Qualification of the UH-60 Main Gearbox Sump – Progress to Date

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Outline

- Introduction
  - H-60 Transmission System
  - Design Requirements
  - Materials Requirements / Performance
- Process Qualification Test Matrix and Results
  - Adhesion
  - Corrosion
  - Fatigue
- Full Scale First Article
- Next Steps

UH-60 Transmission System

Design Requirements

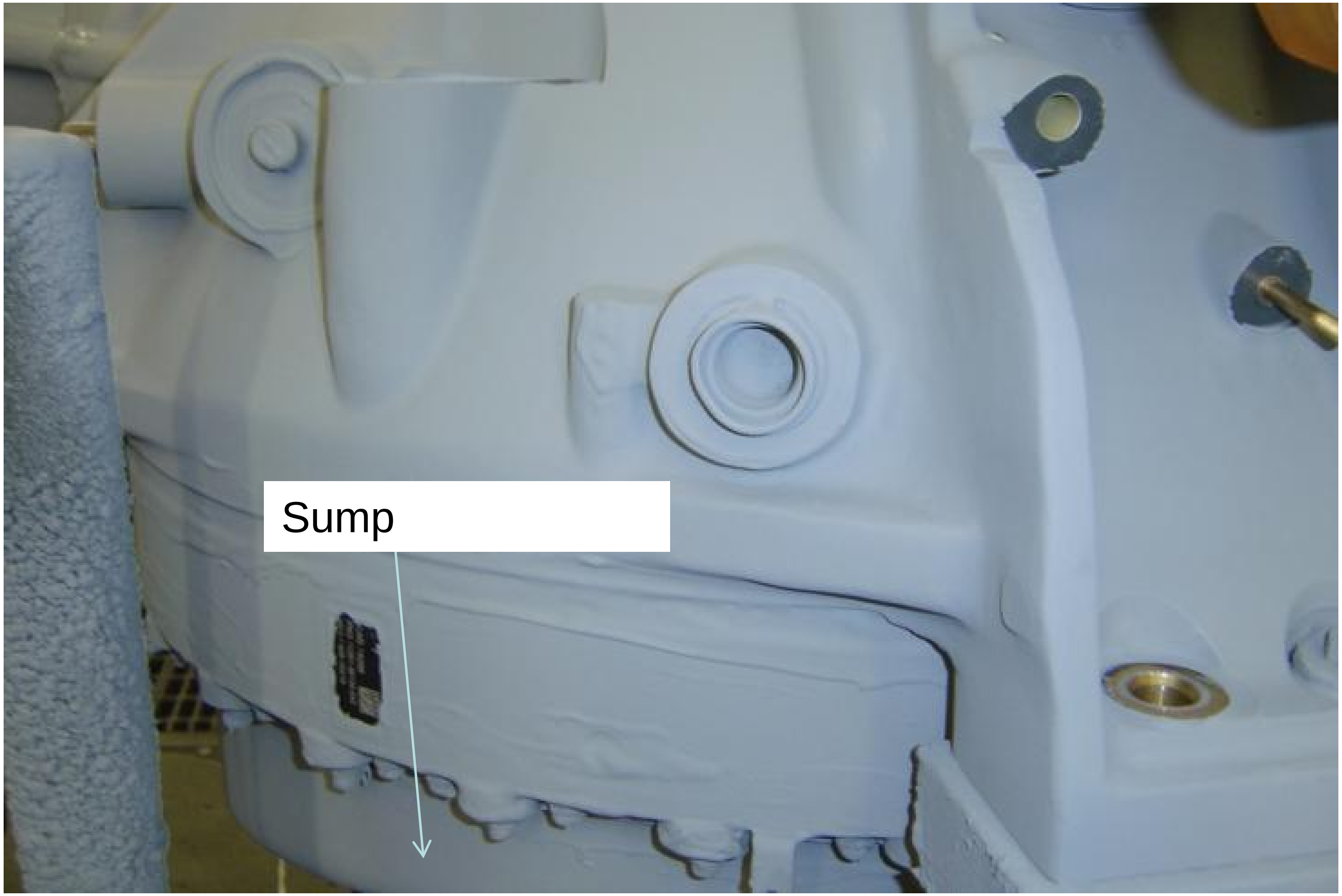
- Complex geometries, thin/thick walls, integral oil passages
- High bending stiffness to weight ratio
- Static/Impact loading
- Fatigue loading
  - Main Rotor Loads
  - Airframe loads
  - Flight control system loads

M&P Requirements

- Availability from multiple foundries
- Capable manufacturing track record
- Castings with reproducible material quality and superior mechanical properties
- Corrosion performance

  (magnesium is prone to galvanic corrosion)
- Sustainable during service, overhaul and repair operations

UH-60 Main Gearbox Sump



Corrosion of Main Gearbox Sump

Comparison of HVOF vs Cold Spray

- Advantages over current HVOF repair of magnesium
  – No preheat of part
  – No post sealing of coating
- Limitations of HVOF
  – No exterior application
  – No feathering of coating
  – No coating of split lines
  – No bearing/shear loads
  – No recovery of strength from coating

Process Qualification Test Plan

- Process Parameters Optimization – ARL
- Coupon Testing
  - Metallurgical Evaluation
  - Adhesion
  - Corrosion
  - Fatigue
- Full Scale First Article Qualification
  - Machining
  - NDI
  - Metallurgical Evaluation (coupon/full scale)
  - Impact to O&R process flow

