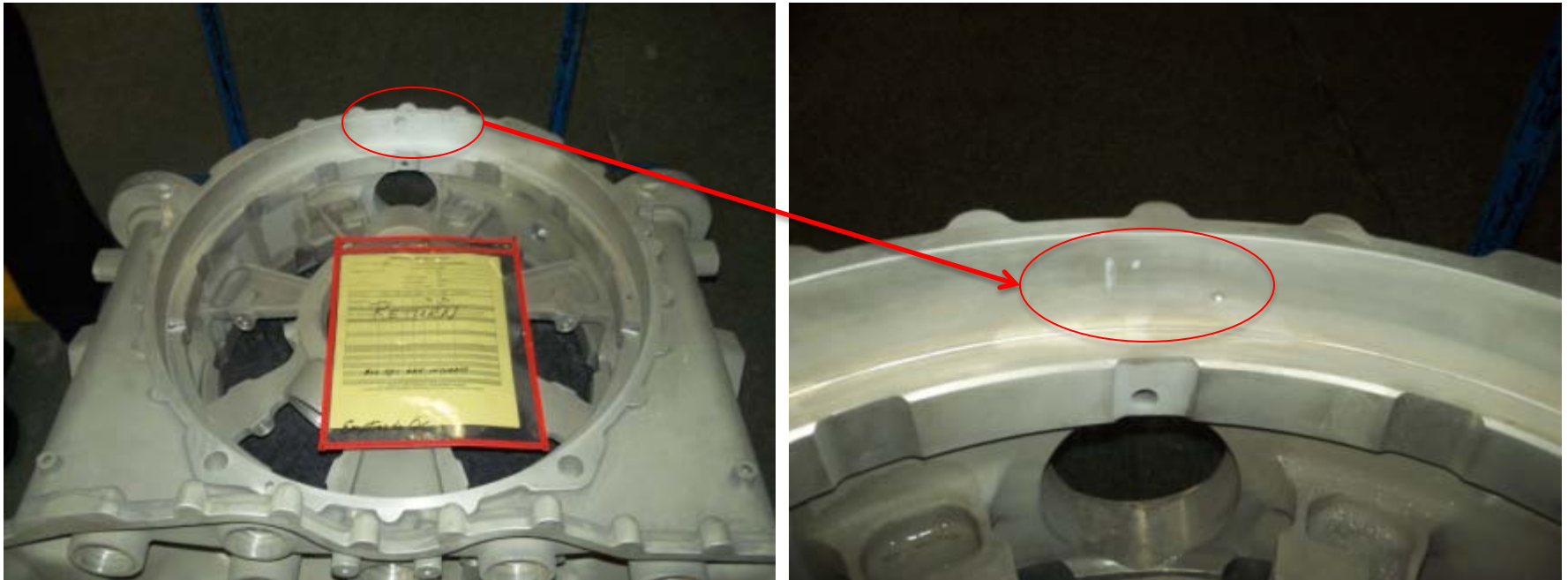
Courtesy of: ARL

Leyman, Phillip. Hrabe, Rob. James, Brian. Widener, Christian. "Titanium Repair Using Cold Spray." 2013. Microsoft PowerPoint Presentation.

