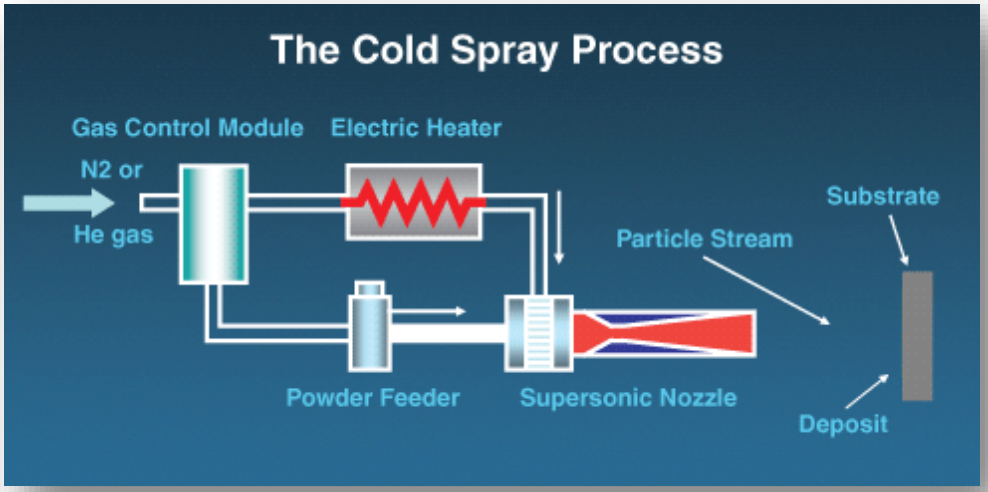
MOOG

Tagnite and Cold Spray Compatibility for Repair of Aerospace Components

Ben Hoiland – Moog

Bill Elmquist – Technology Applications Group

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

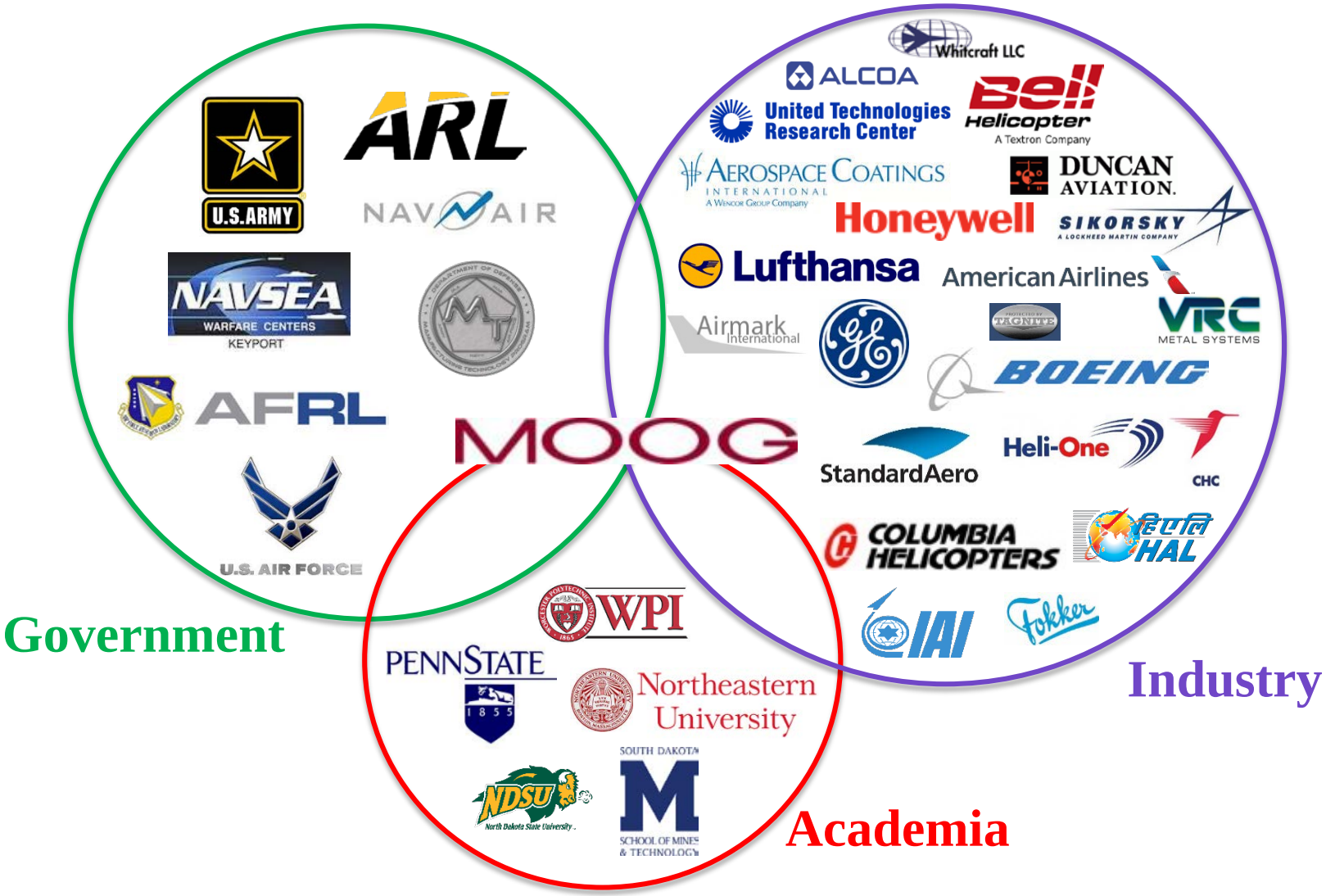
- HP Bond strengths ~ 80-100 MPa (12-15ksi+)
- Aluminum Elongation ~ 3-5%+
- No oxidation
- Compressive residual stress
- Strain hardening
- High density – low porosity (<1%)
- Thick coatings
- Heat treatable free forms
- Minimal surface preparation
- No distortion of substrate
- Limited masking
- Low 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 – 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%	

Moog Cold Spray Partners



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

Military Components

	Component	Qty	Est Value
1.	Bell AH-1 Elevator Horns1	2	5,500
2.	KC-135 IDG Housings	5	231,500
3.	Submarine TD-63 Actuator	3	195,000
4.	T-700 Front Frame	1	12,307
5.	H-60 Sump	2	31,054
6.	B-1 FEB Panel	1	222,400
7.	UH-60 Main Gearbox Housing	1	56,761
8.	F-18 AMAD	4	530,424
9.	Class 688 Submarine Cone Assembly	1	25,000
10.	H-53 Main Transmission	1	492,213
11.	H-53 Nose Gearbox	1	18,000
12.	Patriot Missile Pedestal	1	65,000
13.	AH-64 Static Mast Support	2	28,000
14.	AH-64 Intermediate Gear Support	2	24,434
	Totals	**27**	**$1,915,693**

Commercial Components

	Component	Qty	Est Value
1.	CH47 Case & Rotor	4	106,000
2.	S-92 Sump & Hydro Hsgs	12	771,000
3.	PT6 Housings	3	69,700
4.	AW-139 Upper Scissor Lever	1	1,700
5.	S-76 Components	9	354,800
6.	Landing Gear Wheel Hubs (sets)	50	110,000
Totals		**79**	**$1,413,200**

Potential Military Components

	Component	Qty	Est Value ($)
1.	KC-135 IDG Housings	27	1,250,100
2.	H-60 Sump	21	326,067
3.	UH-60 Main Gearbox Housing	50	2,838,050
4.	F-15 AMAD	10	181,060
5.	F-16 ADG	4	50,653
6.	B-1 FEB Panels	12	1,561,537
7.	AH-64 Static Mast Support	70	1,960,000
8.	AH-64 Nose Gearbox	15	270,000
9.	AH-64 Input Flange	200	615,700
10.	LA Class Submarine Stern Tube	1	195,000
Totals		**410**	**$9,248,167**

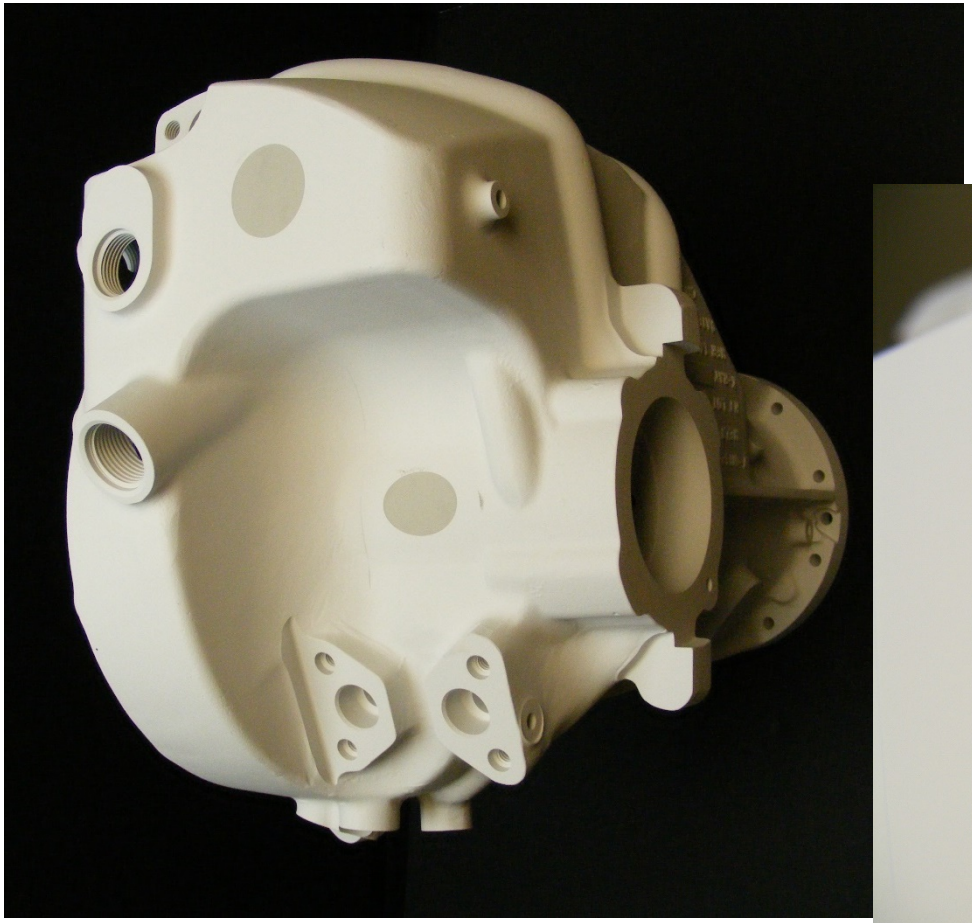
Cold Spray Engineering for Success

- Challenges:
  - Masking
  - Path planning
  - Inspection requirements
  - Premachine geometry
  - Powder/substrate compatibility