Metallurgical Evaluation

CP Coating with CGT KINETIKS 4000

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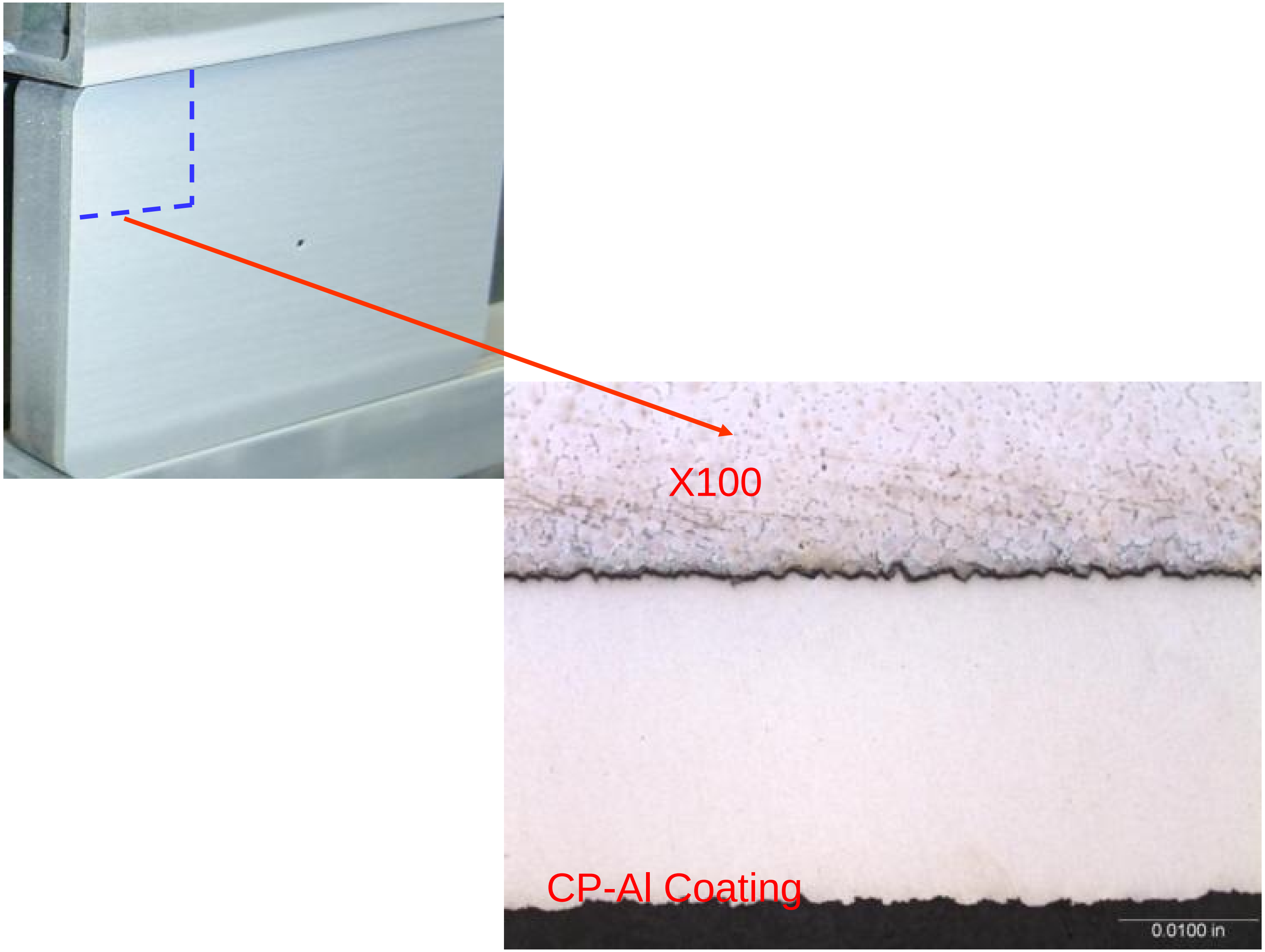
Microstructure of CP Al on ZE41A



Hardness of CP Al and ZE41A

Material	Data Points (HV100)	Average	Standard Deviation
CP-Al Coating as sprayed	67.4, 62.9,64.6,63.2,65.3,62.9,61.9,63.2	63.9	1.8
CP-Al coating exposed to an elevated temperature	65.3, 64.9, 64.9, 66, 66, 65.3, 64.6, 67.4	65.6	0.9
ZE41A substrate	78.1,76.3,79.5,76.8,70.8,78.1,72.5,70.5, 75.9,72.9,80,76.3,70.9,74.6,67,77.2,72	74.3	3.8

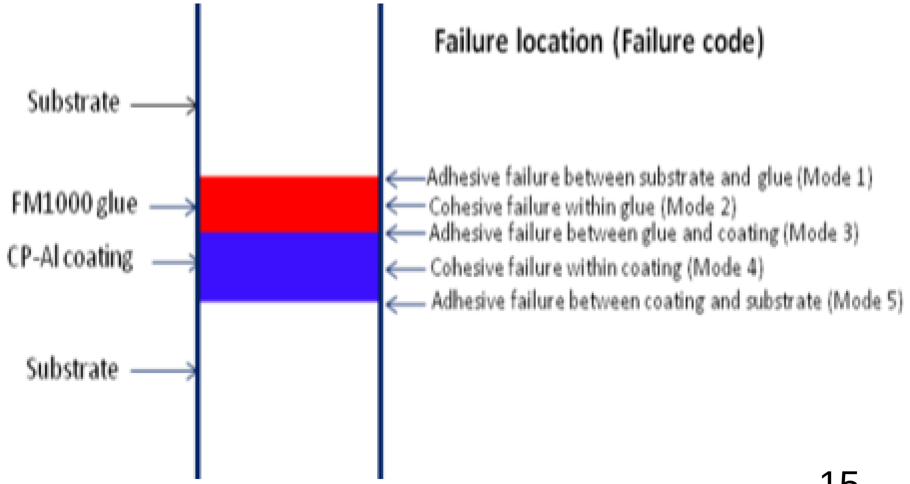
*The Vickers scale hardness from metallographic cross-section utilizing a load of 100g (HV100).