Moog Proprietary and/or Confidential

Cold Spray Repair Demonstrated – Casting Defect

- Casting defect in Magnesium Housing, New Part



Cold Spray Repair Demonstrated – Casting Defect



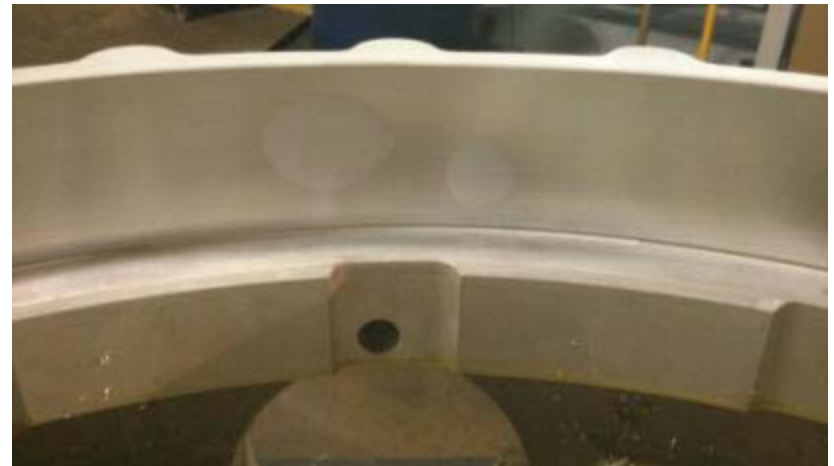
Pre-machined



Masked