Pre-Machined

As Sprayed

Combining Tagnite with Cold Spray

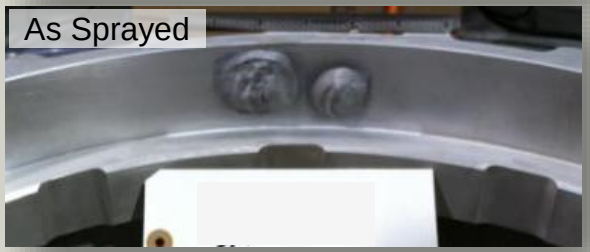


Cold Spray – Accomplishments

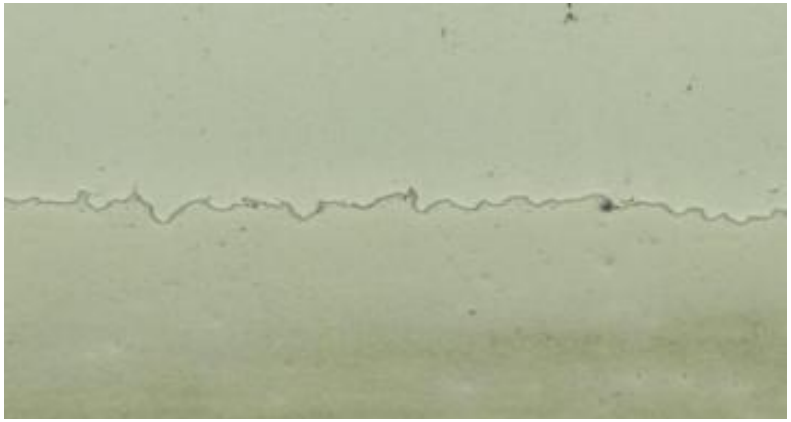
Approved Commercial and Military Cold Spray Applications:

Cold Spray Repair Demonstrated – Casting Defect

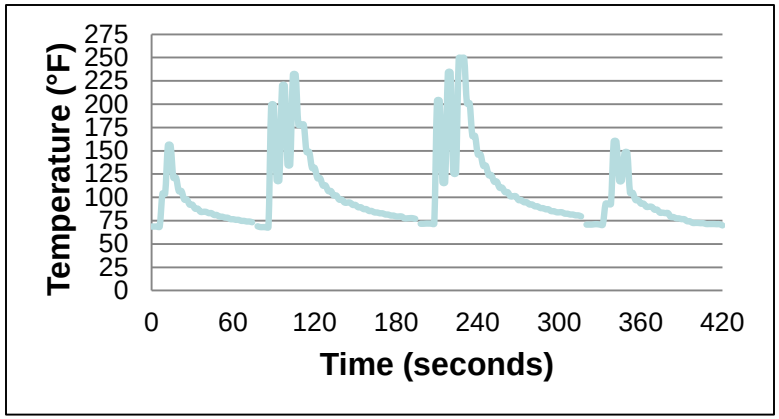
- *<u>Repair approved by Boeing-Mesa</u>*
- *Main Transmission Housing*
- *Casting defect in Magnesium Housing, New Part*



Cold Spray Repair Demonstrated – Casting Defect



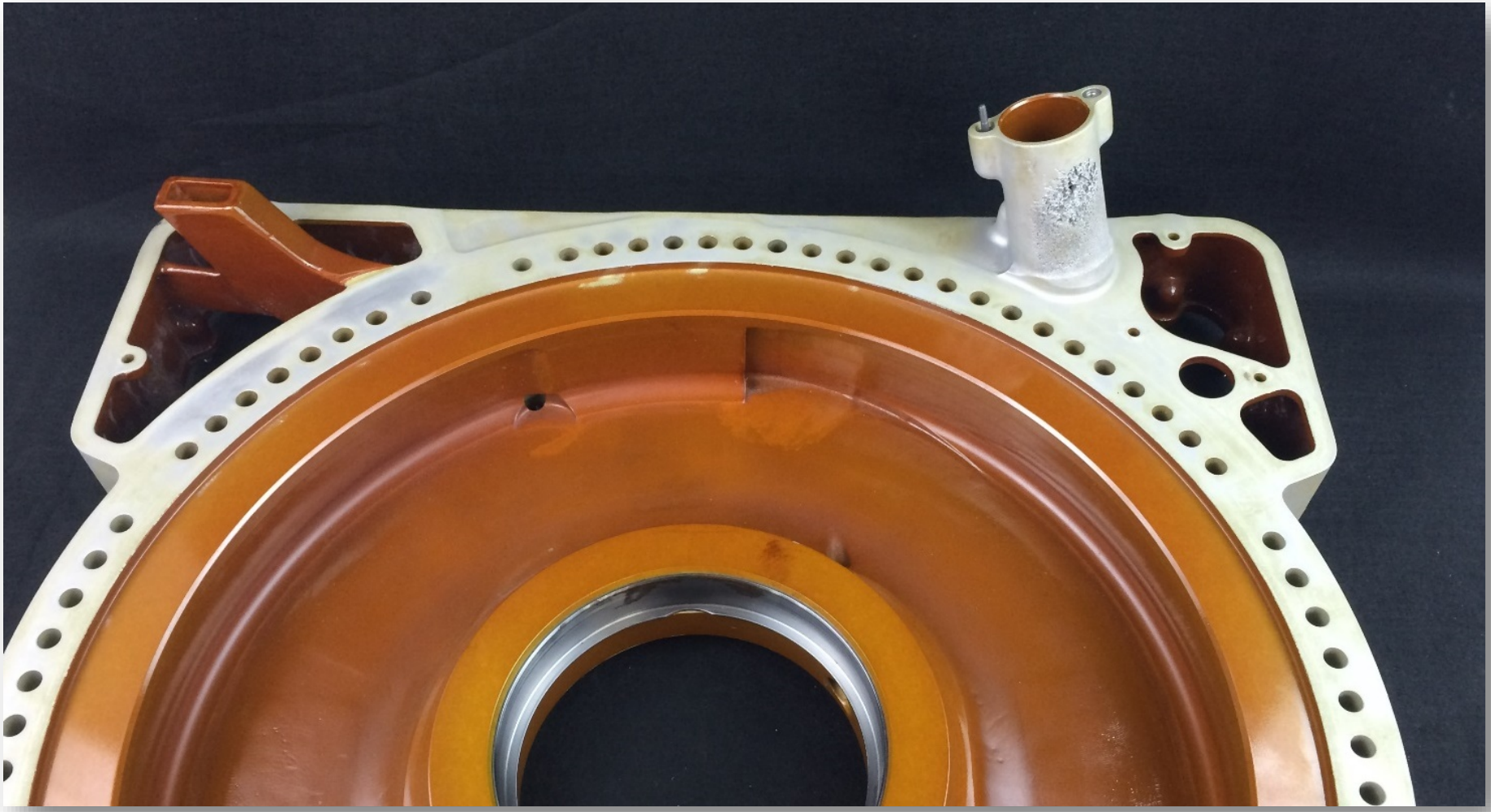
Photomicrograph of coating/substrate interface (400X).