*Exposed to 385F for 6 hours, to simulate (3) cure cycles of Rockhard coating

Adhesion Testing

Adhesion Test Results

Specimen #	Diameter (in)	Max load(lbs)	Adhesion Strength (ksi)	Failure Mode
A1-B1	1	6908	8.8	Fixture thread failure. Coating intact
A2-B2	1	7299	10.1	Fixture thread failure. Coating intact
A3-B3	1	6288	8.01	Fixture thread failure. Coating intact
A4-B4	1	8293	10.56	Glue failure (85% mode 2+15% mode 1)
A5-B5	1	9306	11.85	Glue failure (75% mode 2+25% mode 1)
A6-B6	1	9118	11.61	Glue failure+ partially coating failure (30% mode 5+25% mode 1+45% mode 2)



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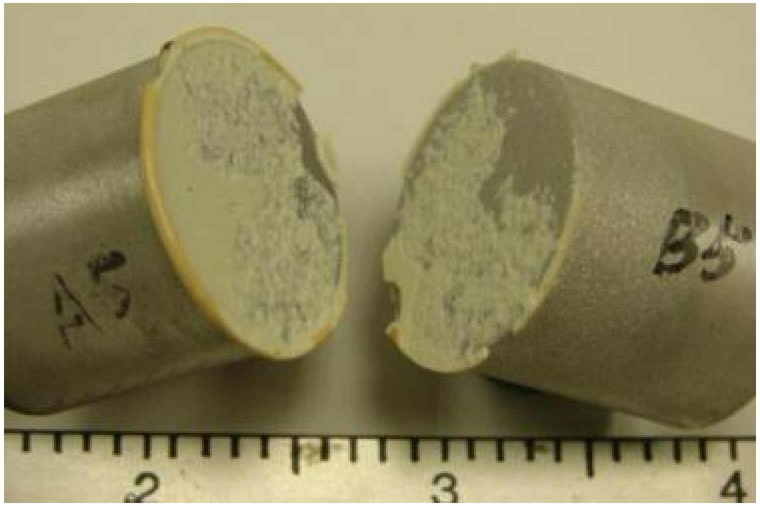
Fracture Surfaces of Adhesion Test Coupons



Corrosion Testing

Corrosion Testing Conditions

- Base Metal : ZE41A magnesium
- Cold Spay CP aluminum (no post sealer)
- Coating thickness 0.015 inch (as-sprayed)
- No scribe and scribed corrosion
- Scribe was made with CNC machine with a depth of 0.030 inch
- HVOF Al-12Si coating sealed with Metco AP sealer as a baseline
- ASTM B 117 salt fog test with scribed (500 hours) and unscribed conditions for 1000 hours

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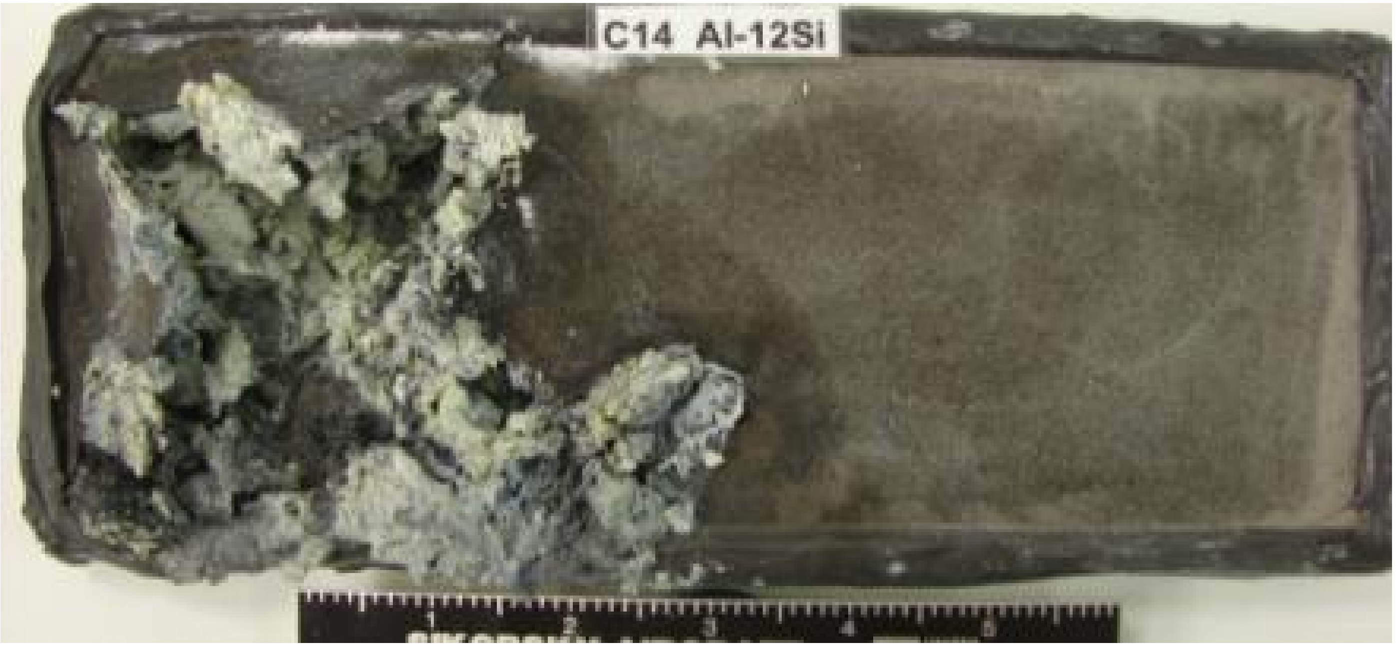
Coupons in ASTM B 117 Chamber

HVOF Al-12Si after 500hrs ASTM B 117



HVOF Al-12Si coating specimens at 500 hours. Coating cracking at 320 hours at C14 panel and peel-off at 365 hours

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CS CP Al After 500hrs ASTM B 117

Scribe Corrosion Damage Characterization

Coating	Panel ID	Corrosion Migration rating per ASTM D1654*	Maximum Corrosion Damage Depth (inch)	The Percentage of Original Scribe Lines Corroded	Weight Loss after 500 Hours (g)***
HVOF Al-12Si	C13	1	0.57	100%	27.13
	C14	0	0.42	100%	30.12
	C16	2	0.36	100%	**
Cold Spray CP-Al	C18	5	0.31	27%	**
	C21	6	0.27	35%	2.38
	C22	6	0.3	31%	3.45

*Rating 10 is the best and rating 0 is the worst.