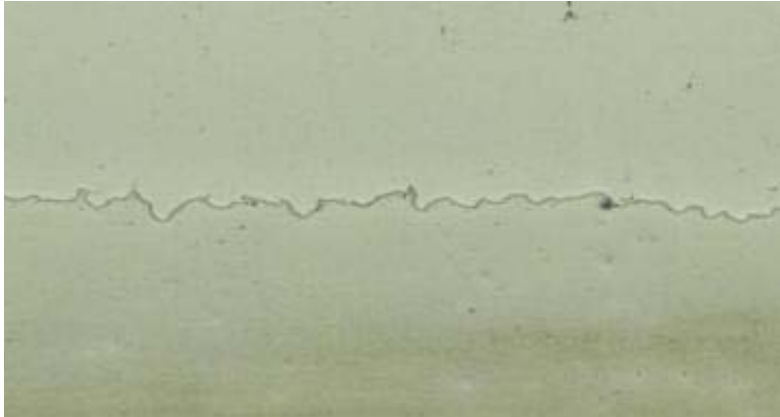


As Sprayed

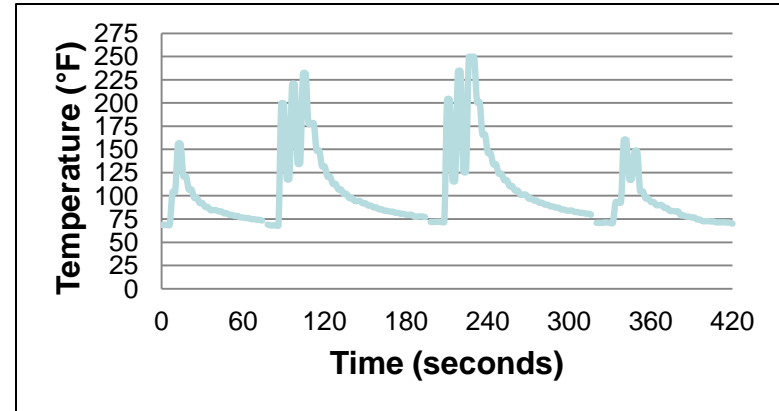


Finished Machined

Cold Spray Repair Demonstrated – Casting Defect



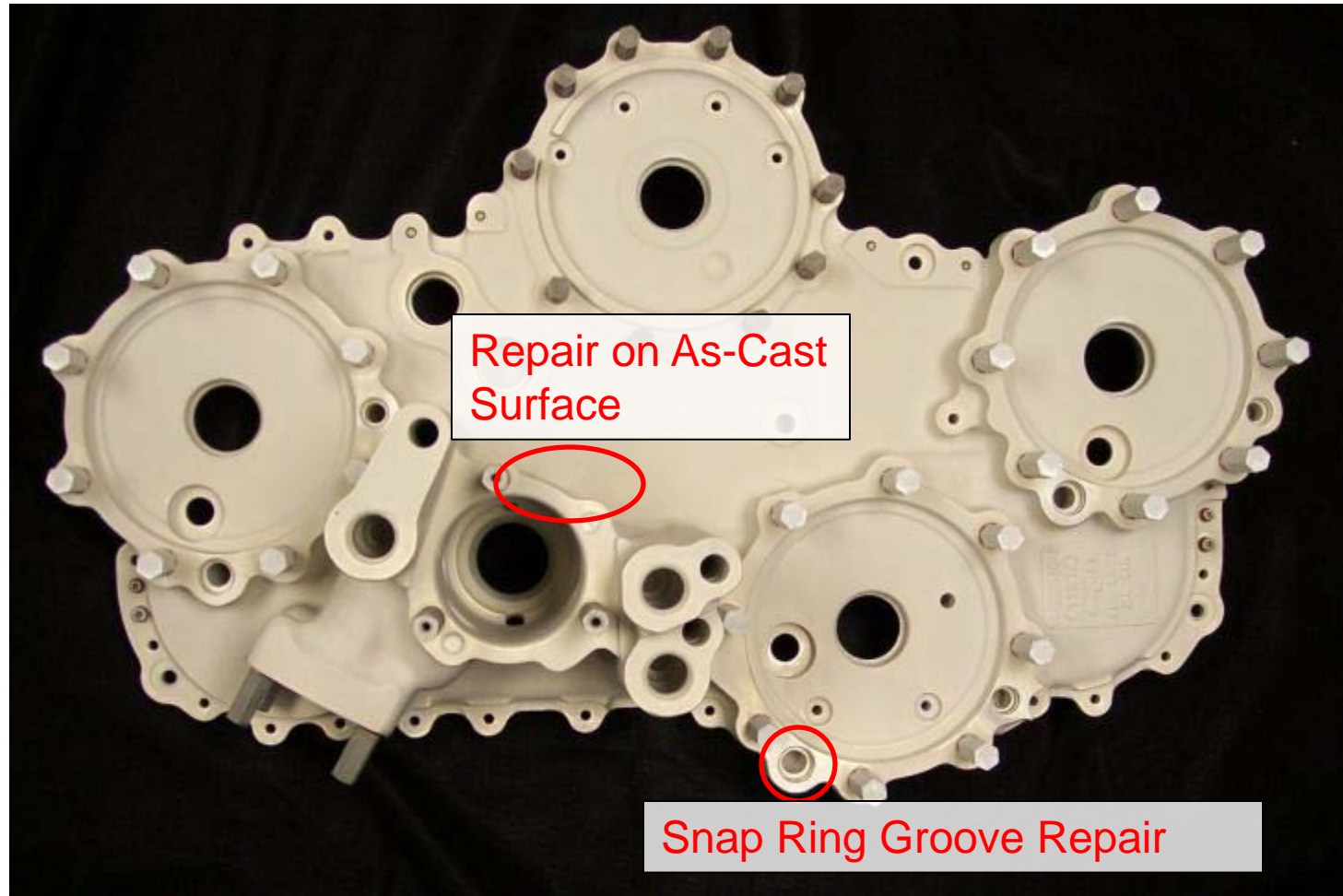
Photomicrograph of coating/substrate interface (400X).