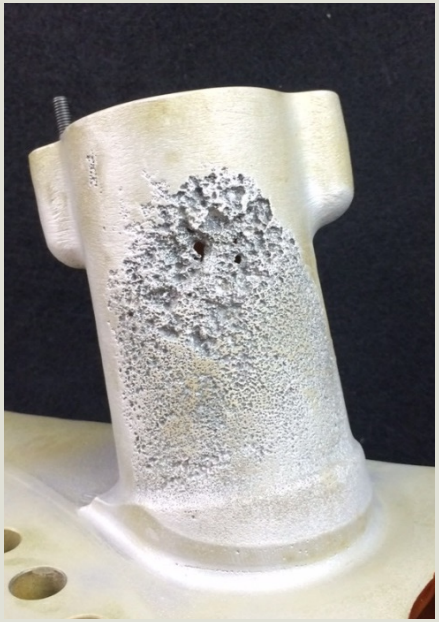
Substrate Temperature Log

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)

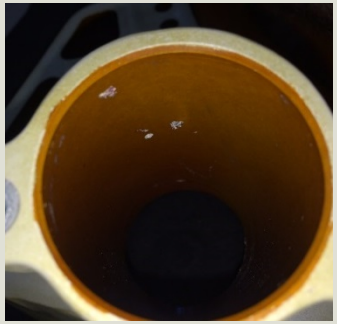
Cold Spray Repair– S-92 Sump



Cold Spray Repair– S-92 Sump

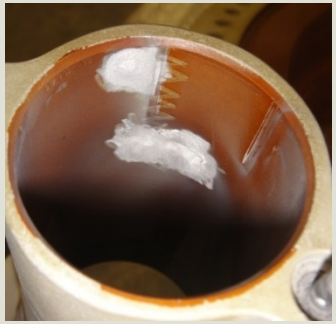


As Received

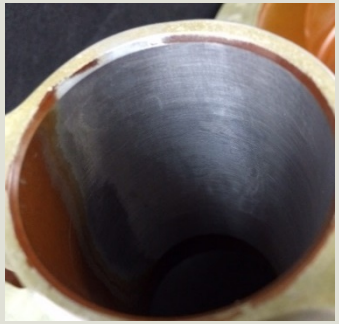


Prepared

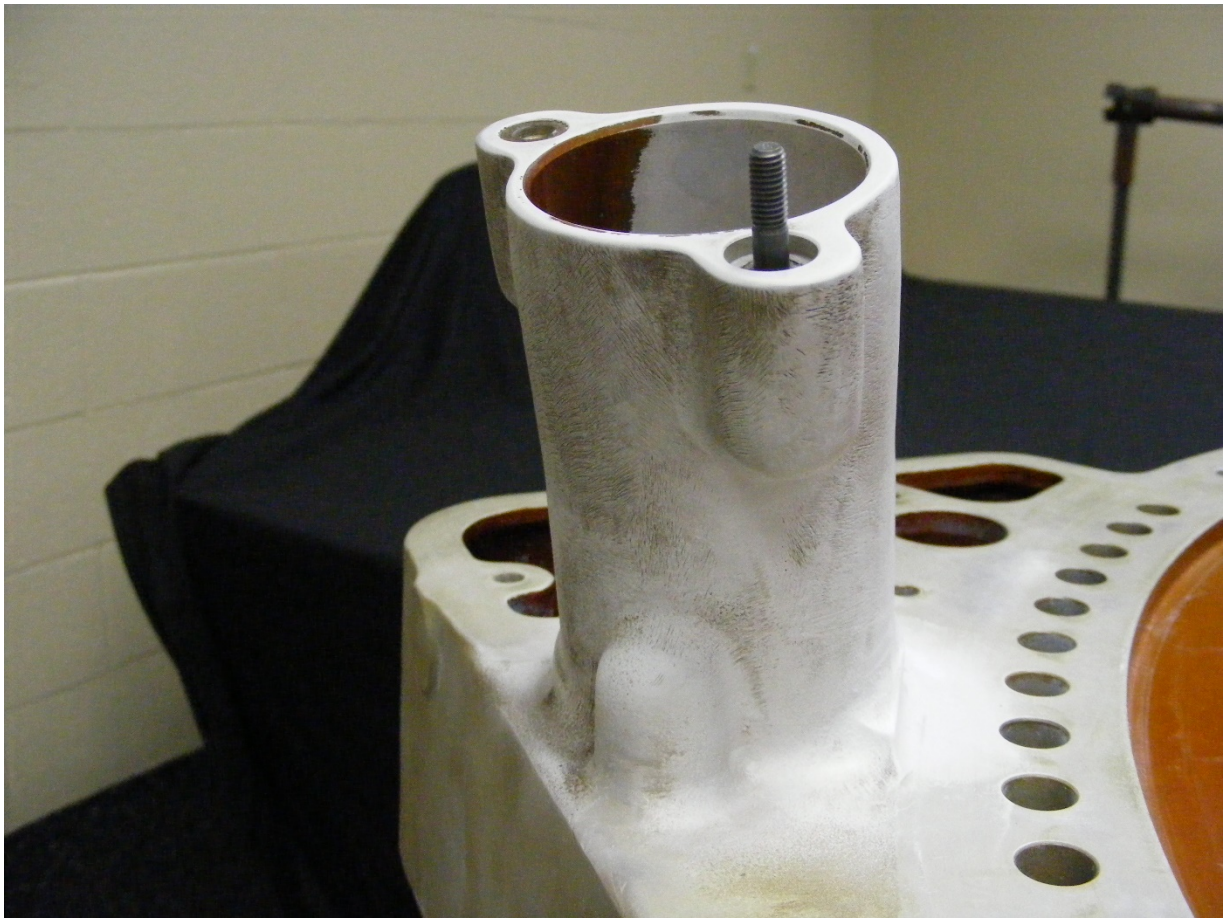
As Sprayed



Machined

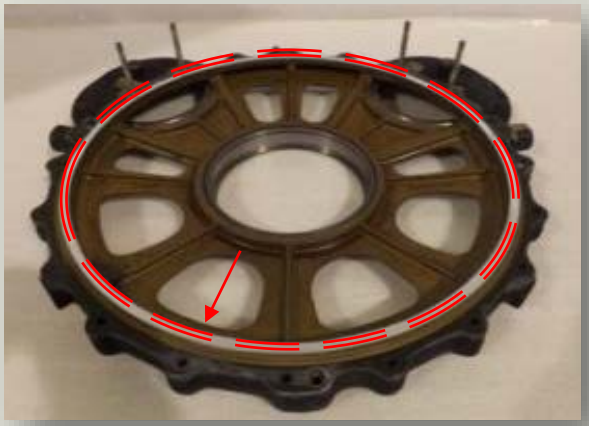


Combining Tagnite with Cold Spray



Cold Spray Repair– S-92 Hydraulic Backup Pump

H-64 Intermediate Gearbox Support

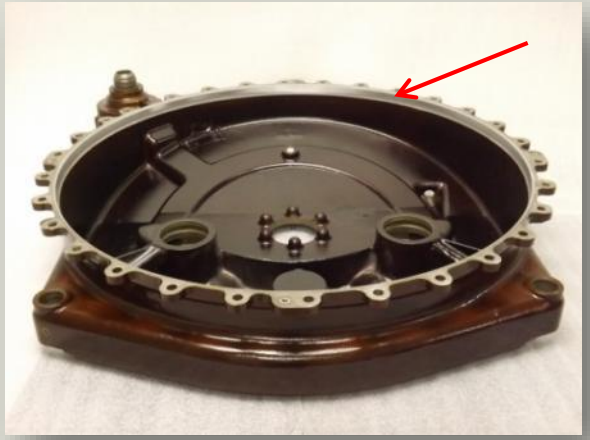


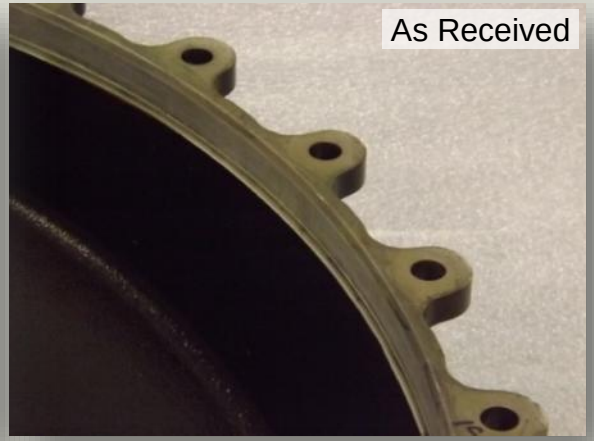
Repair requested by Boeing-Mesa

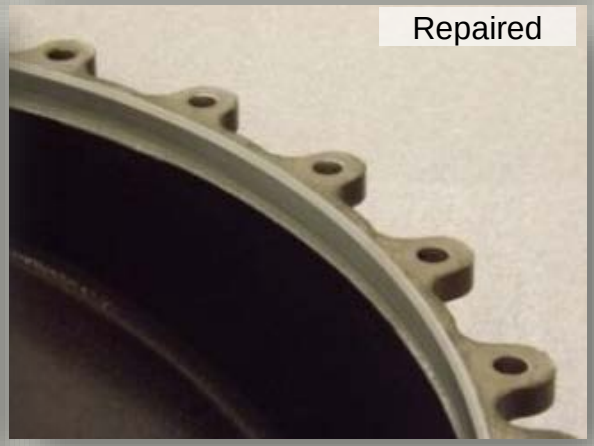
Spares availability problem

High Cost/High Demand

H-60 Sump Housing







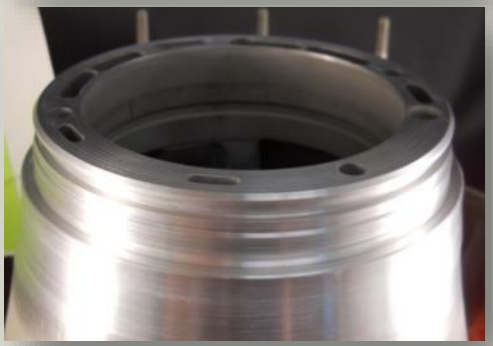
Corrosion / Pitting of sealing surface

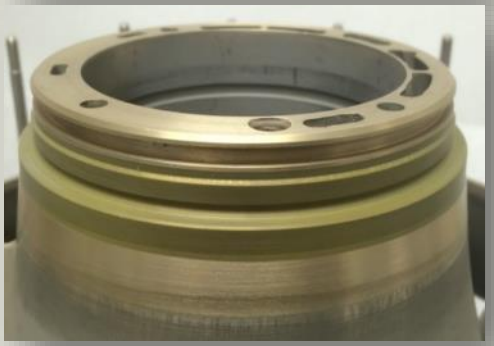
MEO approved.