** No data available due to the sealant breakage and repair on the edge f panels at 261 hours.

*** The weight of the original coated panel is about 590g.

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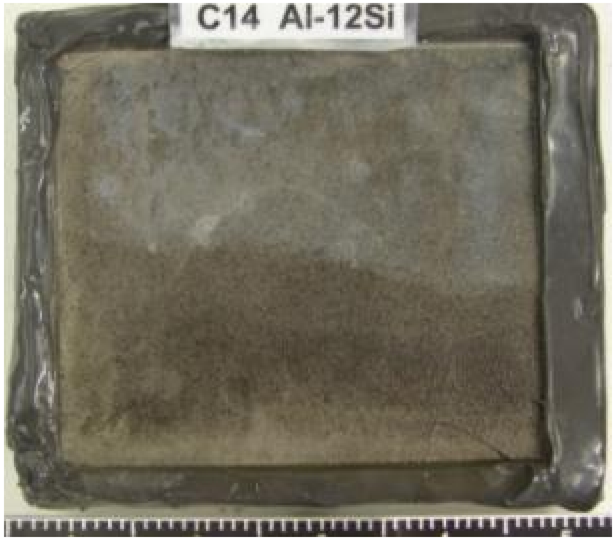
HVOF Al-12Si after 1000hrs ASTM B 117



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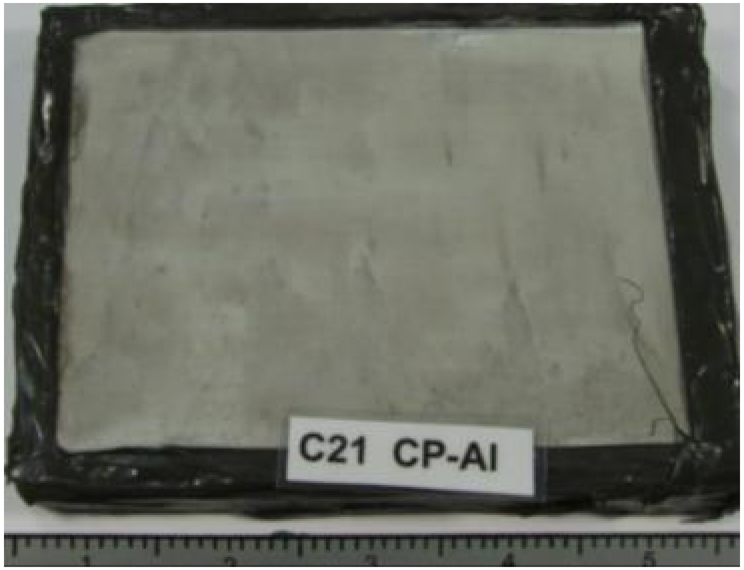
CS CP Al After 1000hrs ASTM B 117



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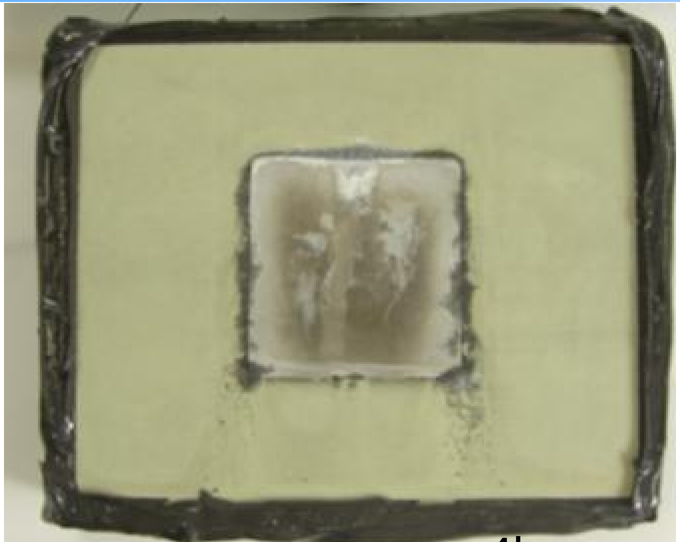
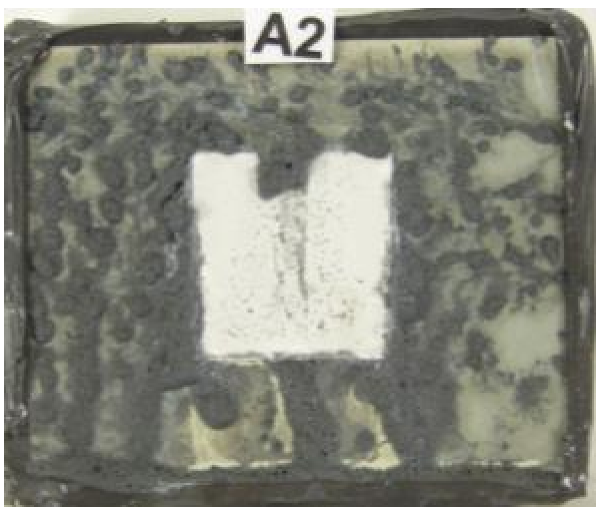
CS CP Al Corrosion at Coating Runout

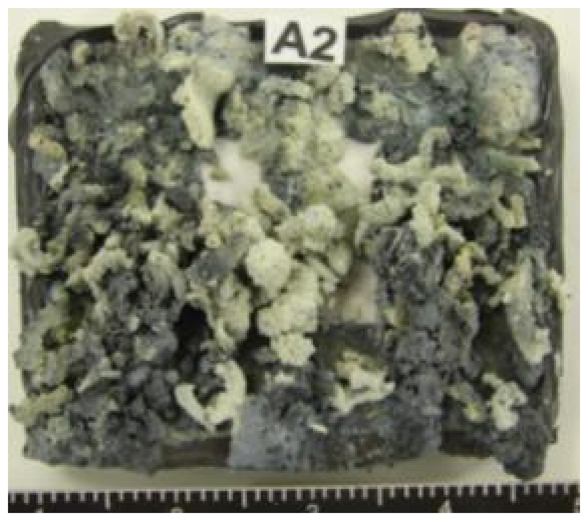


4hrs

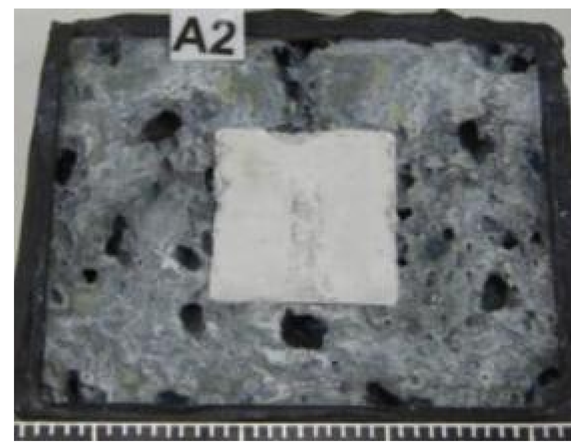
55hrs



125hrs



500hrs



500hrs,cleaned

Corrosion of Typical Fastener (300hrs)

