

Application of Cold Spray Technology in Aviation Industry

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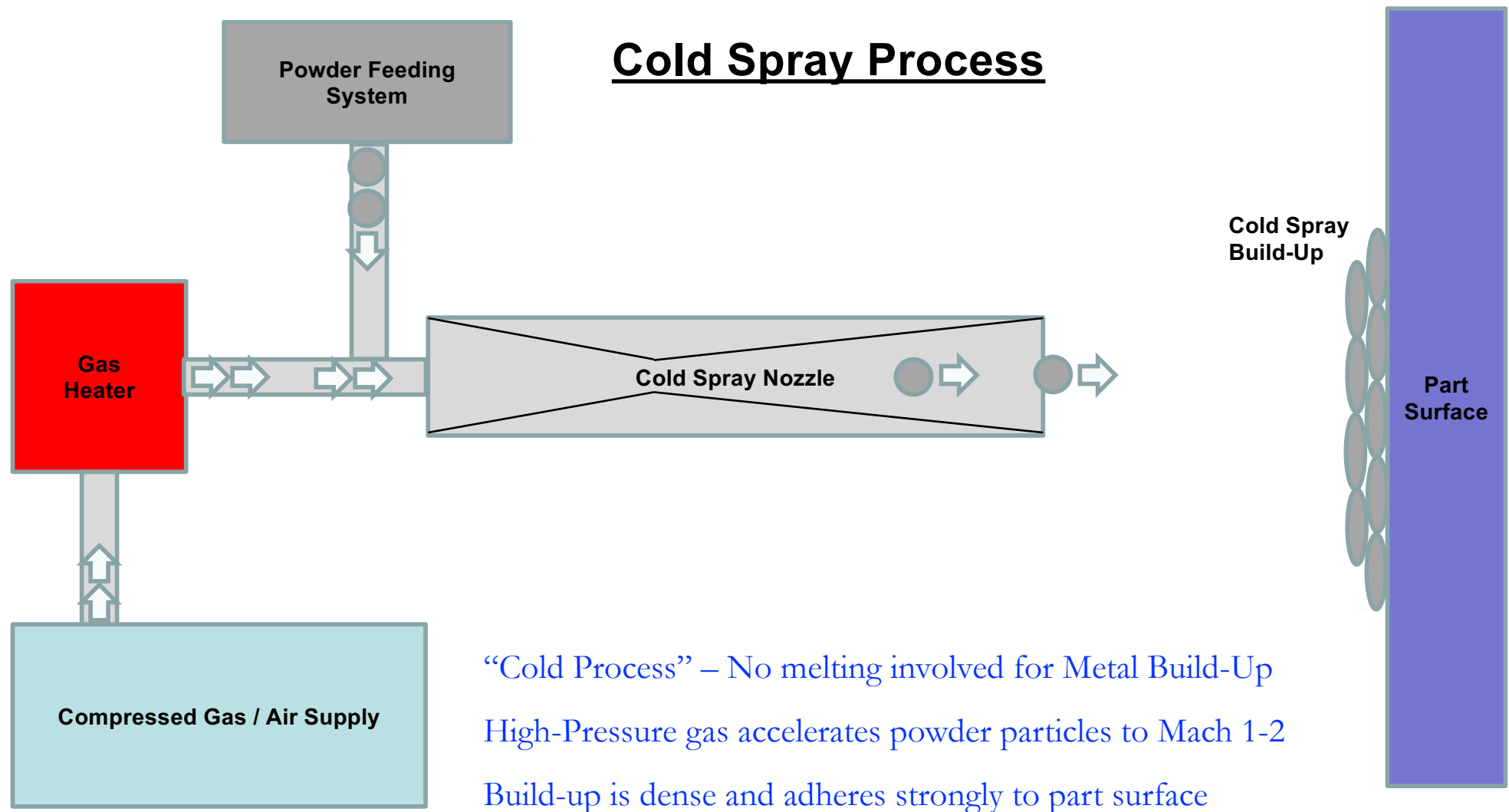
ECK Pte Ltd



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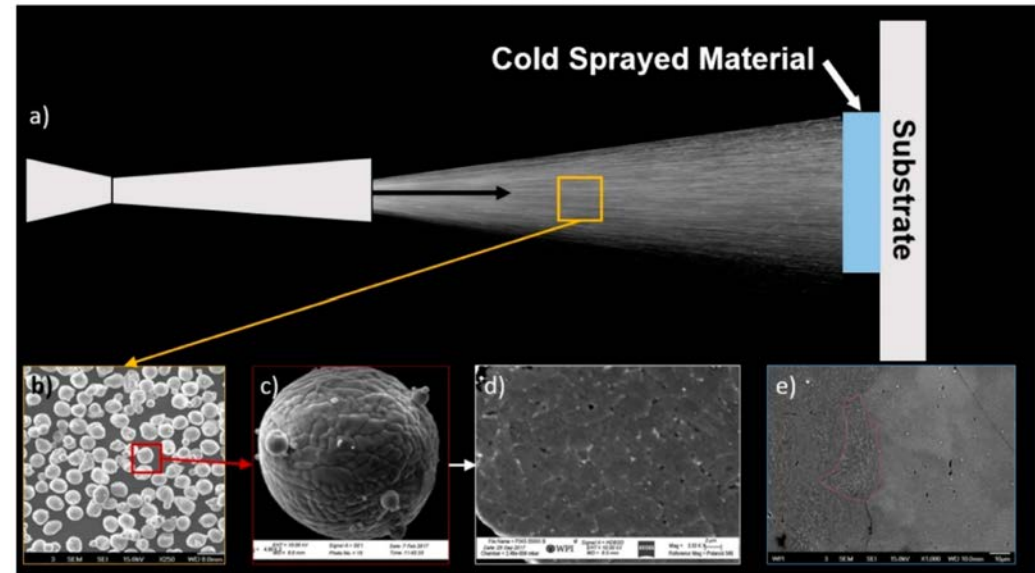




