








Cold Spray Aerospace Applications

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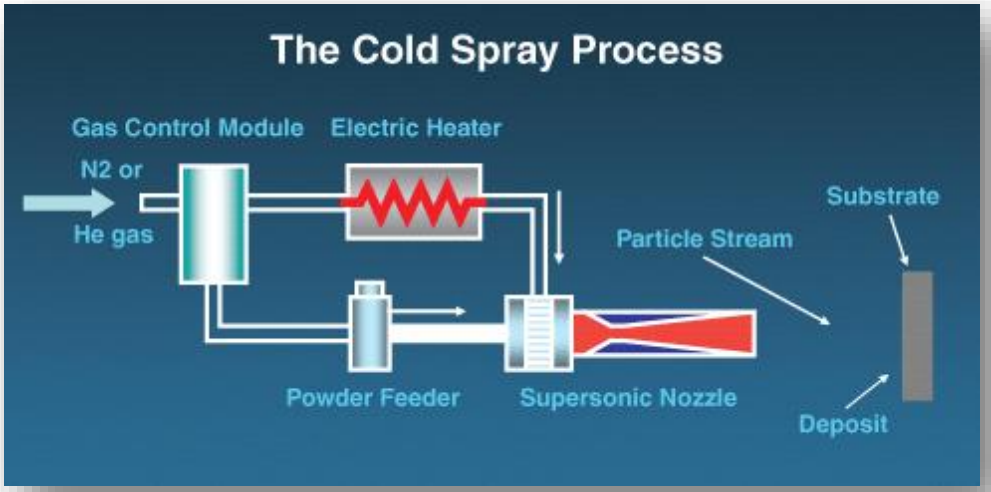
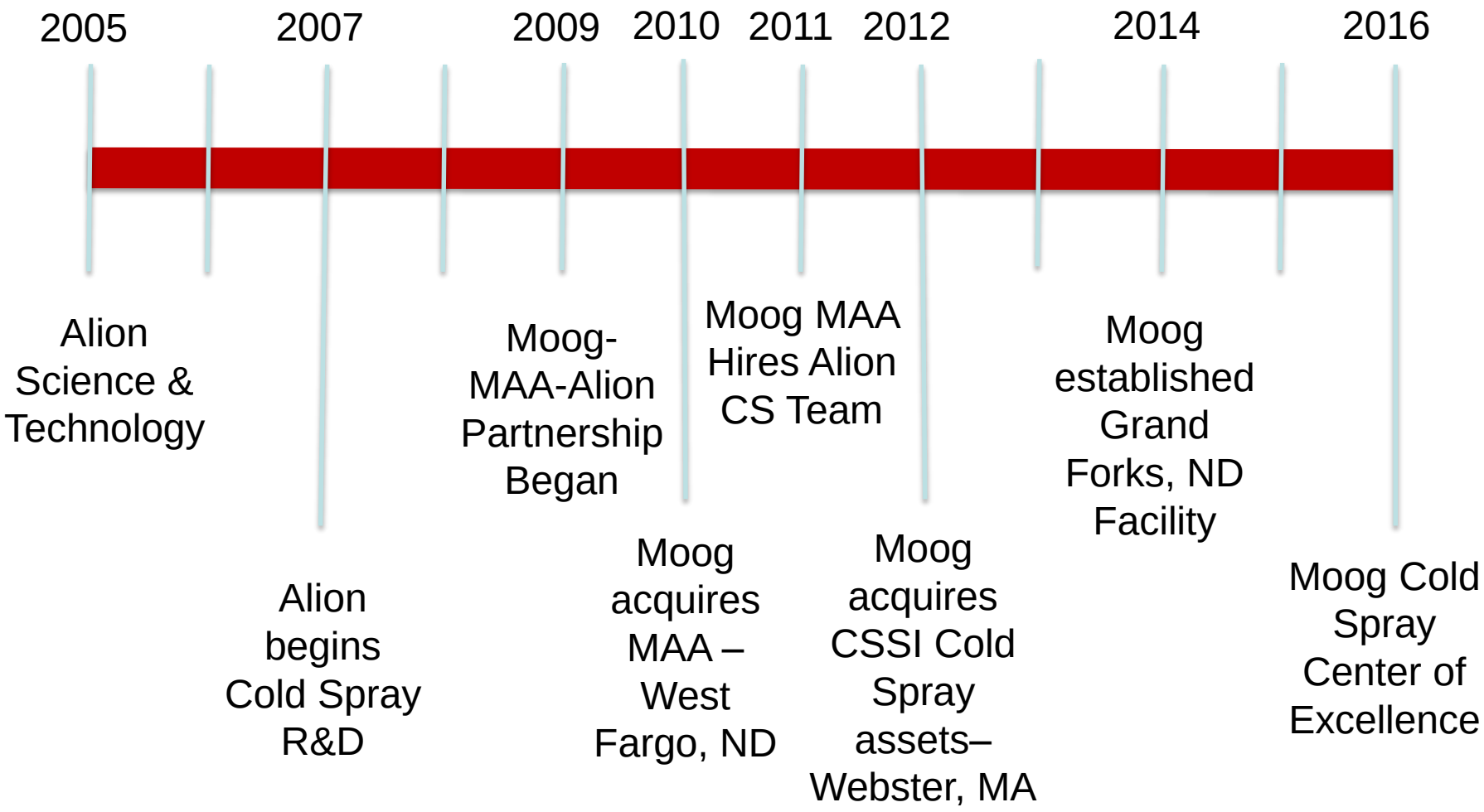
Cold Spray – Technology



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 enable a build-up of the feedstock material onto the substrate. The resultant build-up can be machined, heat treated or otherwise handled like stock material.