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Achieving Corrosion Protection

- Sacrificial (hex. Chromium etc.) not effective
- Compatible couples (HP Al, CP Al, 5056, 6061)
- Sacrificial pigment/coating
- Barrier coatings
  - Thick coatings
  - Dense coatings
  - Coat radii
  - Runout of coating away from galvanic couple and moisture traps

Fatigue Testing

Coupons and Test Parameters

Diameter 0.375 inch
Kt= 1.0
Coat entire reduced section
Coating thickness 0.015-0.020 inch (0.030-0.040 inch on diameter)
R ratio: 0.1 (axial) tension/tension
Surface condition prior to coating: polished, changed to grit blast during coating.
Surface condition of coating: as-coated vs machined

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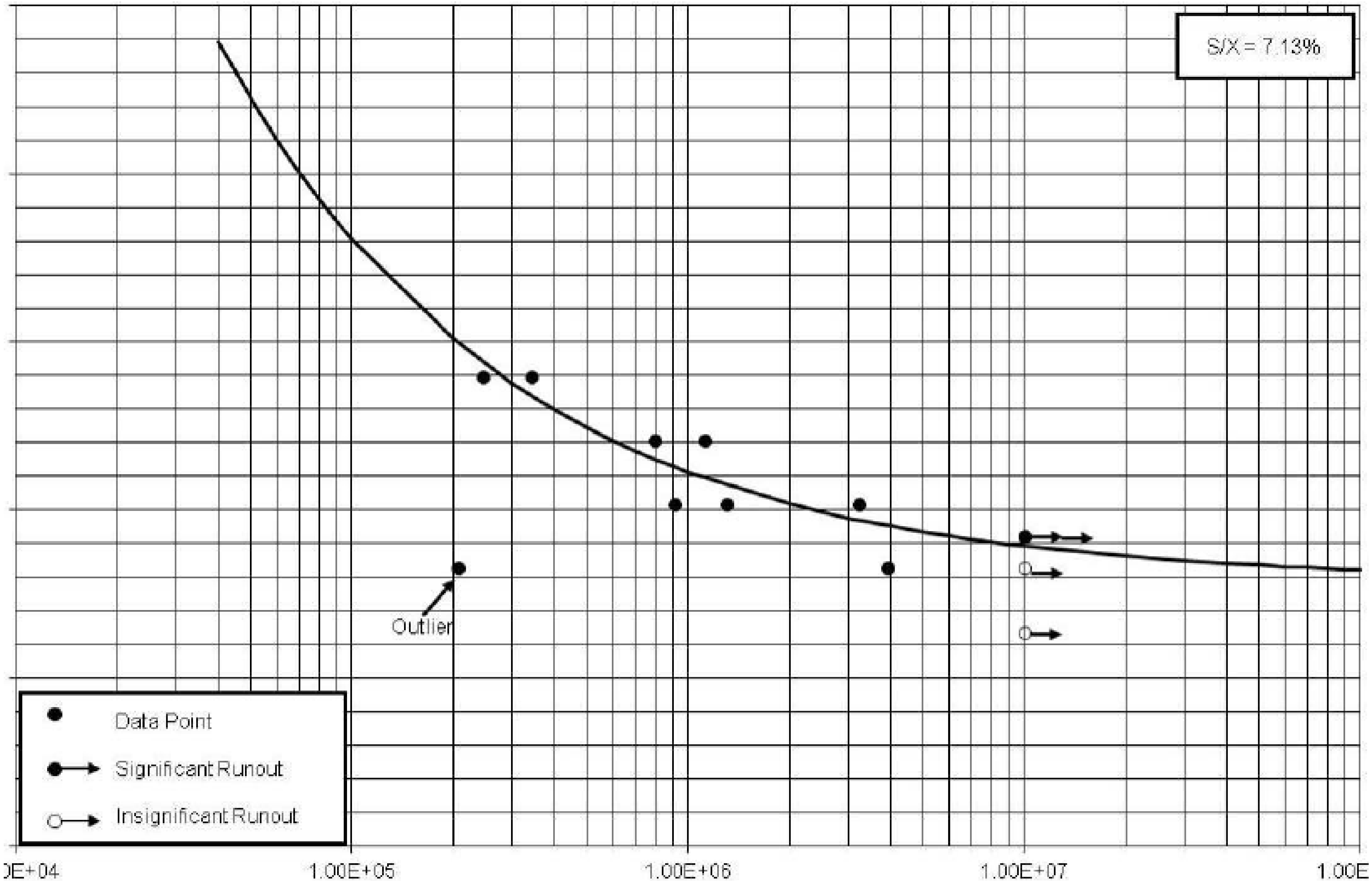
Fatigue Data for CS CP Al