Cold Spray

Materials that can be cold-sprayed:

1. Aluminium & Alloys
2. Steel & Alloys
3. Nickel & Alloys
4. Titanium & Alloys
5. Copper & Alloys
6. Tin
7. Zinc

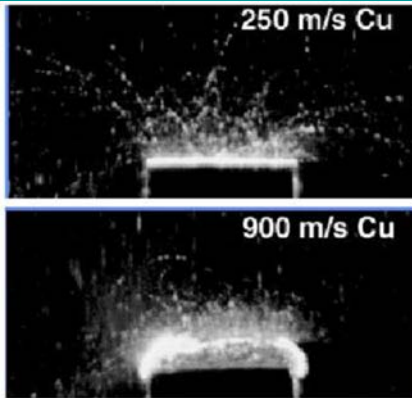


<https://www.mdpi.com/2075-4701/10/9/1195>

** ECK also provides consultancy & process development for materials outside of this list.*



What is Cold Spray?



Particle velocity (V_p) < critical velocity (V_c) solid particle erosion of surface

Particle velocity (V_p) > critical velocity (V_c) particles plastically deform and adhere to the substrate

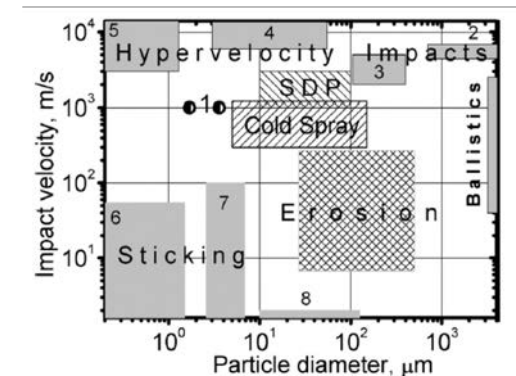
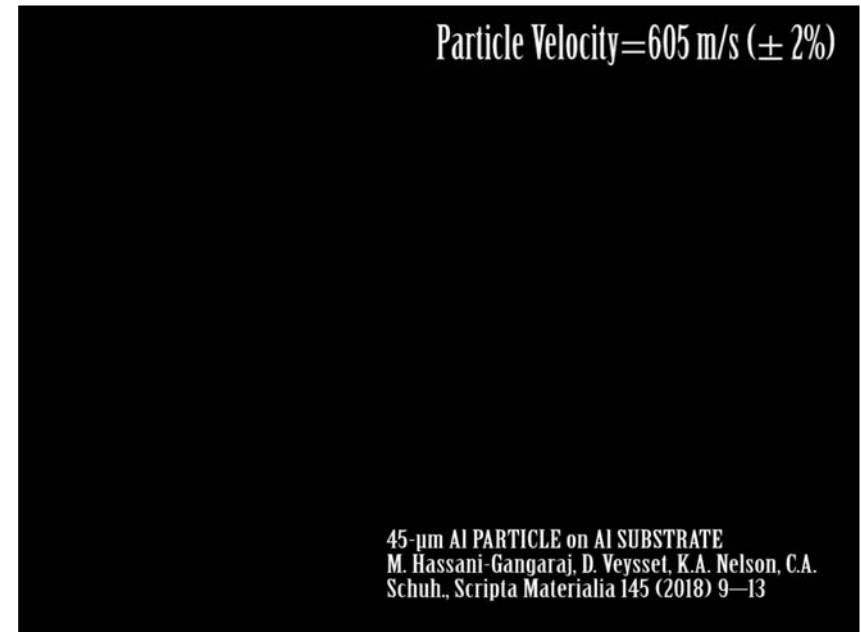
High velocity impact disrupts the oxide films on the particle and substrate surfaces, pressing their atomic structures into intimate contact with one another under momentarily high interfacial pressure and temperature [Karthikeyan, 2004].

Critical velocity [Assadi *et al.*, 2003]

$$V_{cr} = 667 - 14\rho + 0.08T_m + 0.1\sigma_u - 0.4T_i$$

where

V_{cr} :	critical velocity (m/sec)
ρ :	bulk density of powder (g/cm ³)
T_m :	melting temperature (° C)
σ_u :	ultimate strength (MPa)
T_i :	initial particle temperature in ° C



Influence of impact velocity and particle size on features of the interaction [Klinko *et al.*, 2005].



What's so great about Cold Spray?