Substrate Temperature Log

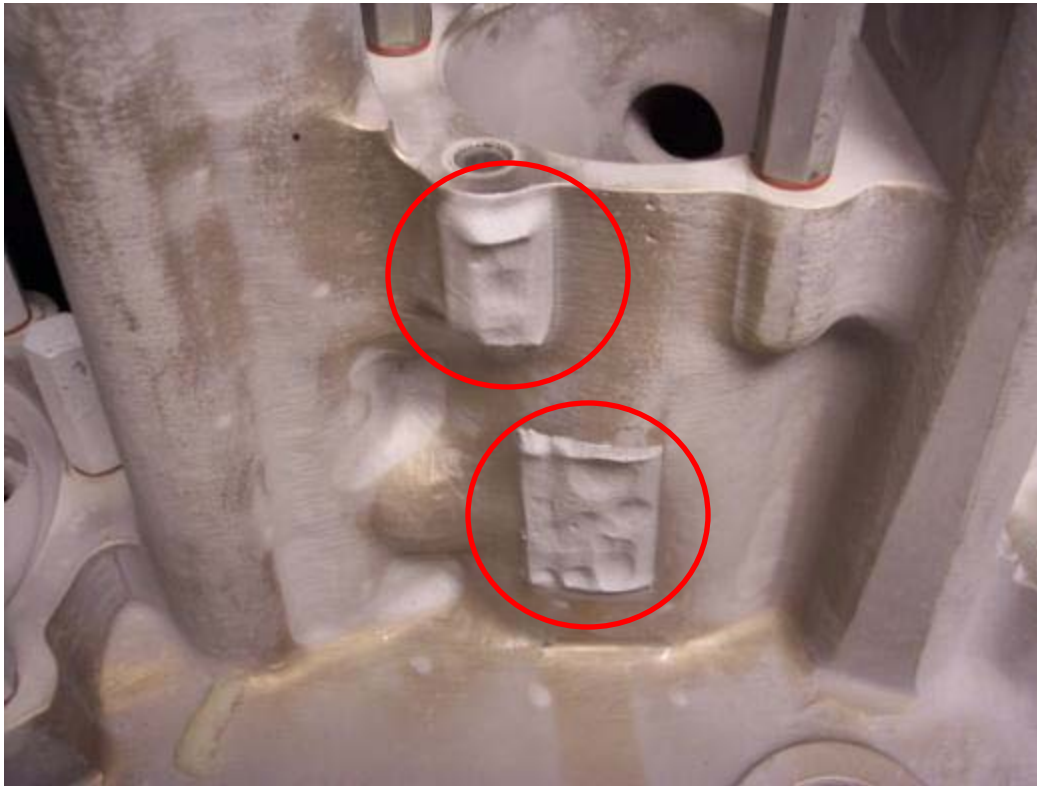
Coating Property	Results
Interface contamination (embedded grit)	Abrasive particles per linear inch---: Zero Length examined: 0.400"
Porosity	Average value: 0.234% Standard deviation: 0.113% Minimum: 0.10% / Maximum: 0.51%
Cracks or interface zone separation	Non observed
Bond Strength	Average: 11925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