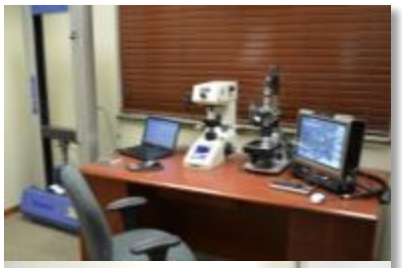
- Lowest operational temperature in thermal spray family
- Capable of highest particle velocity in thermal spray family
- Does not rely on melting/solidification of feedstock for adhesion

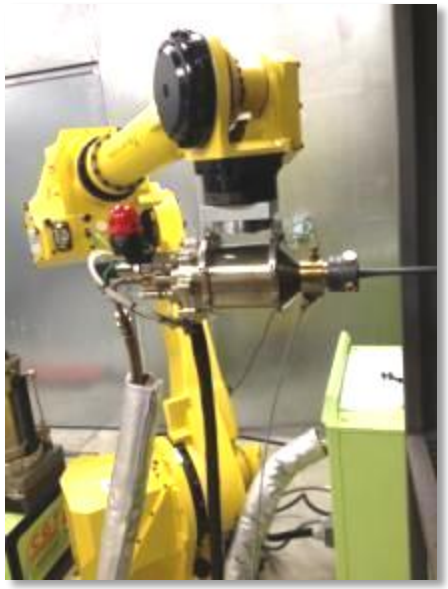
Moog Cold Spray Reference Timeline

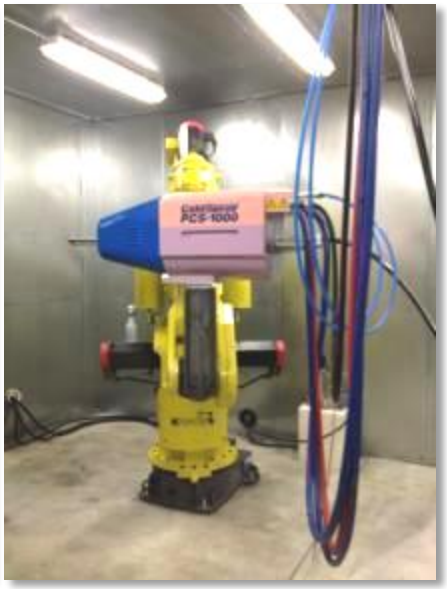


Moog Cold Spray Repair Capabilities

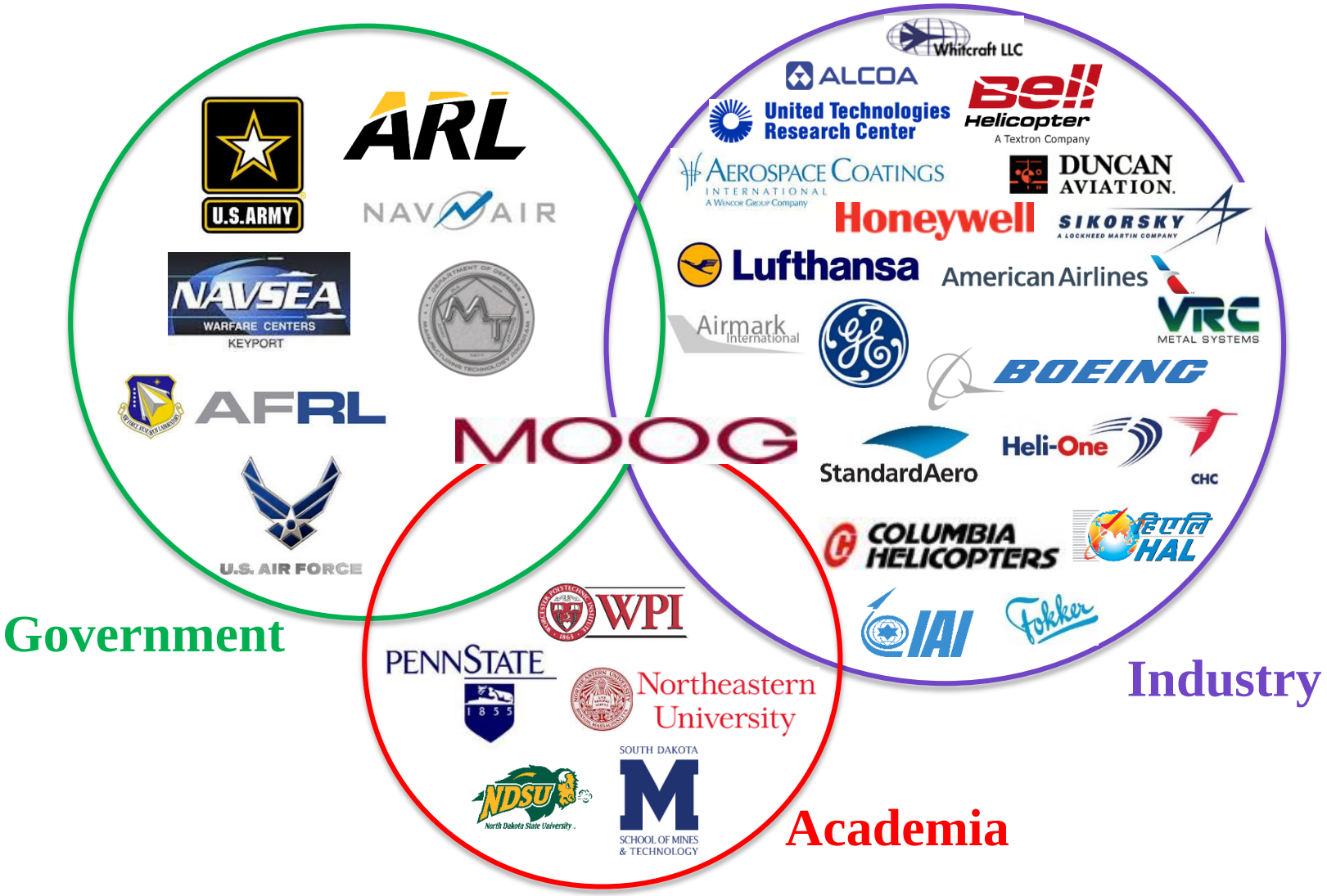
- Cold Spray Vendor
- CS Vendor + (Machining, Inspection, Testing, etc.)
- Total Repair Solutions Entity
- Military or Commercial
- High and Low Pressure Systems







Moog Cold Spray Partners



Cold Spray Aerospace Applications

- ...could be considered “Application of Cold Spray on Aerospace Components”

- Need to consider:
  - Technical Viability
    - Considerations for Geometry
    - Material Compatibility
    - Completely characterize existing condition
  - Engineering Substantiation
  - Controlled configuration managed environment
    - ISO9001 (Moog WF, GF, & WEB is AS9100)
    - FAA 145 Repair Station
  - Cost of Repair
    - More than the cost of consumables.
    - Consider cost of other available repair technologies.

Cold Spray – Characteristics and Benefits

- HP Bond strengths ~ 80-100 MPa (12-15ksi)
- Hardness dependent on Mtl (50 HV to 50 HRC)