Cold spraying of Al powder on glass substrate at
NTU-ST Kinetics Cold Spray Research Centre



- Relatively cool process:
 - low oxide content
 - low shrinkage stress
 - reduced material loss due to vaporisation
 - reduced grain growth/recrystallisation
- Dense coating: up to 99% bulk material property with little change in microstructure
- Build-up: up to 250 μm per pass with deposition efficiency up to 70%
- Able to coat relatively small particles (ranging in size from 1 to 50 μm)
- Small size of nozzle with short spray distance equate to small spray beam
 - precise control over the area of deposition over substrate surface.
- Coatings produced are with compressive stresses
 - ultra thick (5 to 50 mm) coatings can be produced without adhesion failure.
- Pre-coating surface preparation not mandatory.

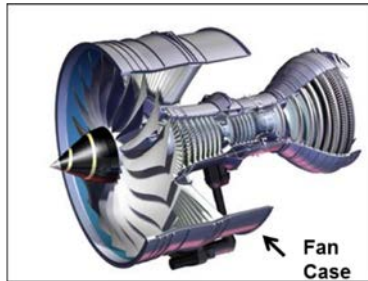


- Hard brittle materials like ceramics can not be sprayed without using ductile binders
- Not all substrate materials will accept coating.
- High gas flows, high gas consumption.
- Carrier gas (e.g. Helium) very expensive unless recycled.
- Small spray trail (typically less than 1 cm in diameter), may not be suited for coating large surfaces.

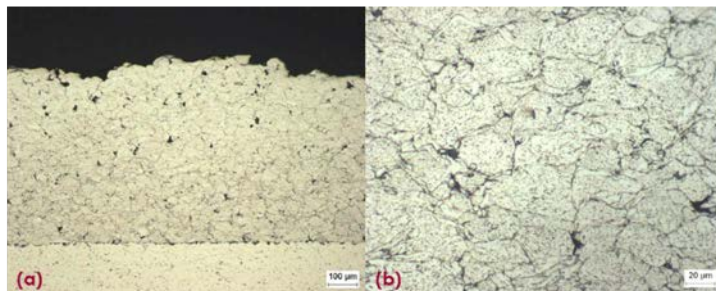


Cold Spray Application

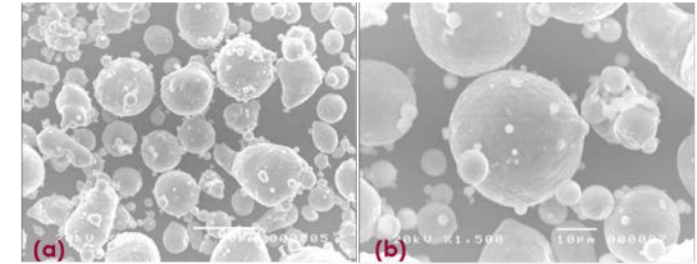
Repair of Corroded Aluminium Gas Turbine Engine Fan Case



Microindentation Hardness (Vickers, 100gf/15 sec)		
Point	Test Coupon	Base Material
1	109.7	105.6
2	97.9	105.6
3	109.2	101.9
4	97.9	104.8
5	108.9	100.9
Average	104.7	103.8



SEM micrographs of a cross-section of the Al6061 coating at (a) 100x magnification and (b) 500x magnification.

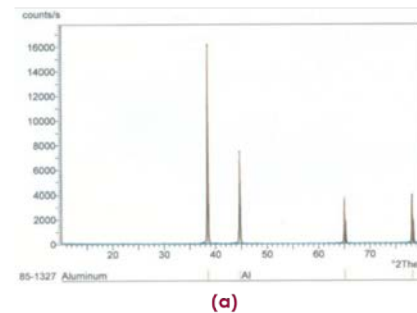


SEM images of the Al-6061 feedstock powder at (a) 500X and (b) 1500X

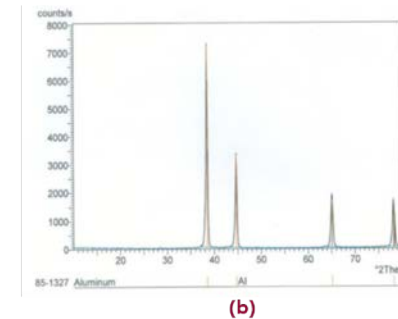
Tensile Bond Strength Test (ASTM C633-01)

Description	Uncoated Sample	Sample 1	Sample 2	Sample 3
Area (mm ²)	473.36	495.60	496.78	496.39
Max. Load (N)	36546	16006	19608	13829
Bond Strength (MPa)	77	32	40	28
Failure Mode	N.A.	A & D	A & D	A & D

Failure: A) Coating/Base Metal Interface
B) Coating
C) Glue/Coating Interface
D) Glue/Pull-off Bar Interface



XRD diffraction patterns for (a) Al-6061 powder and (b) coatings produced using Helium gas as carrier gases.