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

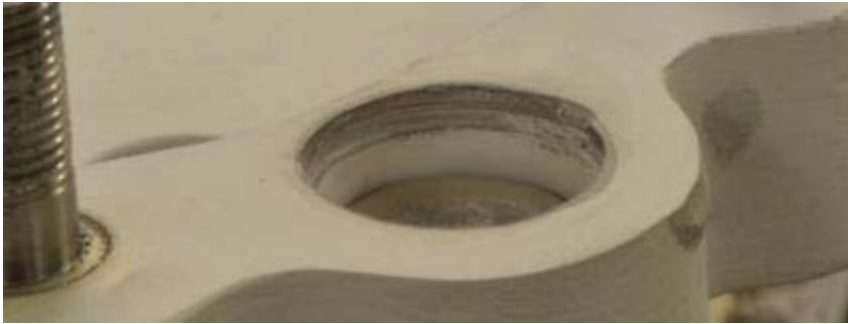


Corroded Snap Ring Groove



Cold Spray Repair Demonstrated – Corrosion

- Corroded Snap Ring Groove



As Received



Prepared for CS



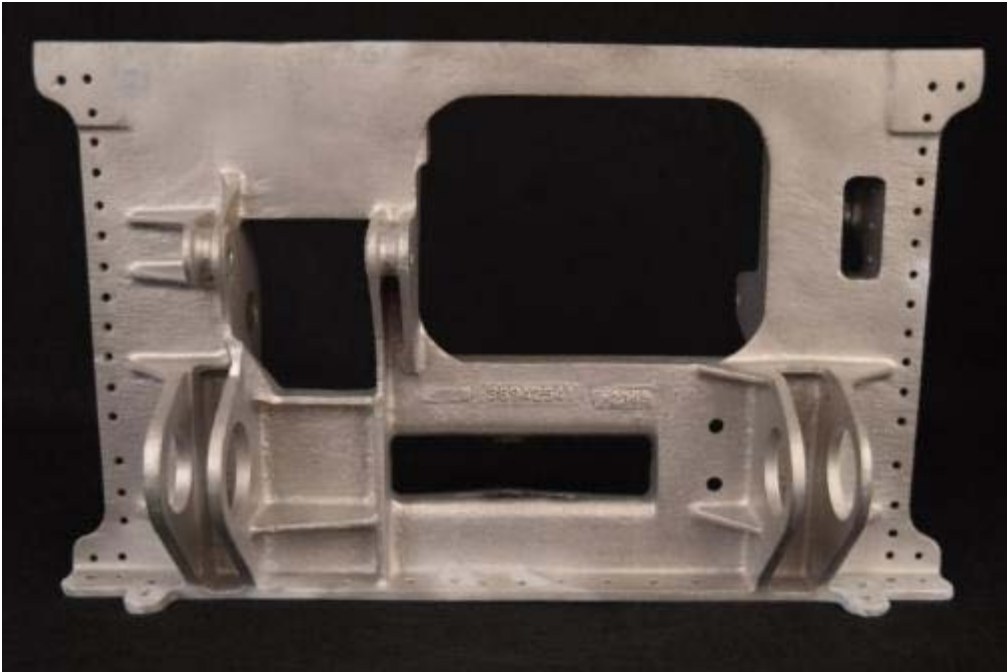
As Sprayed



Finish Machined

Cold Spray Repair Demonstrated – Corrosion

- Cyclic Support Seat Bracket, Rotorcraft
- Multiple corrosion sites
- Removed, sprayed, blended