Spares availability problem

High Cost/High Demand

T700 Inlet Particle Separator

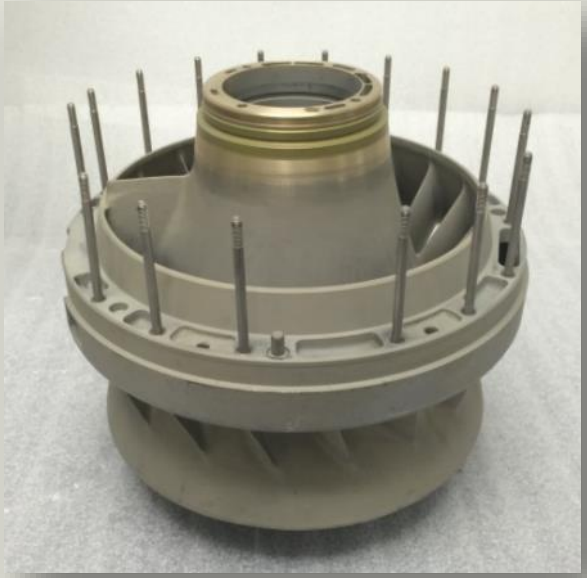




<u>MEO released.</u>

FALLOUT: 30 candidates (SAFR).

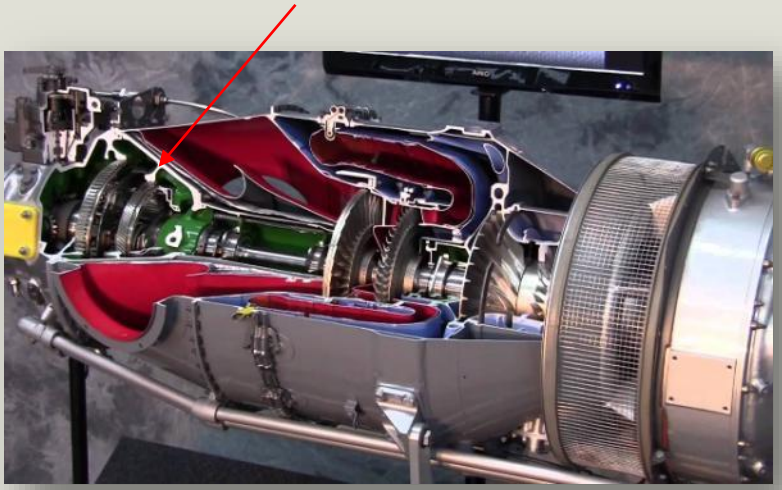
Approx 2 per month, likely increasing due to young fleet aging.



Israel Aerospace Industries (IAI)
Pratt & Whitney PT6 Reduction Gearbox Housing

Nominated by Israel Aerospace Industries for cold spray repair

Spares availability problem



Cold Spray Repair – Tinker AFB

- Repair stator mounts and surrounding recessed area of KC135R Integrated Drive Generator (IDG) Housing.
- Moog developed repair procedure
- Moog generated CAD model of the IDG housing