Cold Spray Application

Honeywell

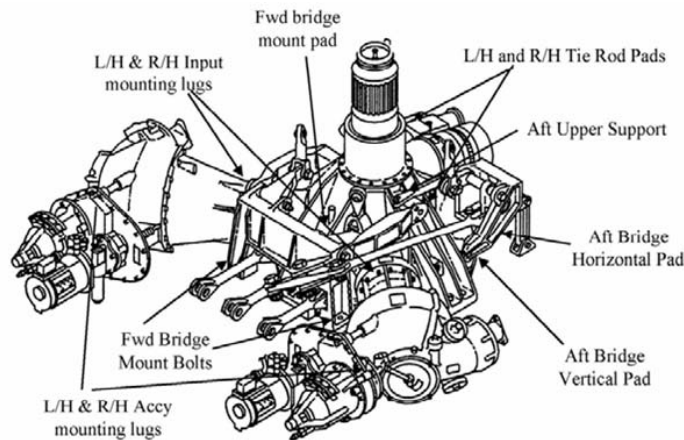
- ✓ Auxiliary Power Units (APU)
- ✓ Propulsion components
- ✓ Fuel/Oil pumps
- ✓ Air cycle machines
- ✓ Gear box housings



- Downstream Injection for Non-structural repair applications
- Repair of casting defects which are picked up after rough machining
- Cold spray has proven to be a viable repair as compared to welding



Cold Spray Repair for Magnesium Aerospace Parts



Areas that are most susceptible to corrosion in UH-60 Main Transmission Housing.



Corrosion locations on a H-53 Tail Gearbox Housing



Corrosion on rotorcraft transmission gearbox

- Magnesium alloys commonly used due to excellent stiffness and damping capacity, low density, thermal conductivity, good machinability and wide availability.
- susceptible to galvanic corrosion (one of the most electrochemically active metals)
- anode reaction with other metallic materials common, especially when operating in salt water environment.



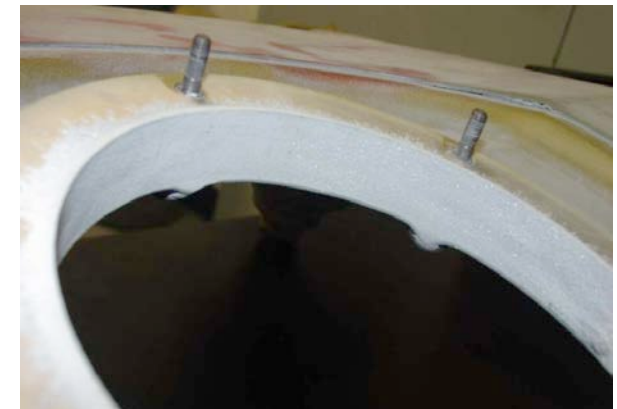
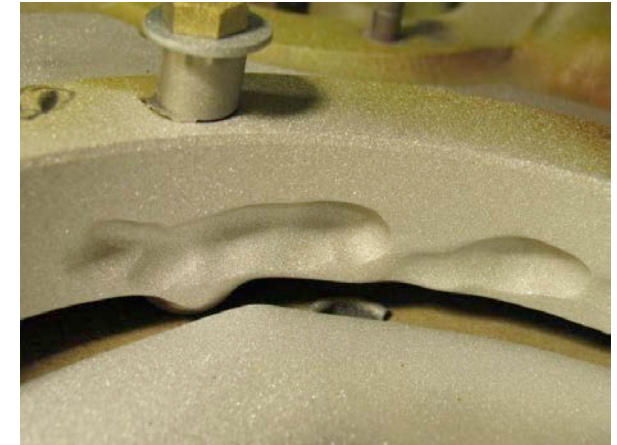
Cold Spray Application



Before and after photos of cold sprayed restored UH-60 Black Hawk main rotor transmission housing.

Repair procedure

- Surface preparation (cleaning, oxide removal by scotch brite)
- Masking
- Cold spray
- Final machining
- Dimensional measurements
- Visual inspection
- Final acceptance test (NDT etc)



Magnesium helicopter gearbox restored with CP aluminium and 6061 aluminium alloy cold spray coatings



Cold Spray Application



B1 Bomber

- 8 equipment bay panels, 4 on each side.
- Forward equipment bay panel is secured to the airframe with 100° tapered flat head TRIDAIR fasteners.
- Fasteners are designed to be installed flushed with the panel for laminar airflow over skin surface.
- Fasteners are made of steel while panels are made from 2024-T6 aluminum.