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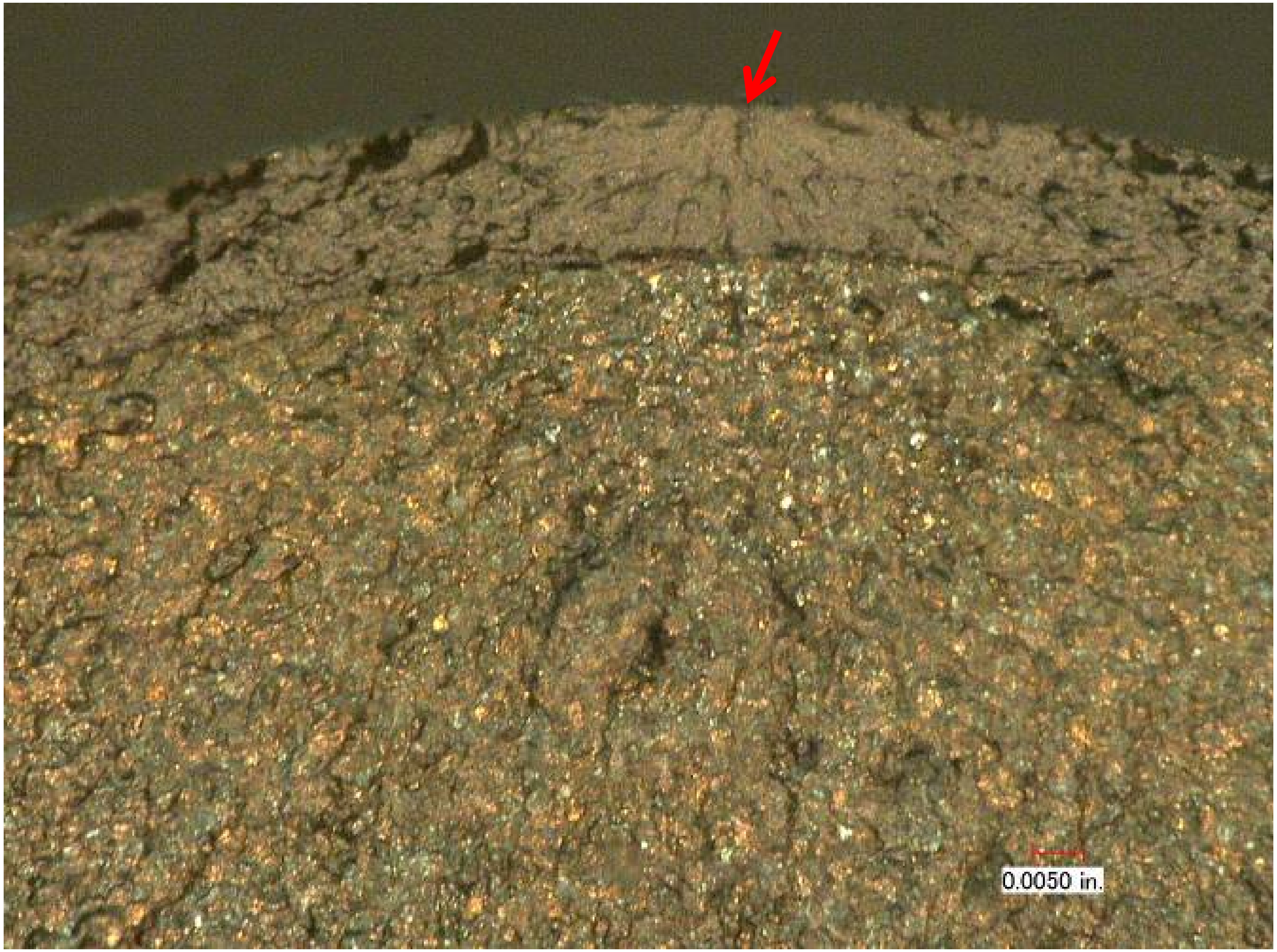
Fracture Surface of Fatigue Specimen



Effect of Modulus Mismatch on Stress

Applied stress on *as-sprayed specimens (ksi*)	Stress on CP-Al coating (ksi)	Stress on Magnesium Substrate (ksi)
14 ksi	18.4 ksi	13.3 ksi
15 ksi	19.7ksi	14.2 ksi
16 ksi	21.0ksi	15.2 ksi
18 ksi	23.6ksi	17.1 ksi
20 ksi	26.2ksi	19.0 ksi

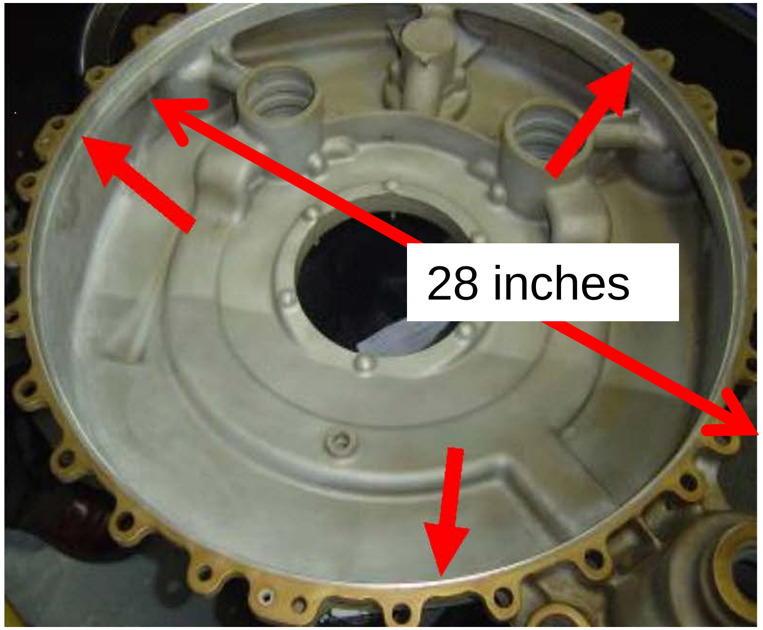
*The stress is calculated based on the modulus of elasticity mismatch. ($E_{CP\text{-}Al}=9x10^6$ psi $E_{Mg}=\sim 6.5x10^6$ psi)

Fatigue Testing Conclusions

- Cold spray CP aluminum, under conditions tested herein, does not degrade fatigue strength of ZE41A magnesium. Fatigue strength of coating is similar to fatigue strength of magnesium ZE41A substrate.
- Fatigue strength equivalent to current HVOF Aluminum-Silicon coating