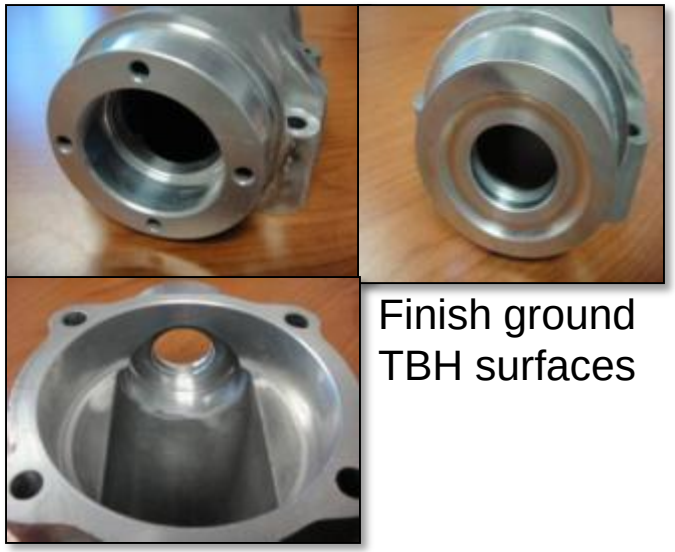
Repaired

Cold Spray Demo Repair: KC-135 Flap Drive Repair

Defective TBH

Machined TBH

Cold Sprayed TBH

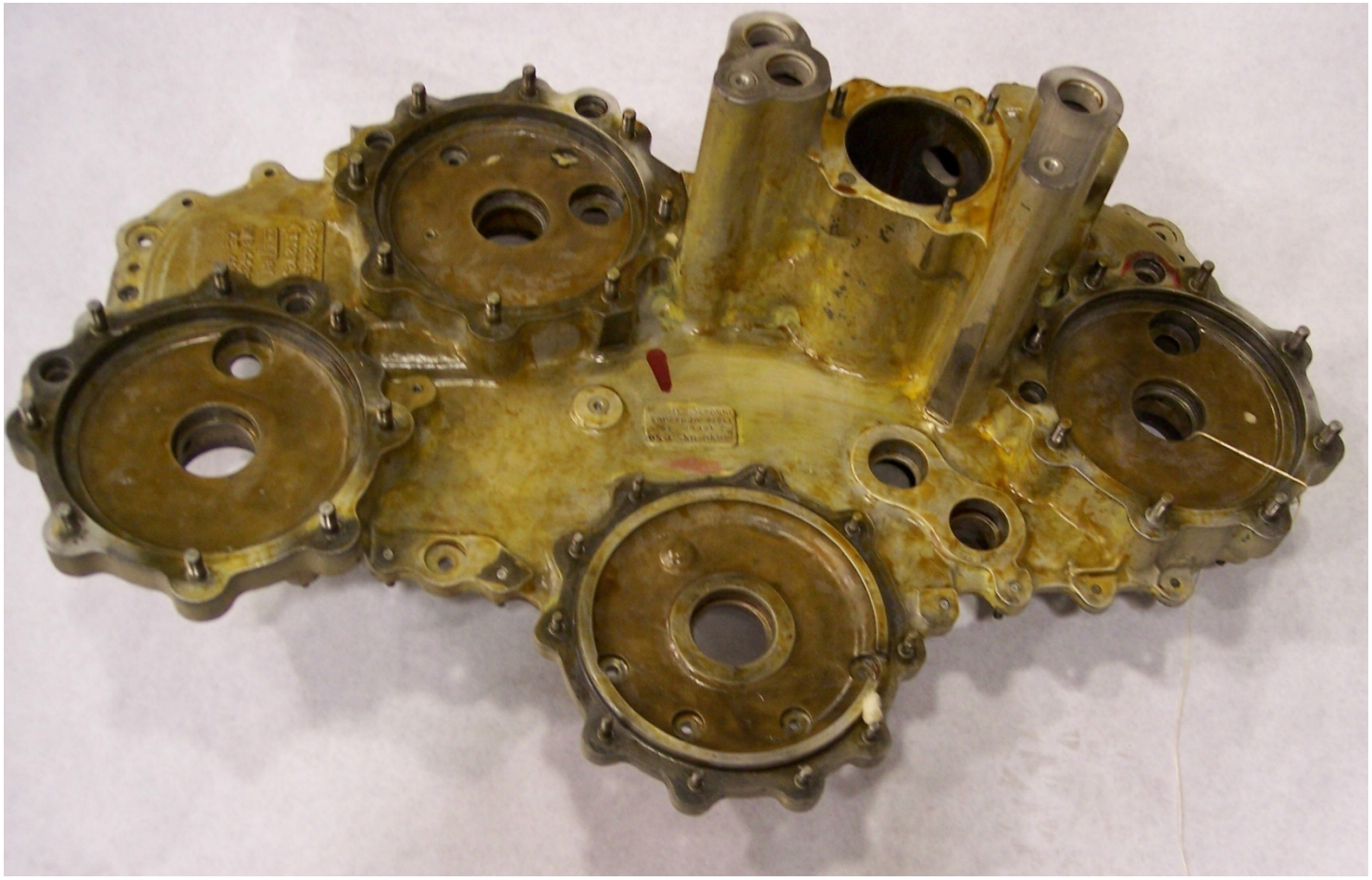


Finish ground TBH surfaces

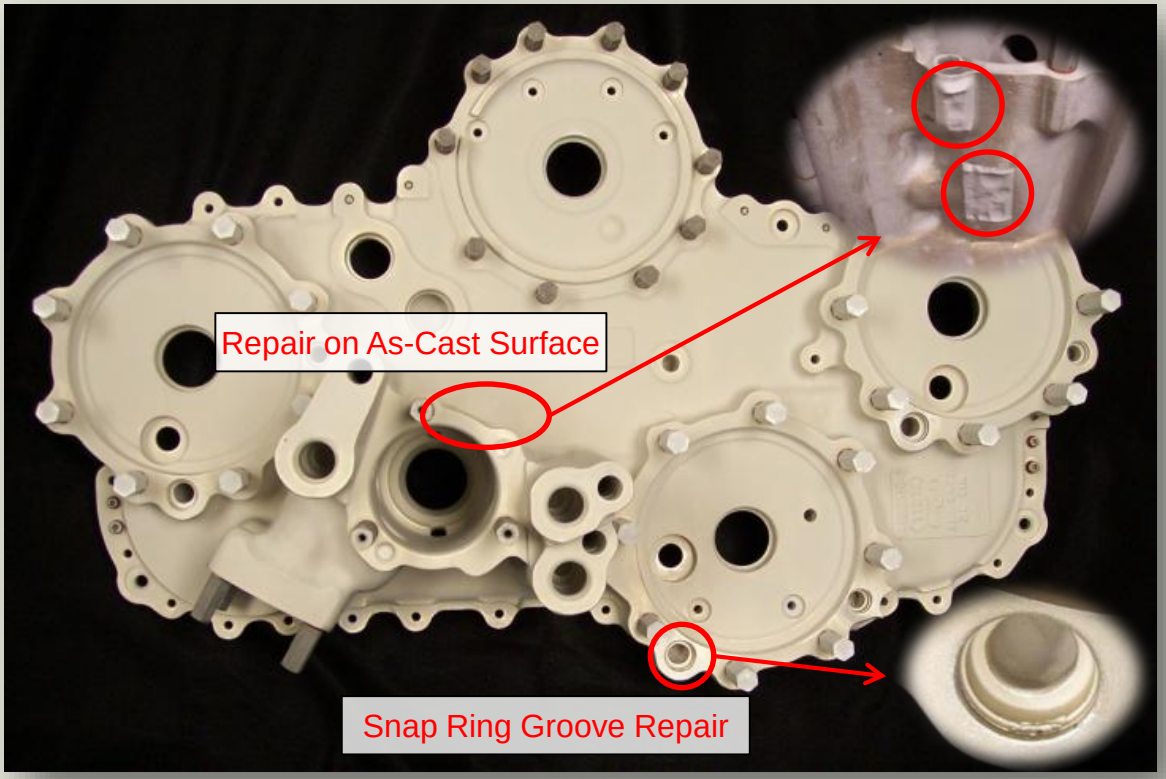
TBH protected by TAGNITE

TBH Finished w/Rockhard

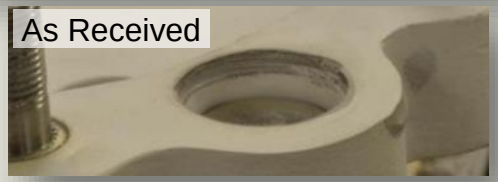
Cold Spray Repair Demonstrated
H-47 Rotorcraft Accessory Cover



Cold Spray Repair Demonstrated H-47 Rotorcraft Accessory Cover

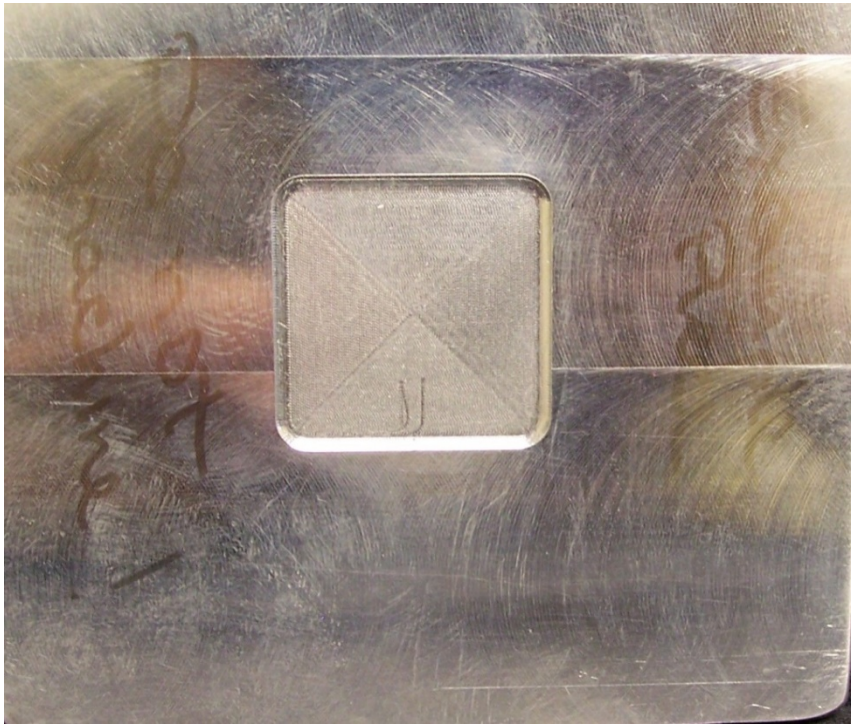


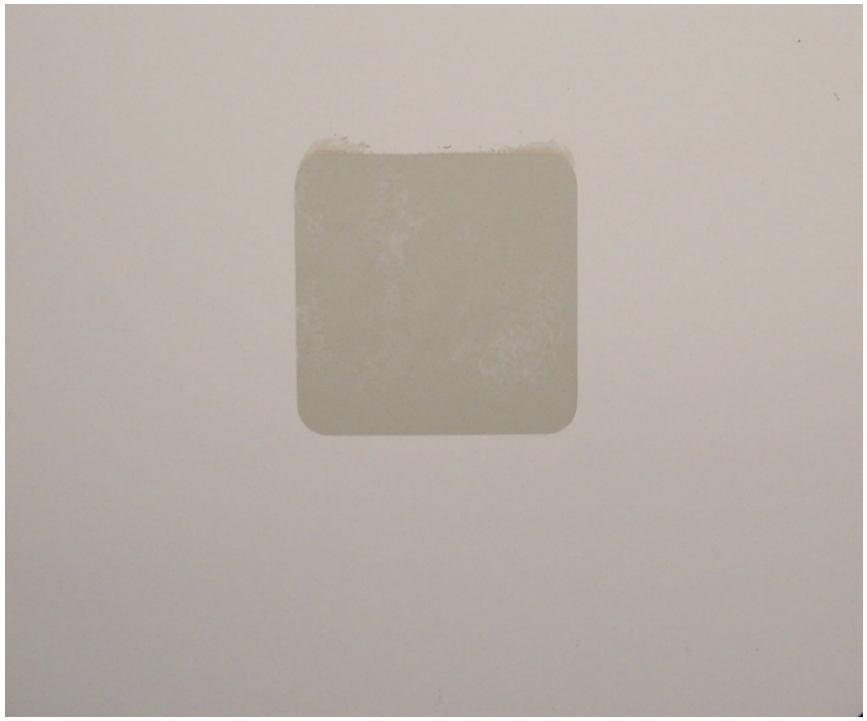
Cold Spray deposited on two areas of the as-cast surface and one (1) snap ring groove.



Combining Tagnite with Cold Spray

All Testing was Conducted over Magnesium Alloy ZE41A. Test Plate Shown Below Before Application of Cold Spray and After Application of Cold Spray, Post Machining and Tagnite





Combining Tagnite with Cold Spray

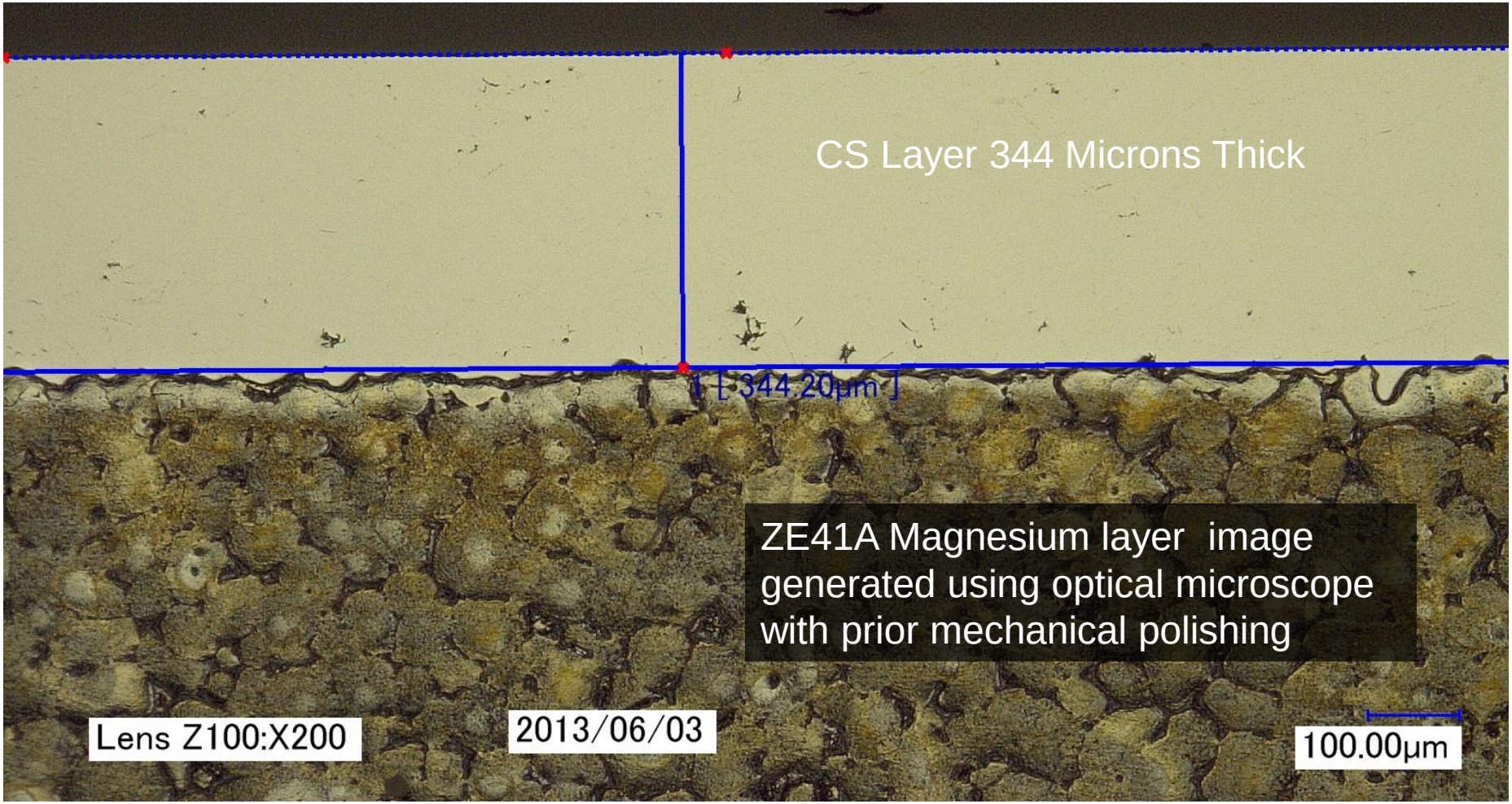
All Surface Roughness Figures Shown are Measured in Micro Inches Ra(μ")