Cold Spray Application

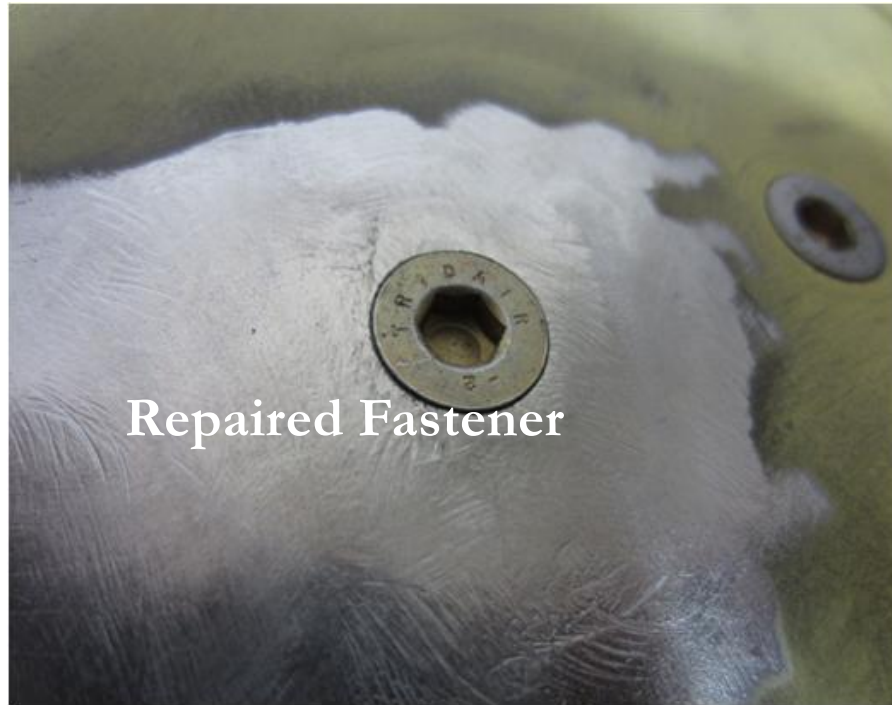


Background

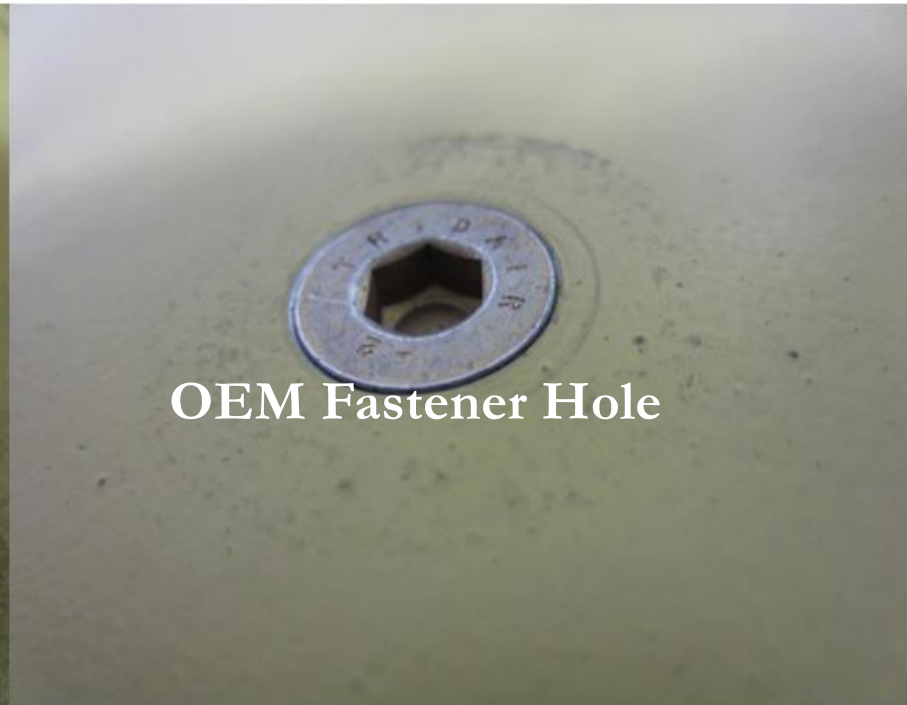
- Repeated opening and closing of the forward equipment bay panels results in chafing wear of fastener holes.
- Fastener holes become elongated and exceed fit tolerance, rendering the panels unserviceable.