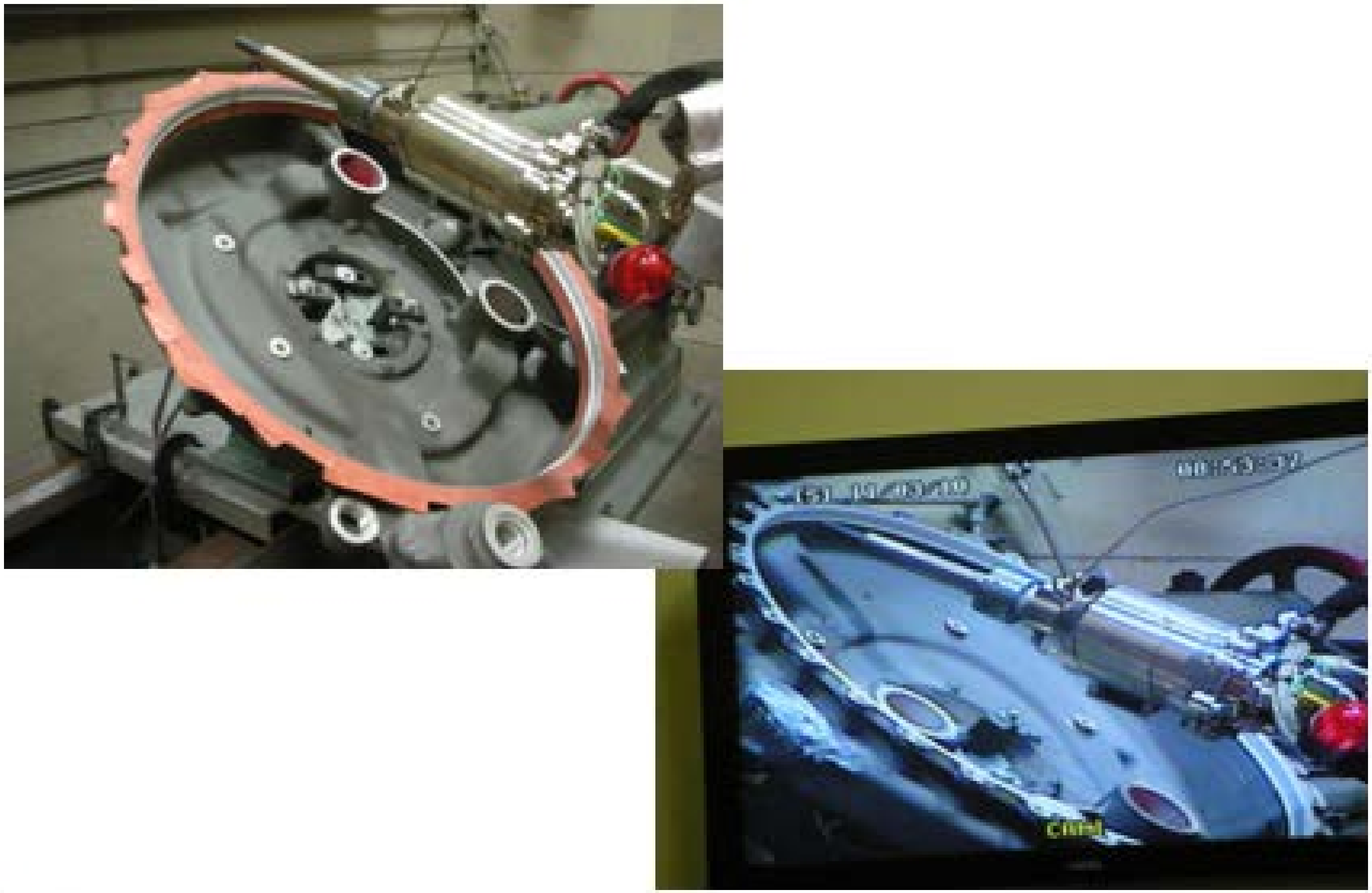
Full Scale First Article

Cold Spray of H-60 MGB Sump



Cold Spray of UH-60 MGB Sump at ARL

Cold Spray of UH-60 MGB Sump at ASB



Evaluation of Cold Spray Sump

- Visual examination showed a uniform coating with no cracking, pitting or chipping
- Metallurgical evaluation showed same coating microstructure and bond line integrity as test coupons (ARL sump)