Surface Measured	Prior to Tagnite Pretreatment	After Tagnite Pretreatment	After Tagnite
Al/Al Oxide Cold Spray	8 Ra(μ")	31.3 Ra(μ")	45 Ra(μ")
6061 Cold Spray	15 Ra(μ")	79 Ra(μ")	58 Ra(μ")
ZE41A Magnesium Surface-1	14 Ra(μ")	20 Ra(μ")	22 Ra(μ")
ZE41A Magnesium Surface-2	8.5 Ra(μ")	12 Ra(μ")	21 Ra(μ")

Tagnite Thickness Average 0.35 Mil

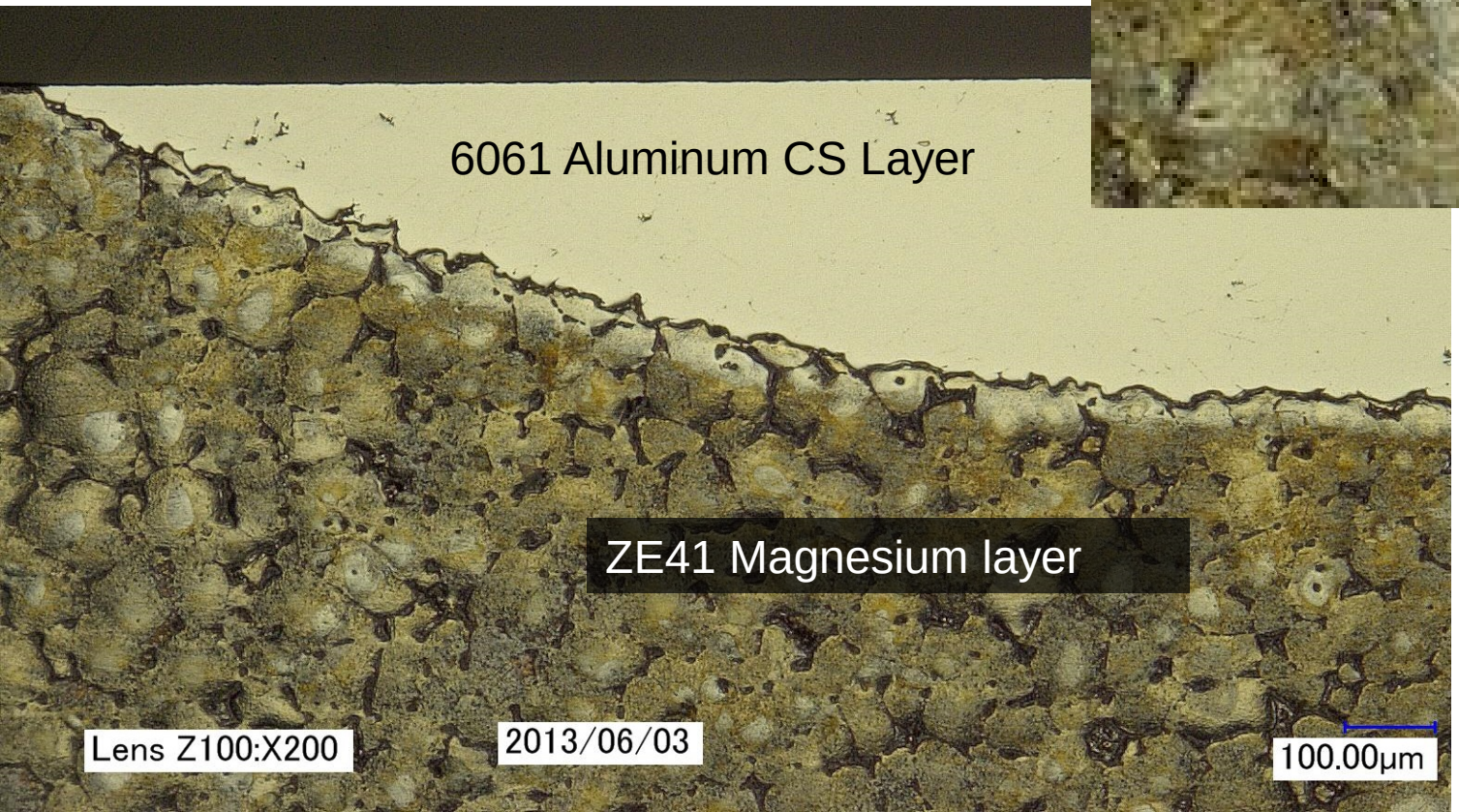
Combining Tagnite with Cold Spray

6061 CS After Post Machine, and Prior to Tagnite



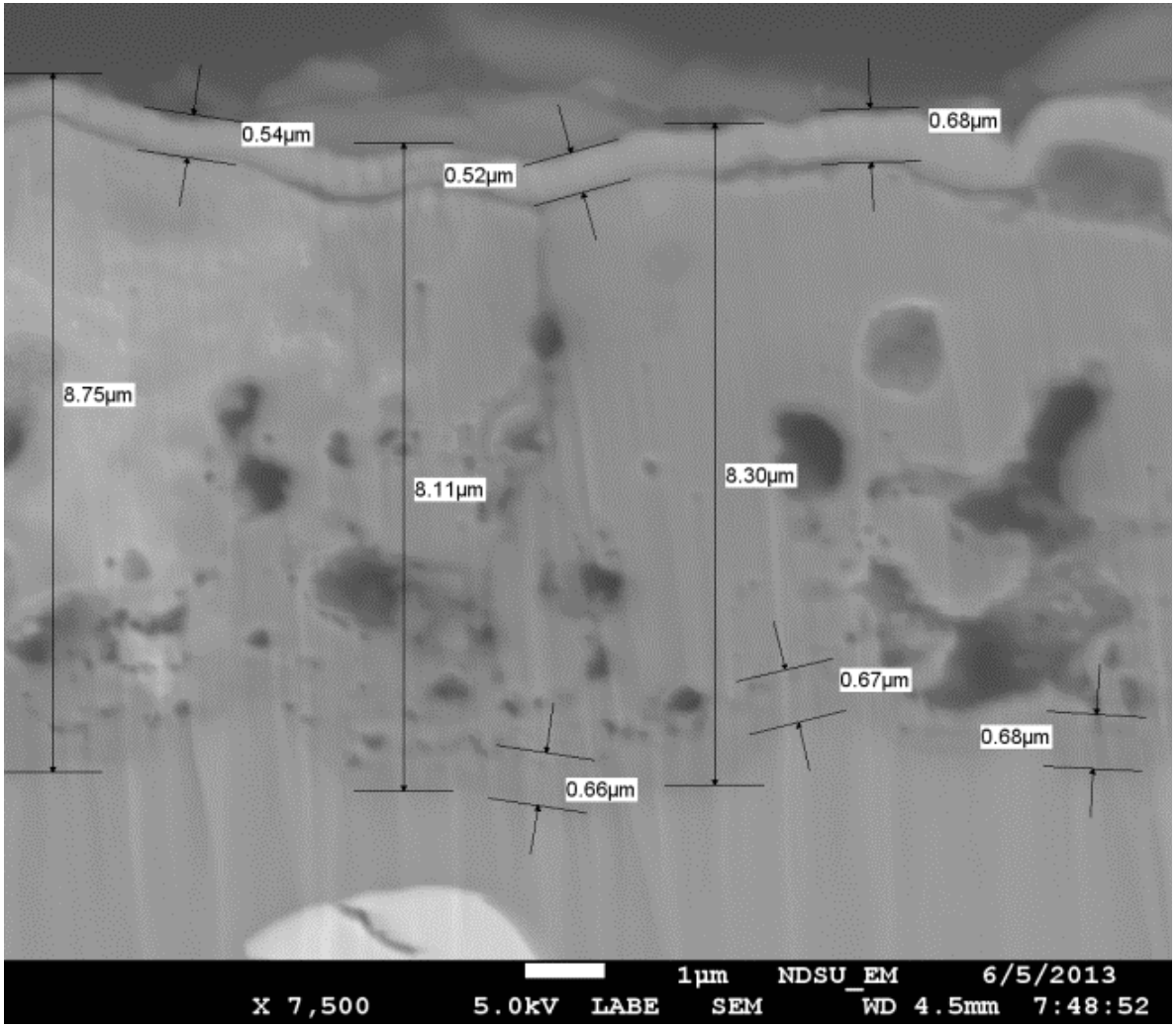
Combining Tagnite with Cold Spray

Images highlight transition point from 6061 CS to ZE41 Magnesium. Mechanical polishing uses liquids which to a degree etch the magnesium exposing grain boundaries.