Cold Spray Application



Repaired Fastener



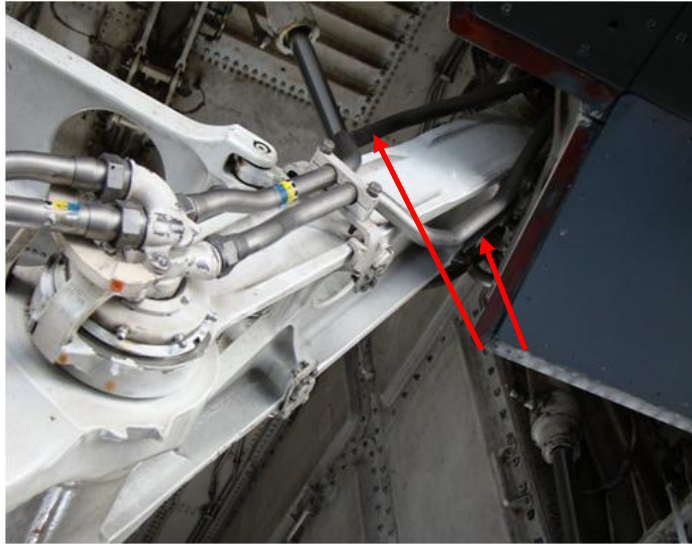
OEM Fastener Hole

Repair procedure

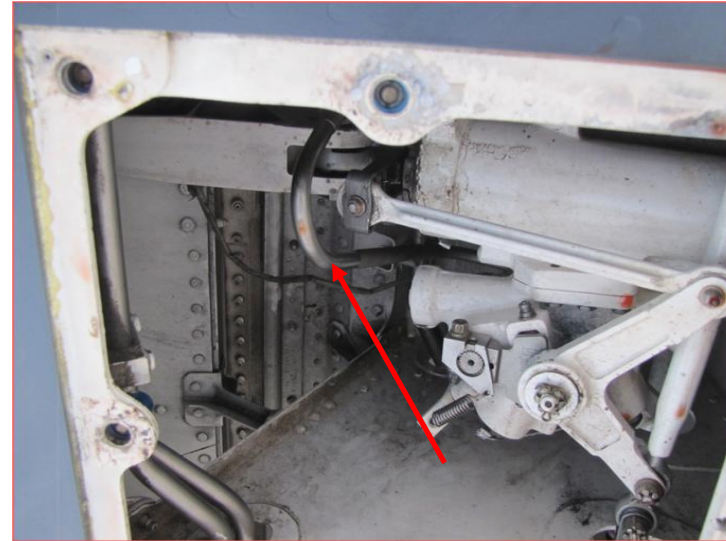
- Al6061 powder cold sprayed on chamfered surface of panel and blended.
- Panel was put through load transfer, fatigue, tensile tests, 3-lug shear test and metallography characterisation.
- Cold spray material did not separate from panel when tested to failure (1.5x bearing yield)
- Fatigue test at 15 ksi tensile stress (typical upper end for aircraft skin load), coupon lasted approx. 500,000 cycles.



Cold Spray Repair of B-1B Titanium Hydraulic Line



Wheel well titanium hydraulic lines that chafe during flight.



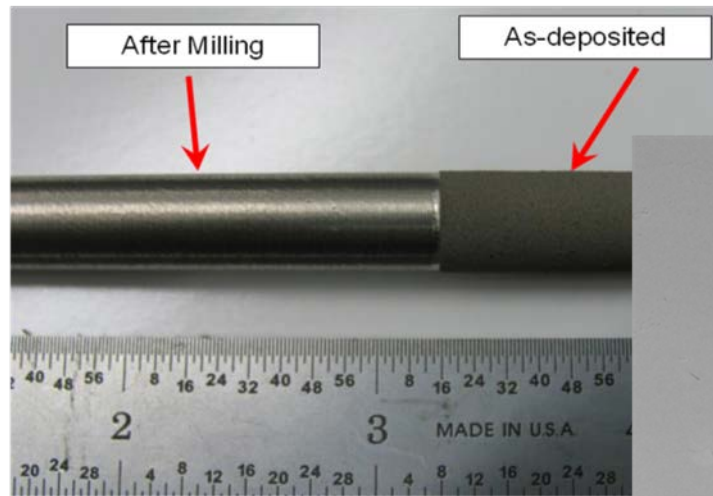
B-1 spoiler actuator lines that chafe during flight operations.

Background

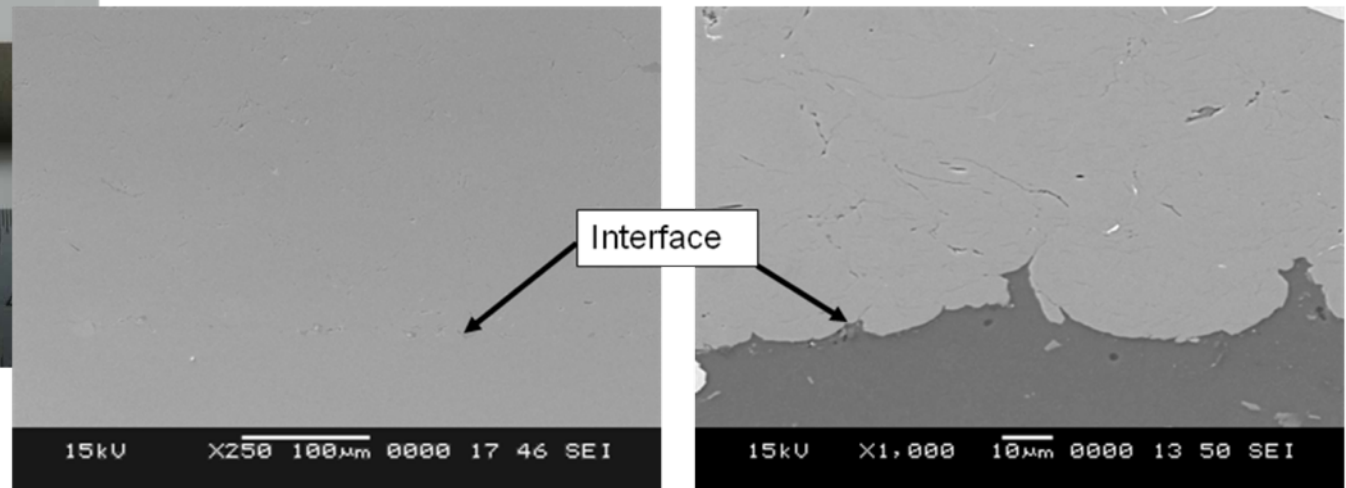
- Vibration and abrasive action result in chafing of titanium ($\text{Ti}_3\text{Al}_{2.5}\text{V}$) hydraulic tubing in the B-1B aircraft.
- 2 areas in which there is high incidence of chafing of hydraulic lines: main landing gear wheel well and wing spoiler actuator.