- 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)

Cold Spray – Some Moog Performance Data

Substrate	Powder	Moog PN	Adhesion	Hardness	Porosity	Additional Properties
Magnesium Alloys (ZE41, AZ61, AZ91, EV31, QE22)	AA6061	EM00258	25 ksi	100-110 HV	<0.50%	Tensile (bulk CS): 38-41 ksi Elongation (bulk CS): 3-5% Lug Shear: 20 ksi
6XXX Aluminum Alloys	AA6061	EM00258	11 ksi (glue)	100-110 HV	<0.50%	Tensile (bulk CS): 38-41 ksi Elongation (bulk CS): 3-5%
7XXX Aluminum Alloys	AA7075	EM00248-002	10 ksi	160 HV	<0.50%	
2XXX Aluminum Alloys	AA6061*	EM00258	11 ksi	100-110 HV	<0.50%	Tensile (bulk CS): 38-41 ksi Elongation (bulk CS): 3-5%
Cast Aluminum Alloys (A356, A357, C355)	AA6061	EM00258	24 ksi	100-110 HV	<0.50%	Tensile (bulk CS): 38-41 ksi Elongation (bulk CS): 3-5% Lug Shear: 22 ksi
Ti6Al4V	Ti6Al4V	EM00248-034	11 ksi (glue)	456 HV	2.0-3.0%	
	CP Titanium	EM00248-016	11 ksi (glue)	230 HV	<1.0%	
Stainless Steel (302, 309, CRES 347, 15-5, 17-4, 300M, 416)	CrC-NiCr	CC13787	11 ksi (glue)	400-450 HV	<1.0%	
	316 Stainless	EM00248-017	11 ksi (glue)	450 HV	<0.50%	
4340 Steel	CrC-NiCr	CC13787	11 ksi (glue)	400-450 HV	<1.0%	
	CP Nickel	EM00248-033	11 ksi (glue)	39-40 HRC	<0.30%	Lug Shear: 12 ksi
Inconel (625, 718)	CrC-NiCr	CC13787	11 ksi (glue)	400-450 HV	<1.0%	
	Inconel 625	EM00248-023	11 ksi (glue)	531 HV	<1.0%	