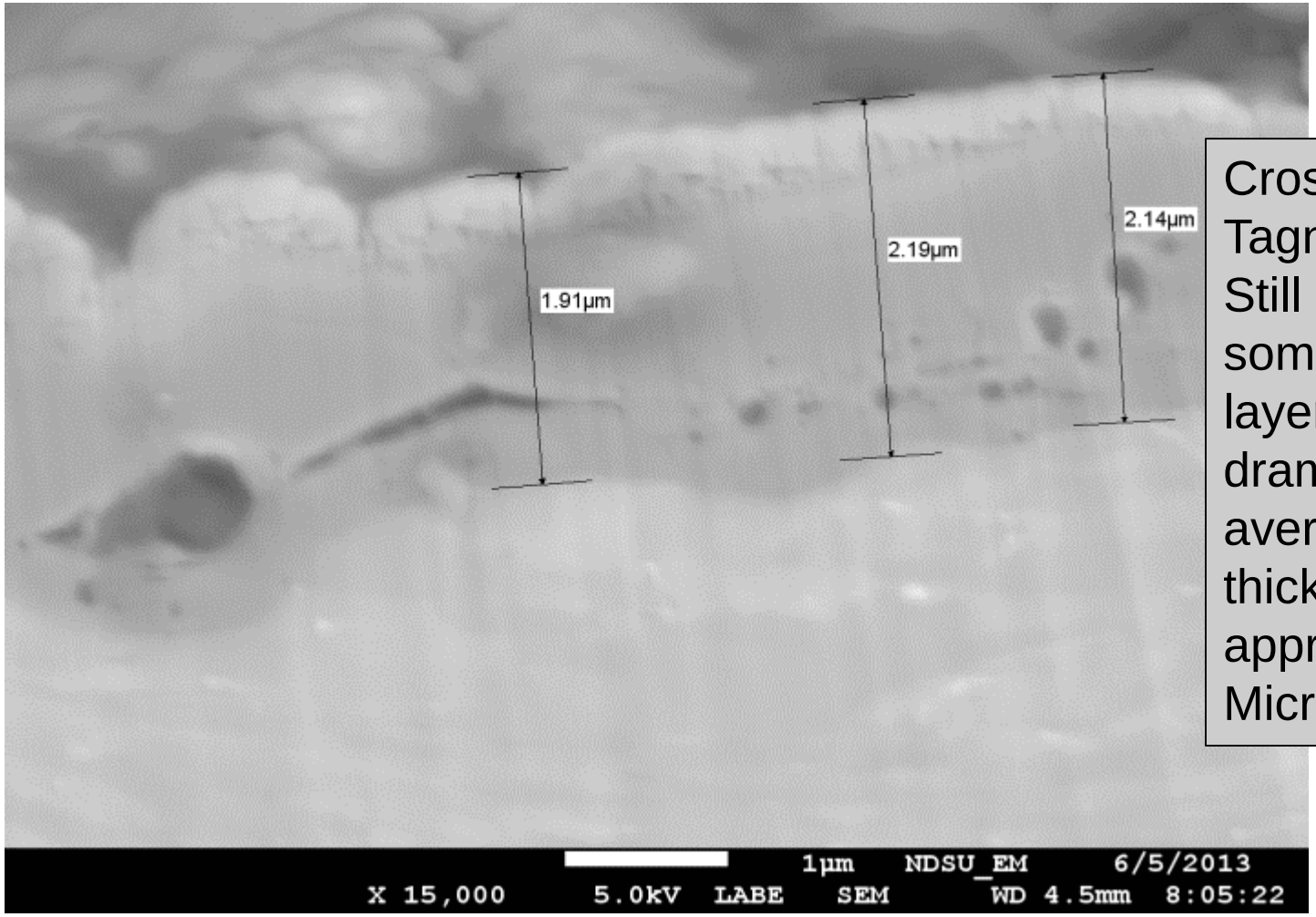
6061 CS After Post Machine, and Prior to Tagnite

Combining Tagnite with Cold Spray



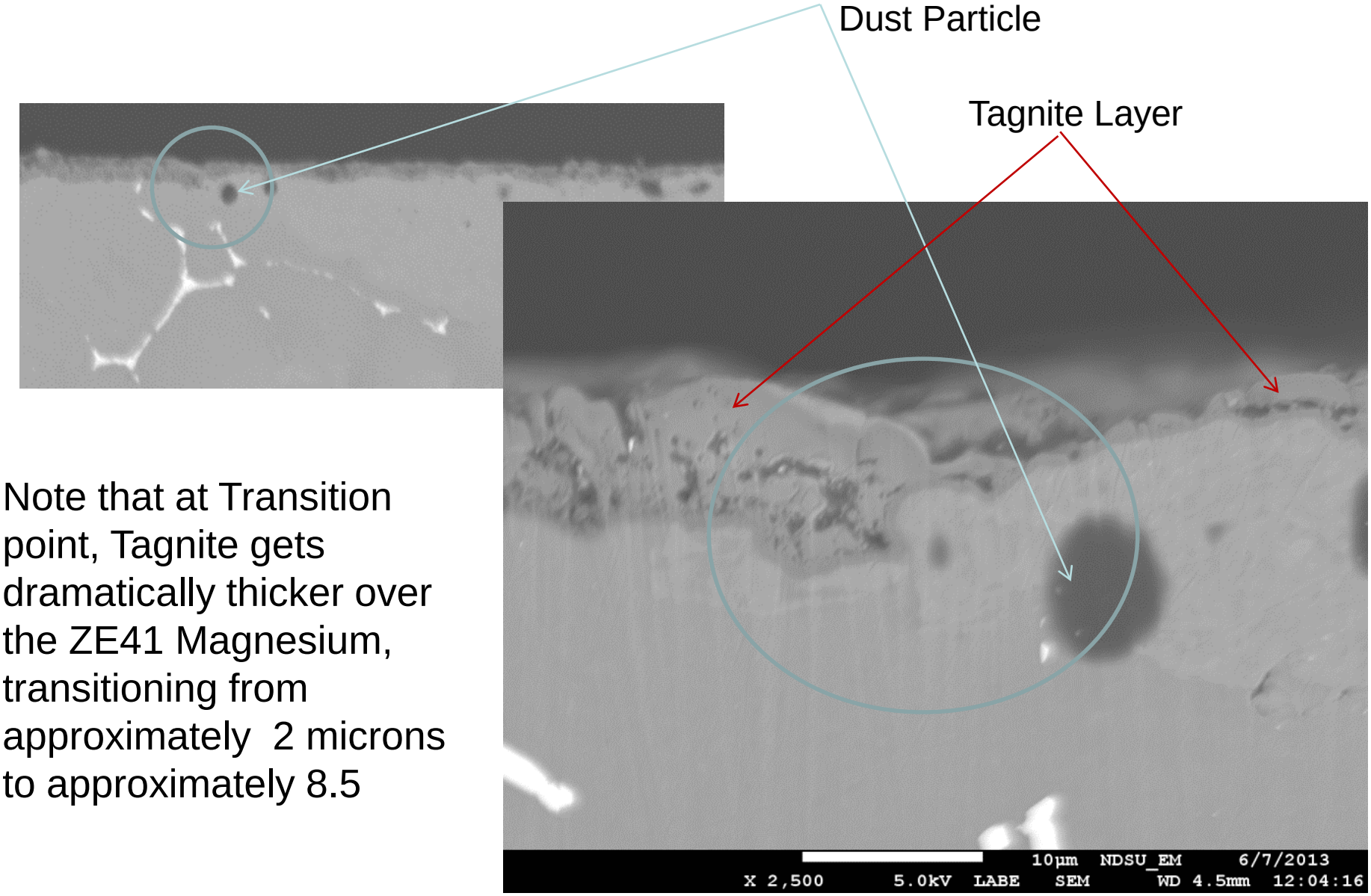
Cross Section of Tagnite Over ZE41, Showing 3 somewhat distinct layers and an average coating thickness of approximately 8.5 Microns

Combining Tagnite with Cold Spray



Cross Section of Tagnite over 6061 CS. Still showing 3 somewhat distinct layers, but a dramatically thinner average coating thickness of approximately 2 Microns

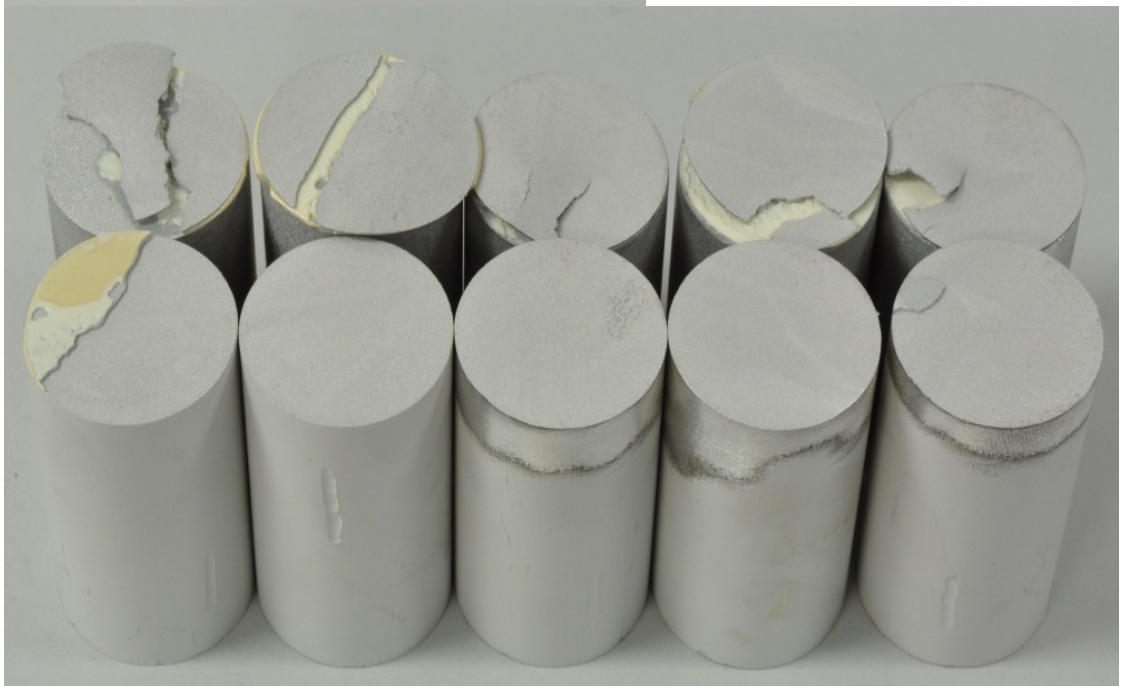
Combining Tagnite with Cold Spray



Note that at Transition point, Tagnite gets dramatically thicker over the ZE41 Magnesium, transitioning from approximately 2 microns to approximately 8.5