Cold Spray Application



As-sprayed CP-Ti on right and machined on the left.



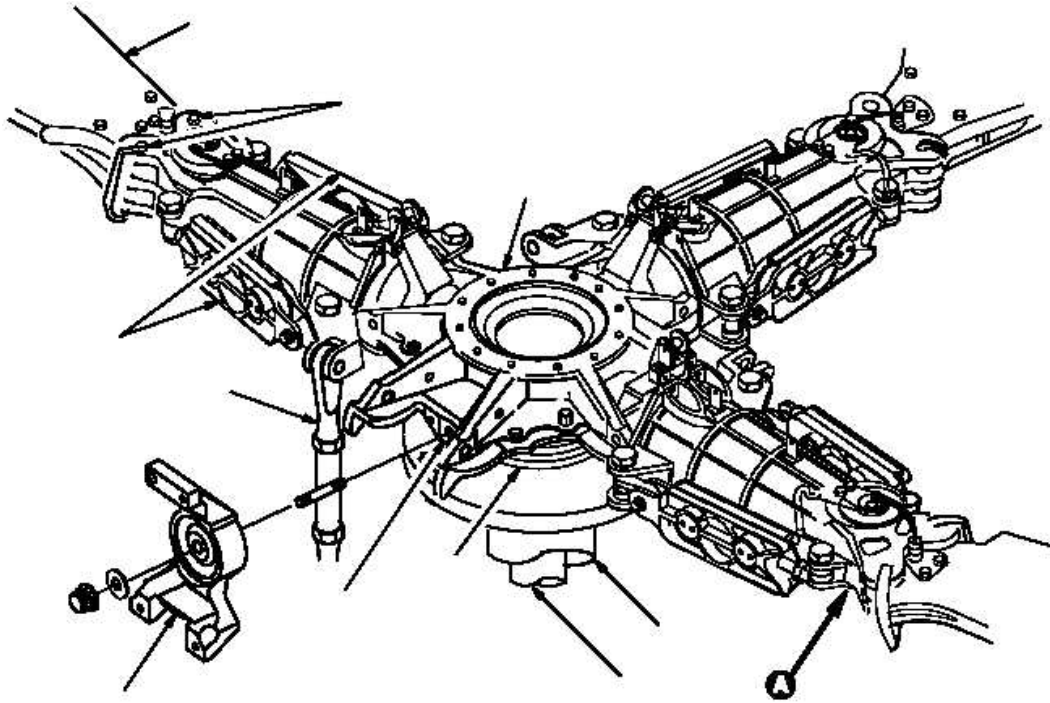
Scanning electron microscopy of the interface between the cold spray CP-Ti coating and the Ti3Al2.5V hydraulic line showing high density and bond line integrity.

Repair procedure

- Titanium coating was cold sprayed on the titanium tubing as a sacrificial wear surface.
- Effectiveness was validated by bond strength (> 12 ksi), density (99%), hardness (93 HRB), deposition efficiency (70%), microscopic evaluation of microstructure, bond line integrity and porosity ($< 1\%$).
- Operational wear test was subsequently performed on a B-1 nose landing gear accumulator hydraulic line which was cold sprayed coated. The aircraft flew for 4 years with no adverse effects and no observed chafing beyond limits.