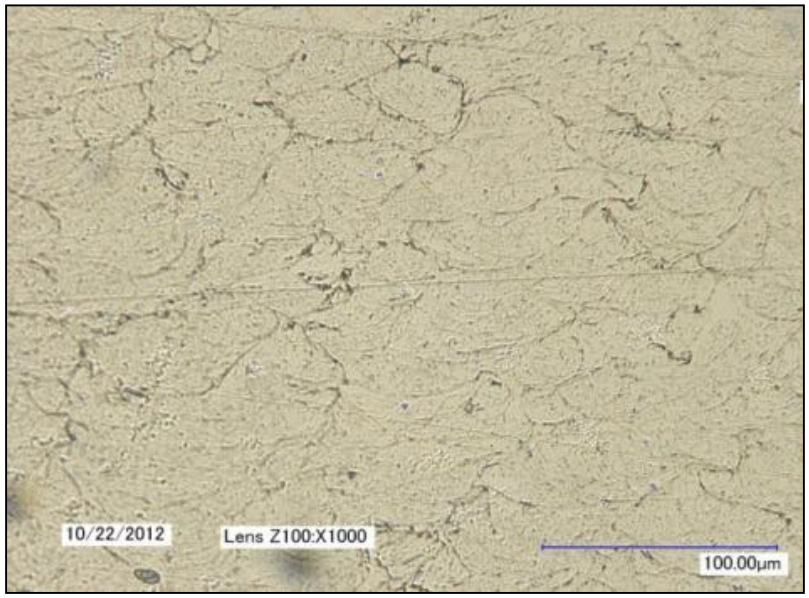
Cold Spray – Common Applications

- 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

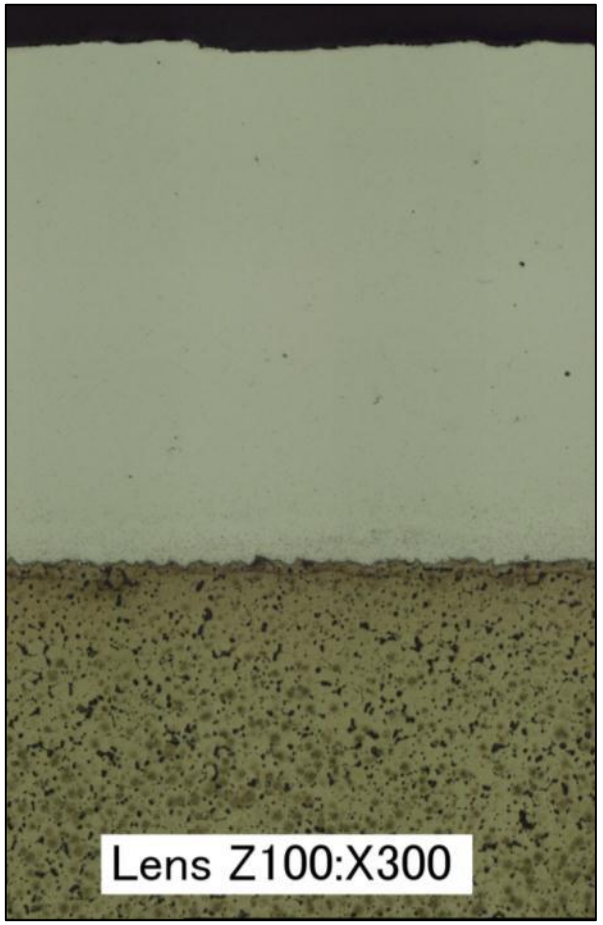
    - On to applications…

Magnesium Repair with 6061 Al Cold Spray

- 6061 aluminum deposited on ZE41 magnesium
- Porosity: **<1%**
- Adhesion Strength (ASTM C633-01 / MIL-STD-3021)
  - **>11,000 psi** (limited due to glue)
- Hardness: **≈100 HV**



6061 coating etched to reveal splat deformation (1000X)