Combining Tagnite with Cold Spray

Baseline
Tagnite Over ZE41 Magnesium 11,950 PSI

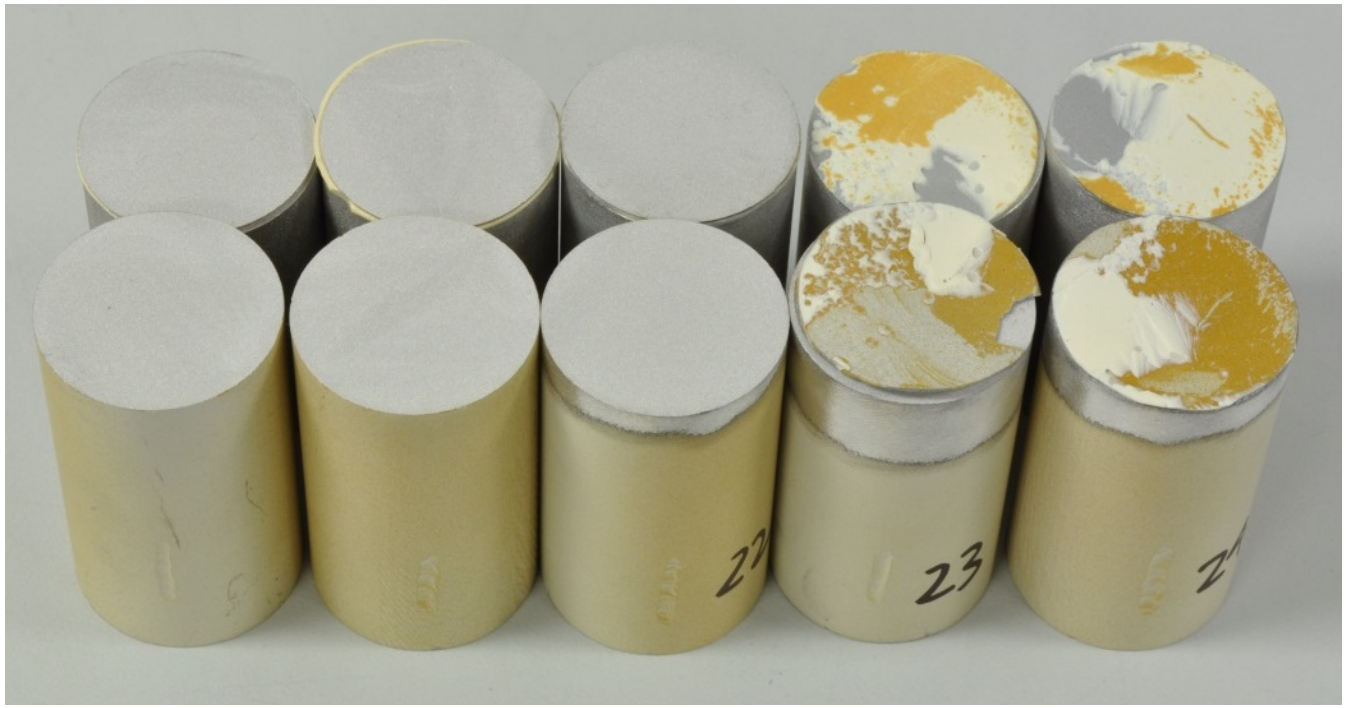


ZE41 – 6061 Cold Spray - Tagnite(after adhesion testing) Adhesion Strength: 11576 psi (4 sample). 1 sample (far left) removed from average due to glue failure.

Conclusion is very good adhesion of Tagnite anodize to 6061 Cold Spray over magnesium alloy ZE41A

Testing Conducted by MOOG

Combining Tagnite with Cold Spray



Adhesion Strength:
9,902 psi (4 sample)

Conclusion is very good adhesion of Rockhard over Tagnite anodize to 6061 CS over magnesium alloy ZE41A

Failure appears to be cold spray coming off of in 3 of 5 samples, 1 sample appears to have Rockhard adhesion failure and sample five was removed from determining average due to glue failure.

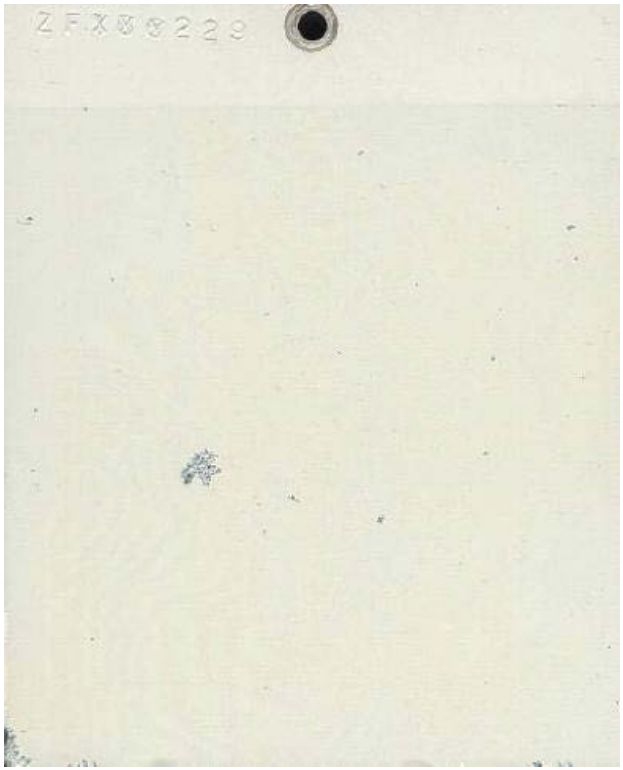
Testing Conducted by MOOG

Combining Tagnite with Cold Spray

Traditional Adhesion Test After Warm Water Immersion for 96 hours at 49^{0}C Per ASTM D870 (water immersion) and ASTM D 3359 method B

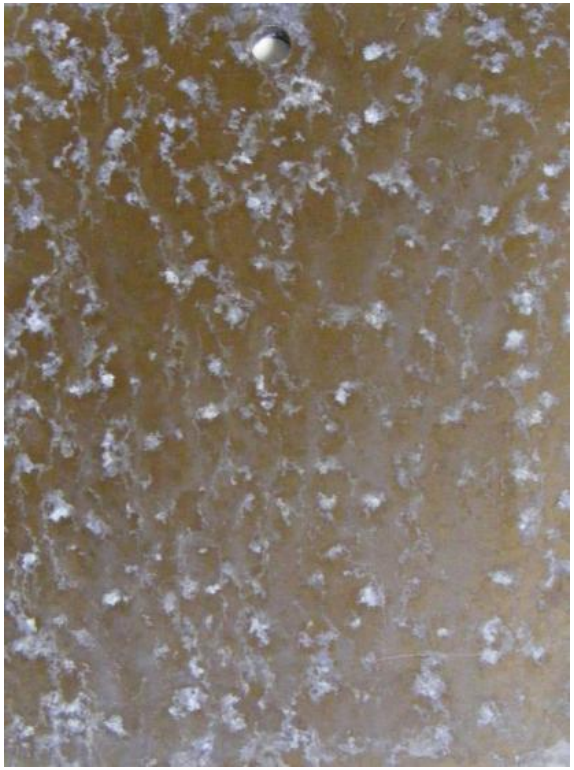
Rockhard to Tagnite over aluminum Cold Spray is Excellent

Combining Tagnite with Cold Spray



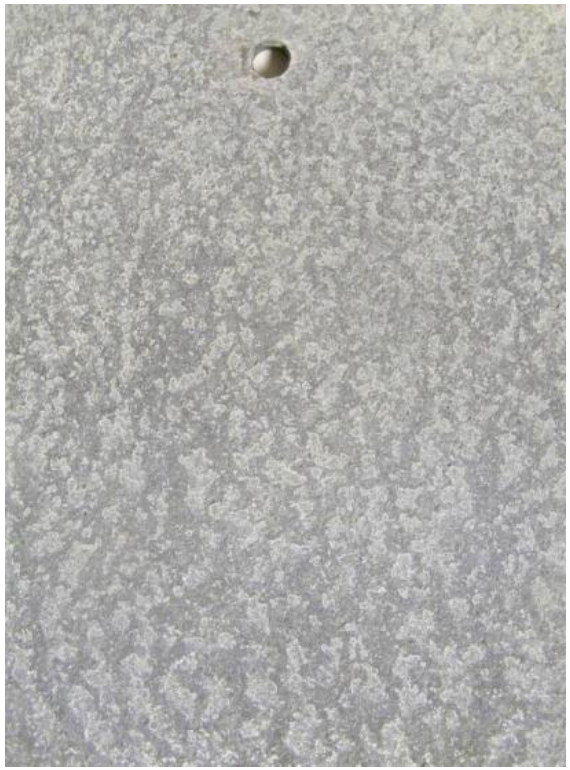
Tagnite ZE41A 168 Hours

Salt Spray Exposure



Dow 7 ZE41A 9 Hours

Salt Spray Exposure



Dow 7 ZE41A 9 Hours

Salt Spray Exposure

Combining Tagnite with Cold Spray

- Cold Spray is a very effective means to repair expensive magnesium castings used in the aerospace industry
- The Tagnite anodize coating is compatible with 6061 cold spray
- The adhesion of Rockhard resin seal applied to Tagnite which is over cold spray aluminum is excellent
- Cold spray repaired magnesium castings have been Tagnite coated and placed back into service.

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