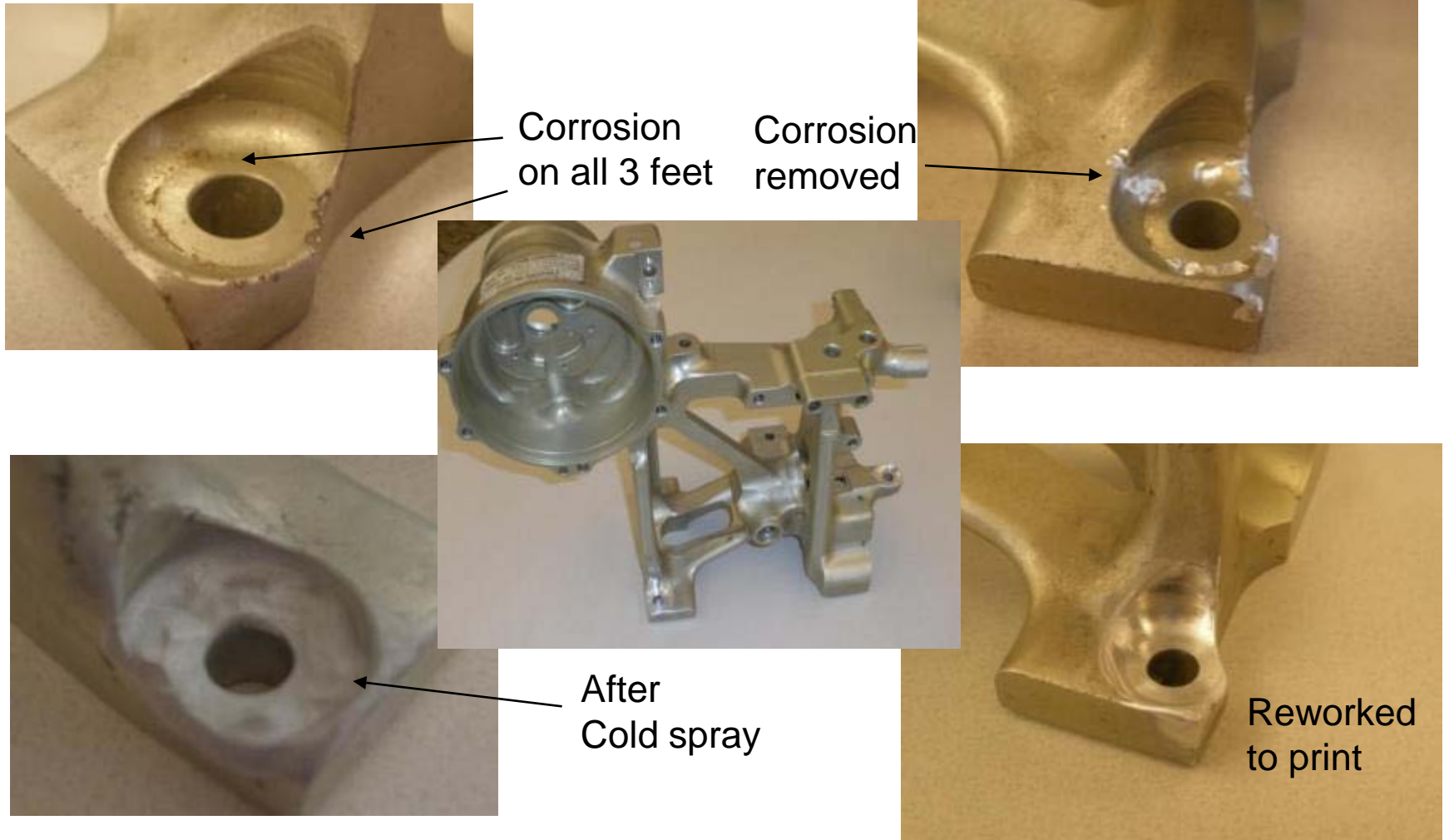


Cold Spray Repair Demonstrated – Corrosion



- Nose Wheel Steering Component
 - Refurbished with corrosion prevention coating.