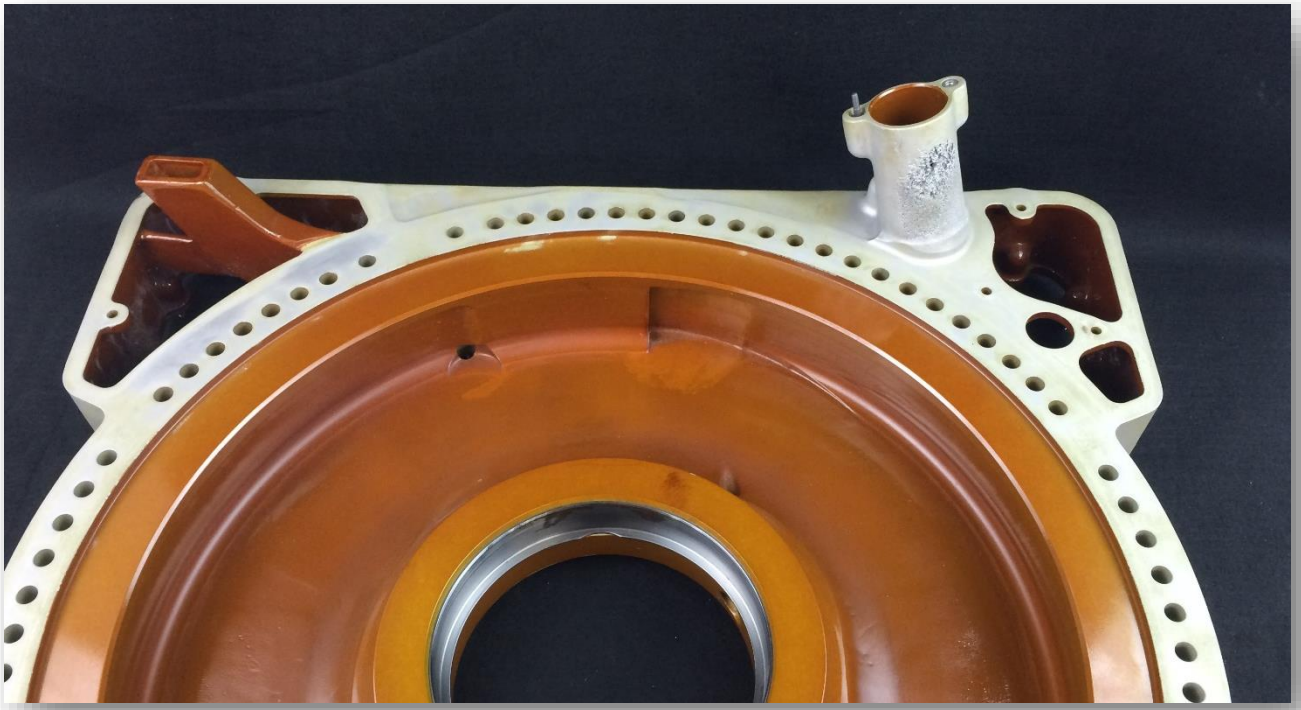
6061 cold spray coating (300X)

Cold Spray Repair – CSD/IDG Housing

- Repair stator mounts and surrounding recessed area of Integrated Drive Generator (IDG) Housing.
- Moog developed repair procedure
- Moog generated CAD model of the IDG housing