Machining of CS CP Al MGB Sump

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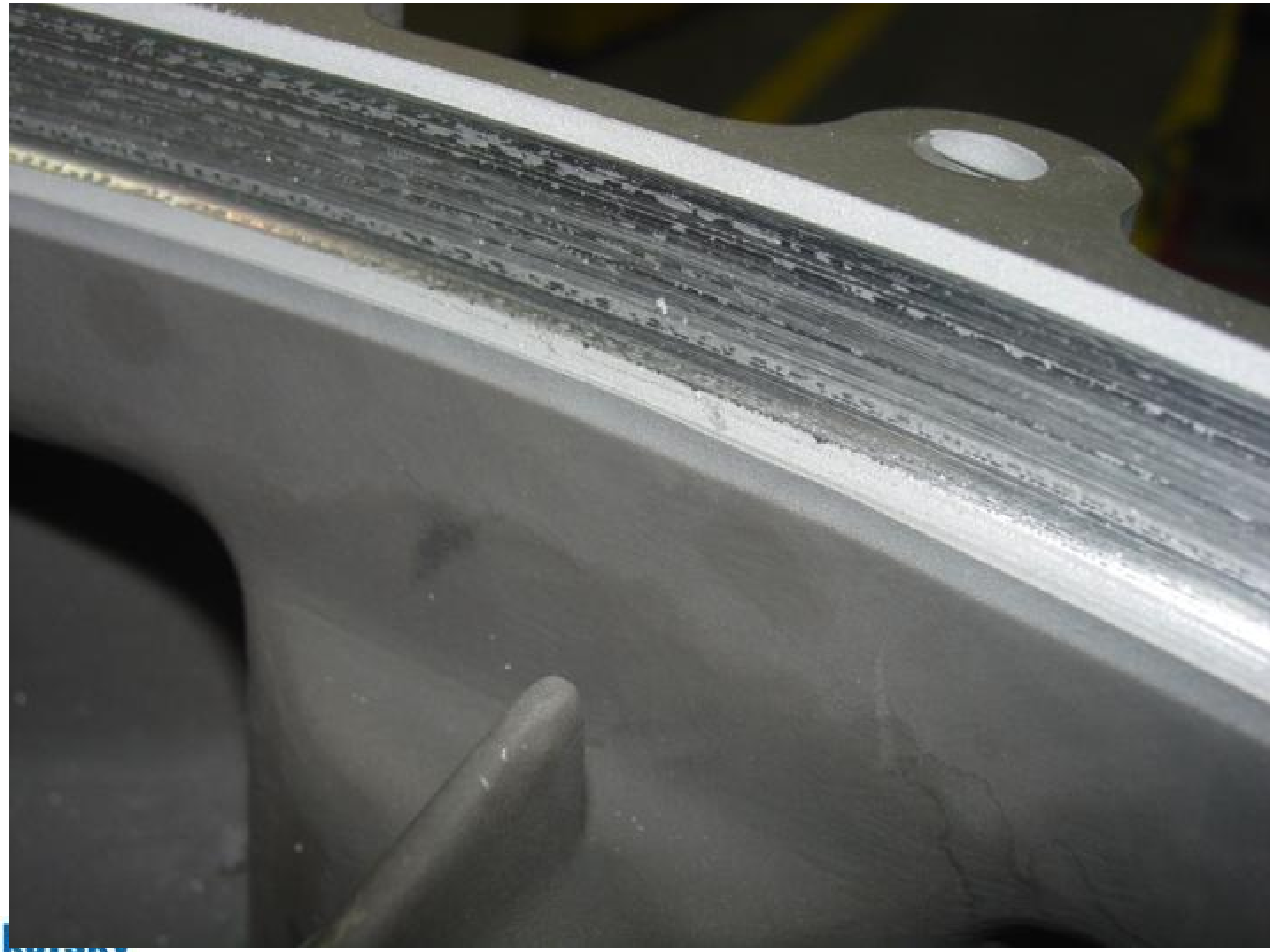
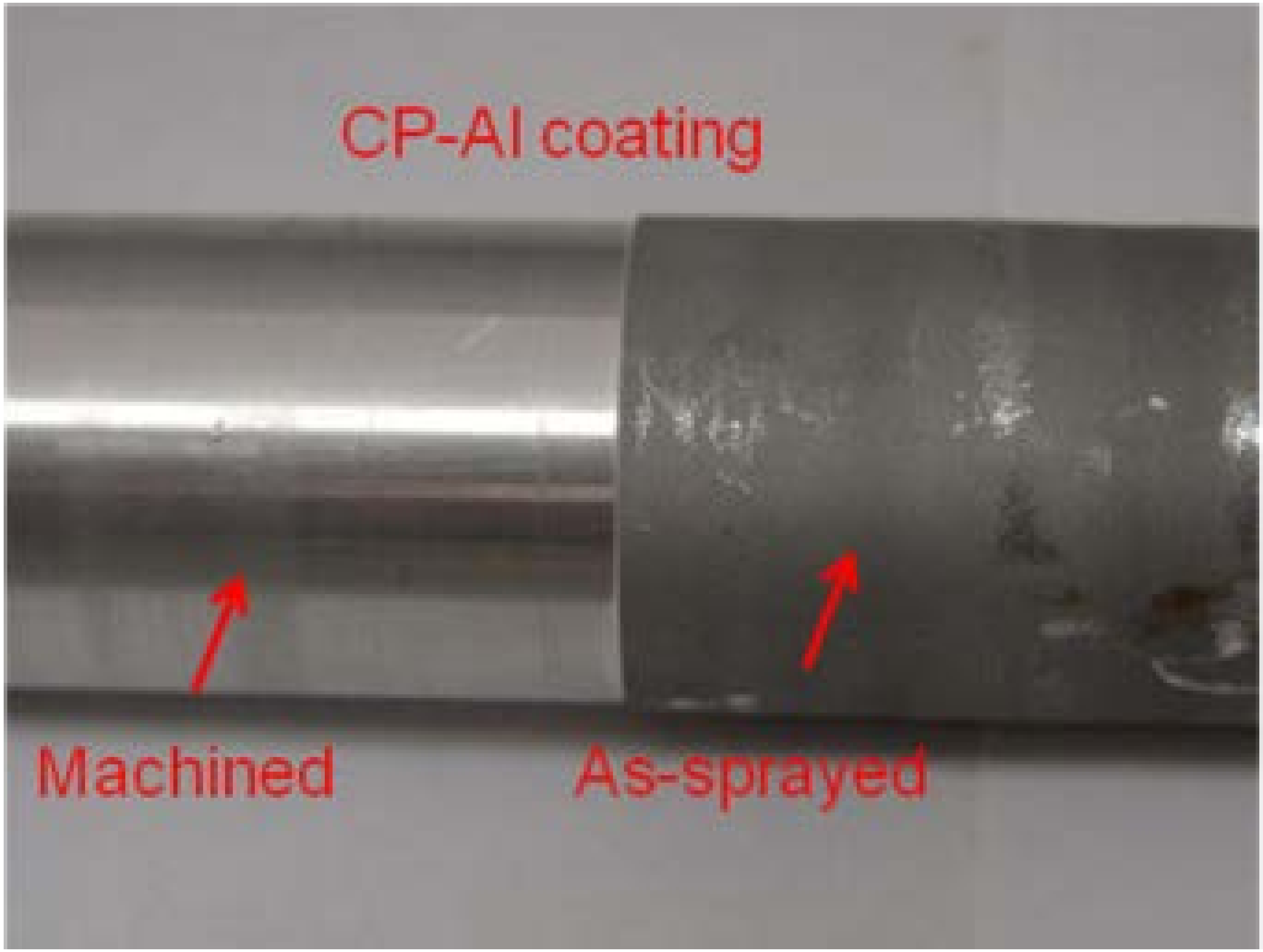
Machined Surface of CS CP Al



Machining of CS CP Al on Rod



Machining of Cold Spray CP Al at O&R

- Witnessed no peeling, flaking or chipping during machining
- Not a drop in for current HVOF coating
- Machining parameters optimization in progress

Next Steps

- Finish full scale first article qualification
- Submit data and secure process approval from DoD customers
- Pursue Cold Spray suppliers to be added to Sikorsky Qualified Suppliers List
- Gain production/run time experience with H-60 sump.
- Continue with structural applications

Future actions

- Advanced design analysis tools will be needed to validate structural applications
- Structural load analysis needs tie-in to metallurgical structural variables by advanced modeling
- Address impact on current NDI methods

Acknowledgements

- Victor Champagne and ARL Cold Spray team
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Questions?