Cold Spray Repair Demonstrated – Corrosion



Cold Spray Repair Demonstrated – Corrosion

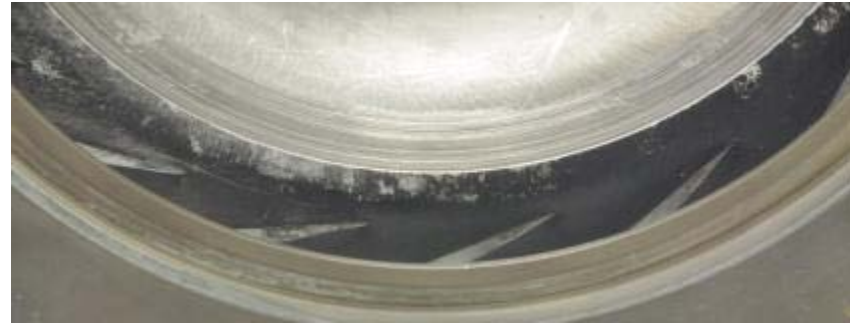


As-Received → Pre-Machined → Cold Sprayed → Finish Machined



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



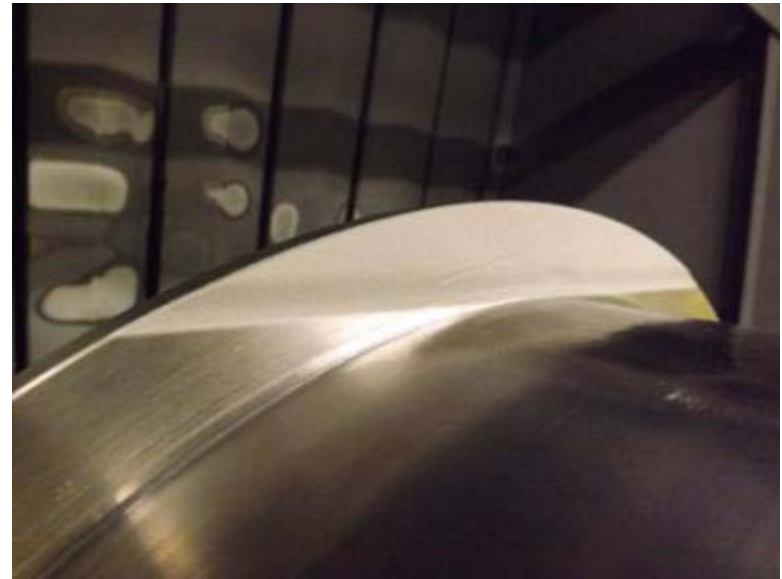
As Sprayed

Cold Spray Repair Demonstrated – Designed Wear

- Tantalum Dome – Niobium Ring



Damaged Ring



As Sprayed

Cold Spray Repair Demonstrated – Designed Wear

- Tantalum Disc



Coupon



Repaired Disc - As Sprayed

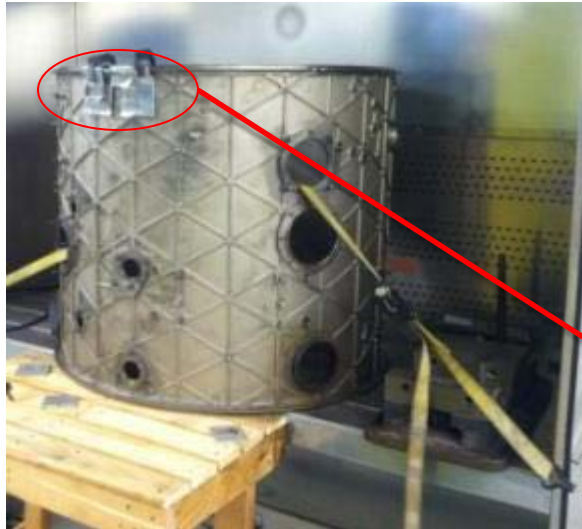
Cold Spray Repair Demonstrated – Non-Designed Wear

- 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)



Damaged



**Cold Spray
Repaired**

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**



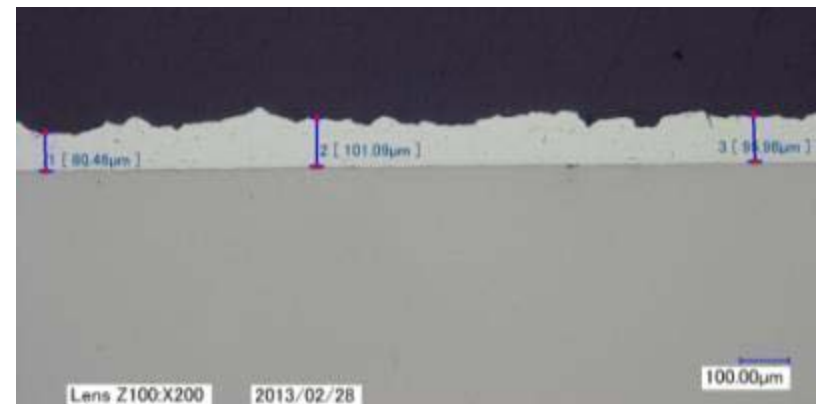
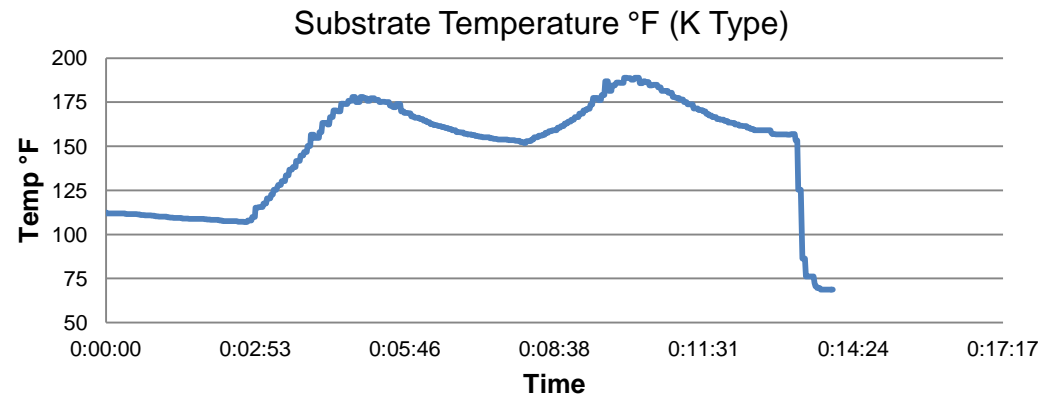
**TBH Finished
w/Rockhard**

Cold Spray Repair Demonstrated – IVD Replacement



Uniform thin coating.