Repaired

Cold Spray Repair– S-92 Sump



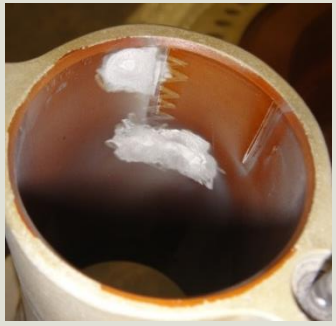
Cold Spray Repair– S-92 Sump

As Received

Prepared

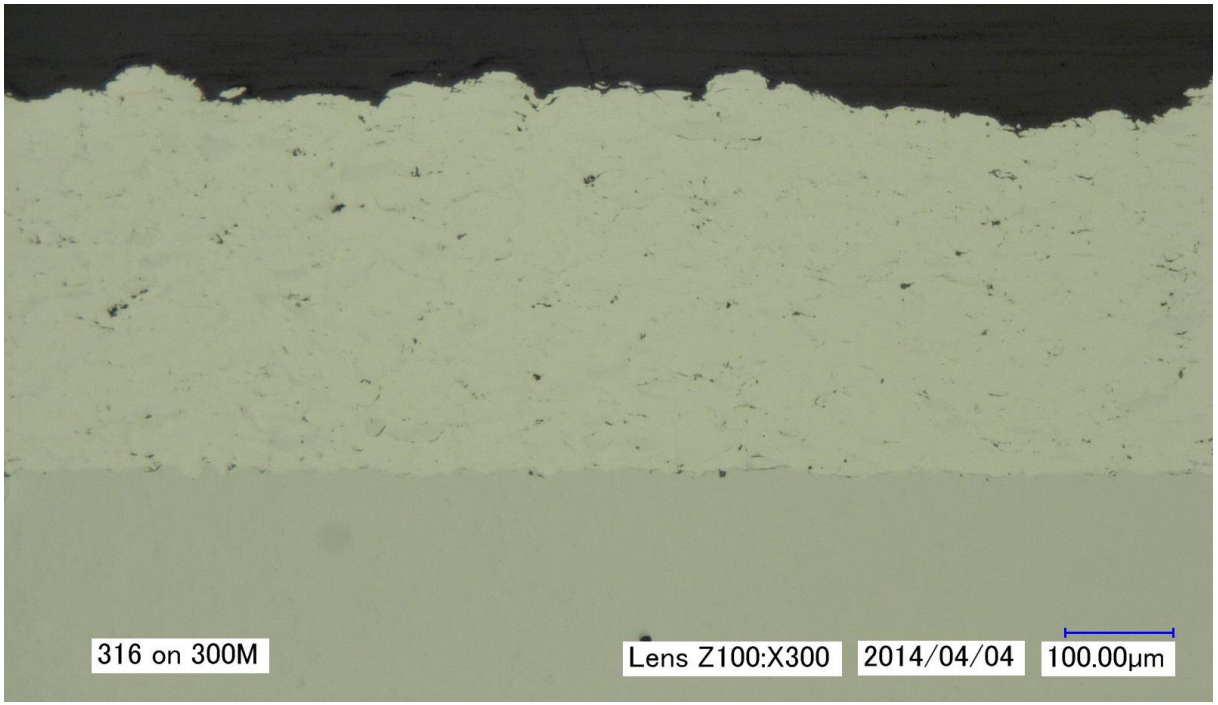
As Sprayed

Machined



Stainless Steel Repair with 316 SS Cold Spray

- 316 Stainless Steel on Various Steel and Stainless Steel Alloys
- Porosity: **≈0.5%**
- Adhesion Strength (ASTM C633-01 / MIL-STD-3021)
  - **>11,000 psi** (limited due to glue)
- Hardness: **45 HRC**



Stainless Steel Repair Cold Spray

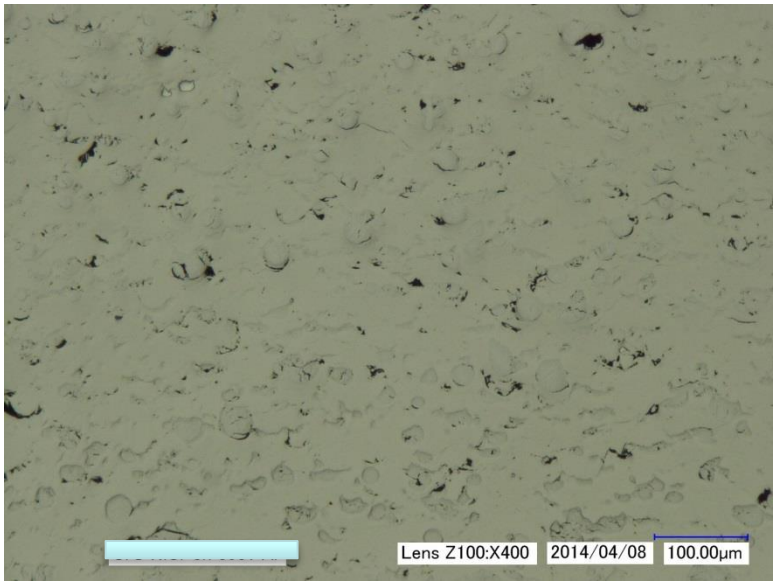
- Repair of Aerospace Valve Component

Stainless Steel Cold Spray Repair

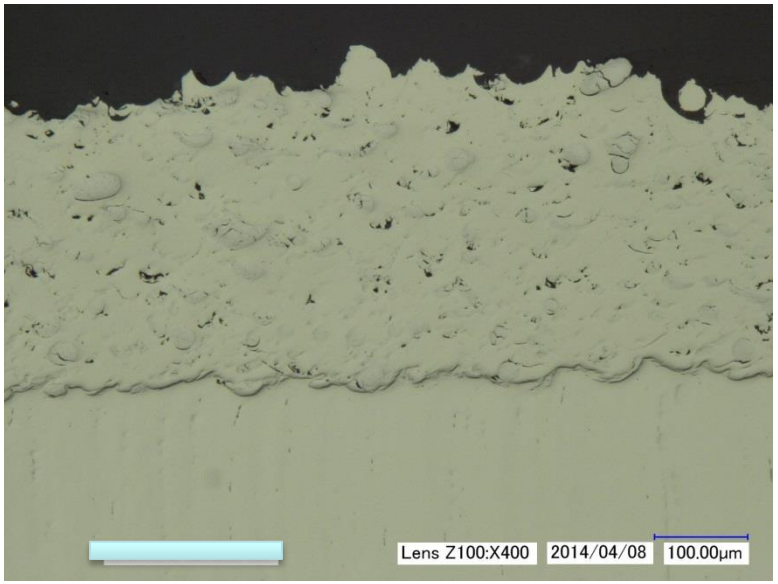
- Two Repair Areas
  - Mid Shaft
  - Wear Lugs

Cold Spray Repair with Nickel-Carbide Matrix

- Nickel-Carbide Matrix on various Stainless Steel and Inconel Alloys
- Porosity: **<1%**
- Adhesion Strength (ASTM C633-01 / MIL-STD-3021)
  - **>10,000 psi** (limited due to glue)
- Hardness: **400-460 HV**

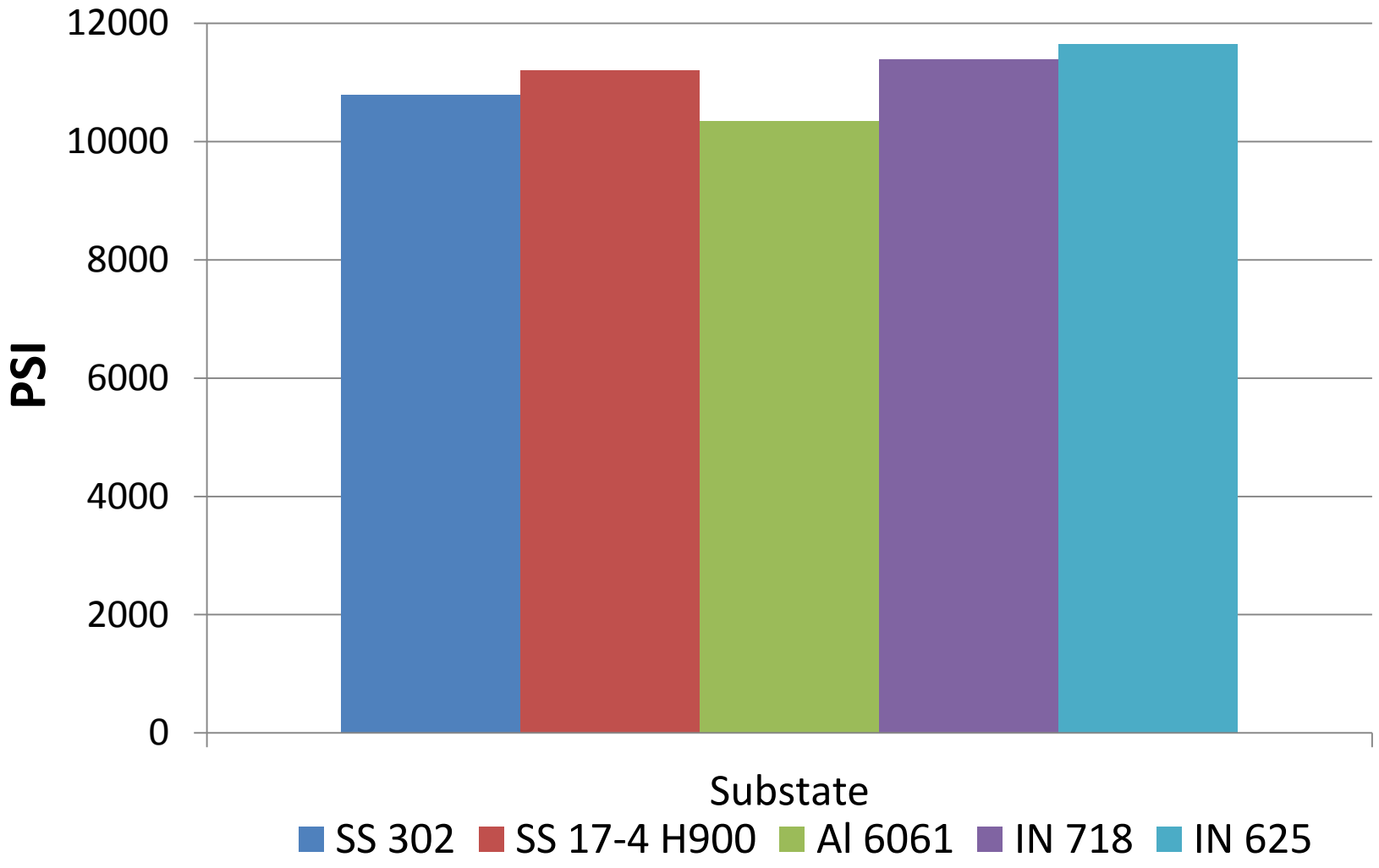


Ni-Carbide Matrix (400X)



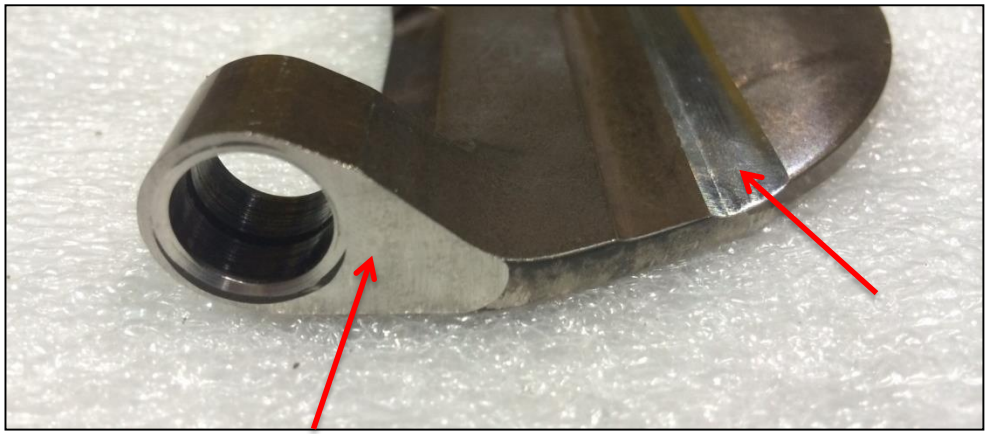
Ni-Carbide Matrix on SS 302 (400X)