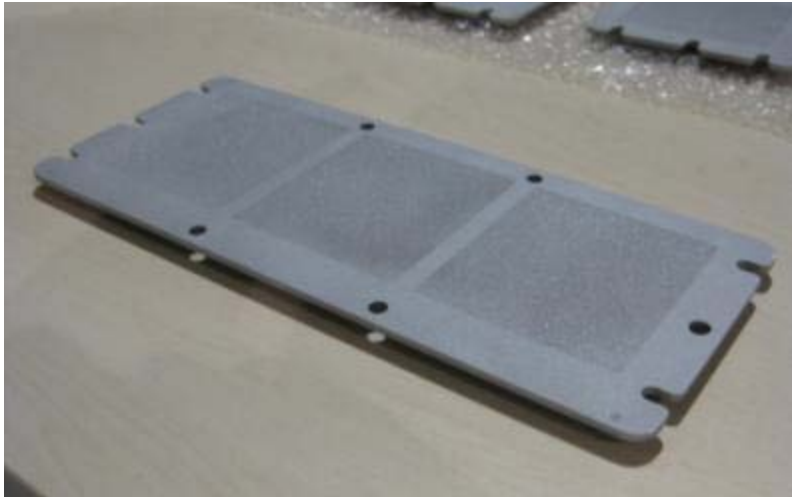
Mean value	St. Deviation	Minimum	Maximum
109.40 μm	12.41 μm	80.46 μm	140.29 μm



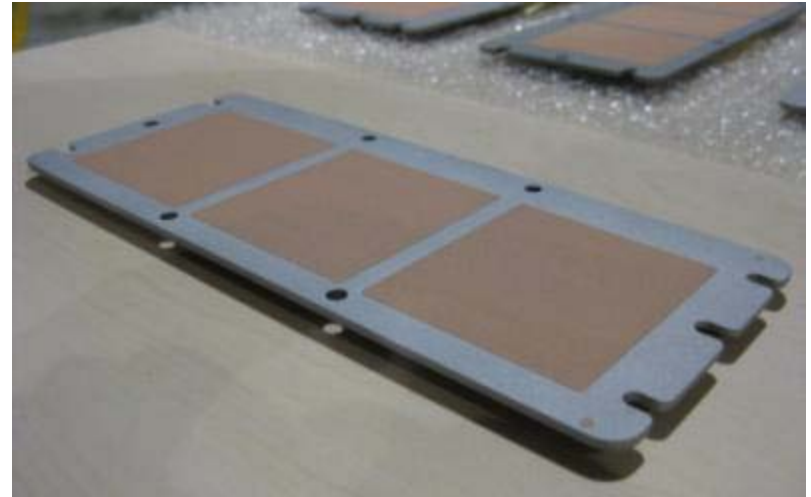
Fully dense (1.2% porosity)

Cold Spray Manufacturing - Automotive

- New component manufacture – Cu solder zone with improved electrical and thermal conductivity over conventional plating process.



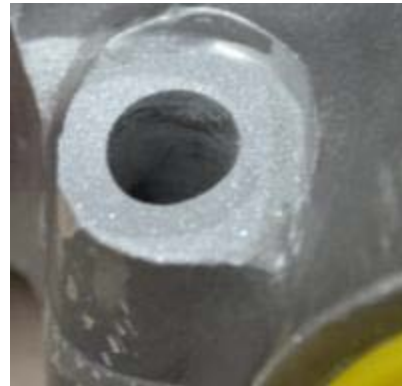
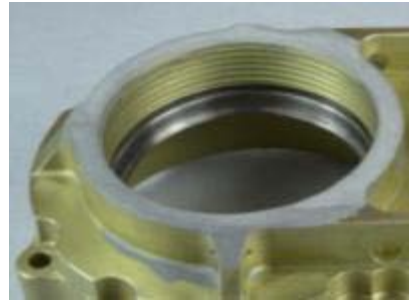
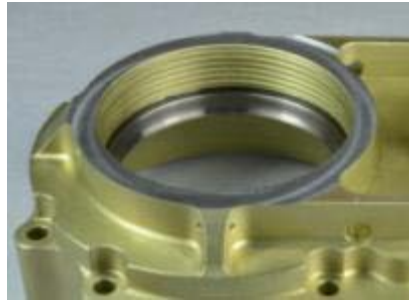
Pre-spray



As Sprayed



..And Others



Cold Spray Demonstrated – Evaluation

- Engine Gearbox for Commercial Client Test Evaluation



Pre-Machined



As Sprayed

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

- Ranko Todorovic, Ph.D. – Moog
- Christopher Howe – Moog
- Jarrod Schell – Moog
- Walter Mroch – Moog
- Ben Hoiland – Moog
- Mike Parzych - Moog
- Victor Champagne - ARL