Cold Spray Repair with Nickel-Carbide Matrix



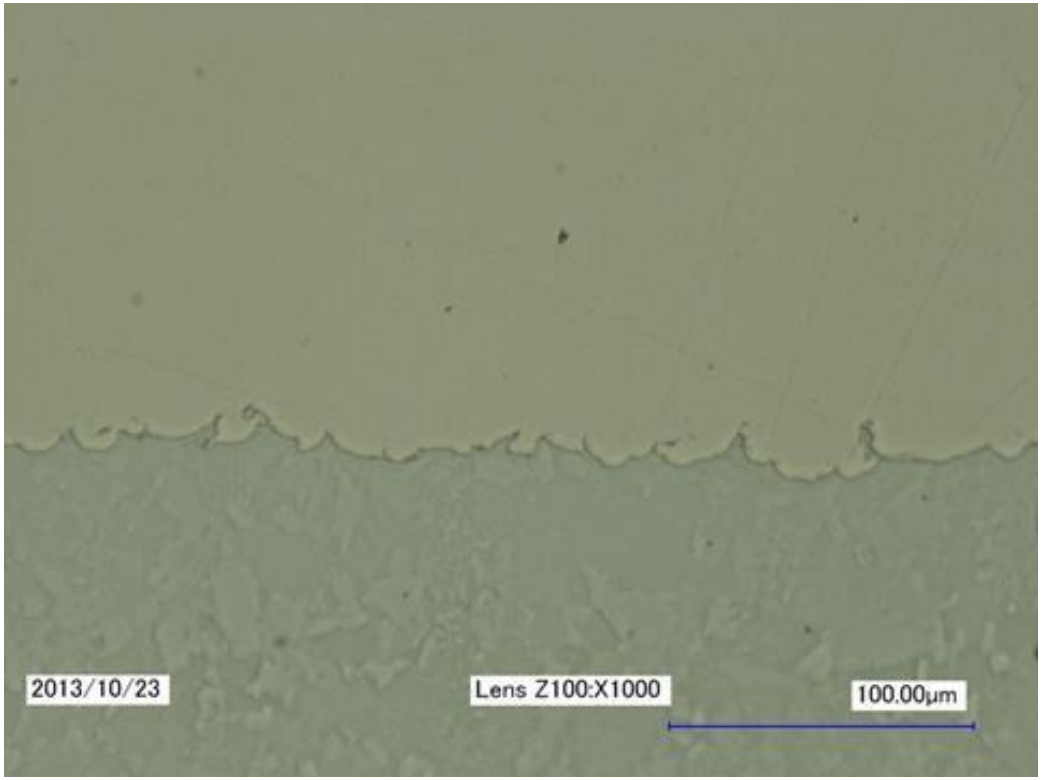
Cold Spray Repair with Nickel-Carbide Matrix

- Repair of Aerospace Valve Components



Corrosion Protection with Nickel Cold Spray

- Commercially Pure Nickel on 4340 Steel
- Porosity: **<0.5%**
- Adhesion Strength (ASTM C633-01 / MIL-STD-3021)
  - **>10,000 psi** (limited due to glue)
- Hardness: **≈ 370 HV**



Nickel Cold Spray Repair

- Nose Wheel Steering Component
  - Refurbished with Nickel Cold Spray

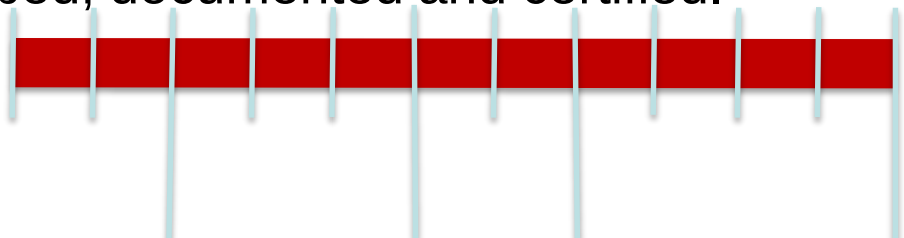
Staff

- 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
- Cold Spray Technician – 10+ years of thermal spray experience and 20 years in aircraft and armament systems maintenance.
- AS9100 and AS9110 Certified
- FAA 145 Repair Station Certificate(s)
- Cold Spray Equipment – VRC GEN3, 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

Conclusion

- Significant total cost savings
  - Save on inventory, lead time and labor costs
- Repair vs. Replacement
  - Repair time reduction
  - Reduced acquisition timeline & cost
- Improved production yield
  - Salvage parts with manufacturing defects
- Versatile coating method
- Numerous Coating/Substrate combinations
- Engineered coating properties

- When properly assessed, developed, documented and certified.



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