Cold Spray Application



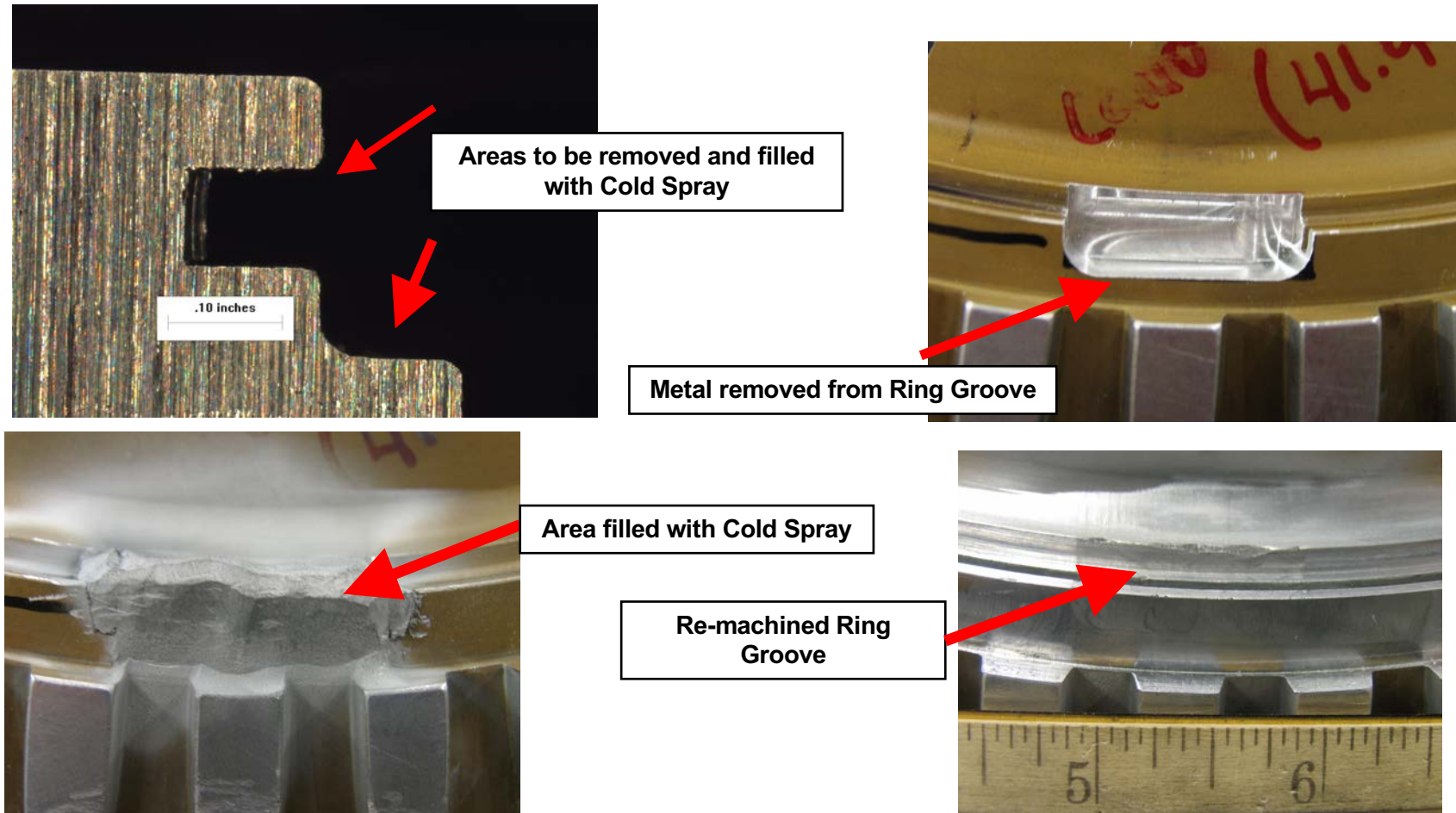
AH-64 Apache Helicopter Mast Support.

Background

- Corrosion and mechanical damaged common on AH-64 mast support, rendering the helicopter non-serviceable.
- Main support fabricated from Aluminum Alloy 7149.
- Remediation without re-building lost material possible but could only be performed for a limited number of times.



Cold Spray Application



Repair procedure

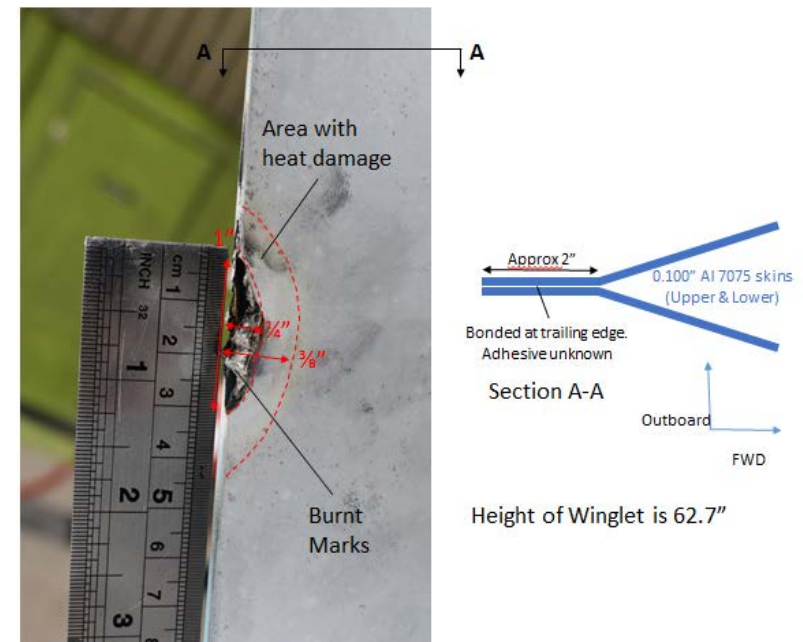
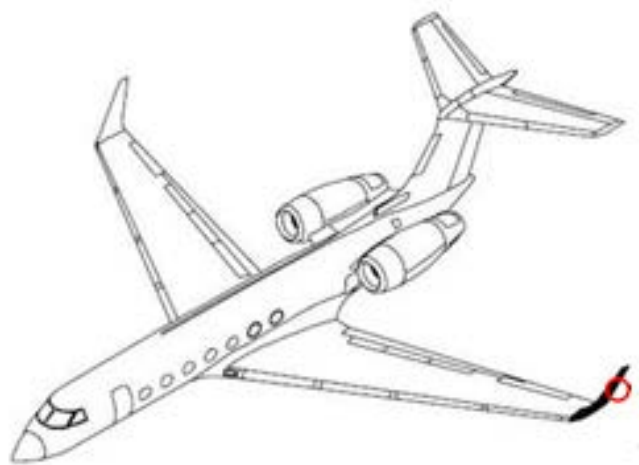
- Corroded or mechanically damaged areas are first blended and machined off.
- Aluminum powder is cold sprayed on the affected area.
- The part is finish blended and machined to original dimensions.



Cold Spray Application

Background

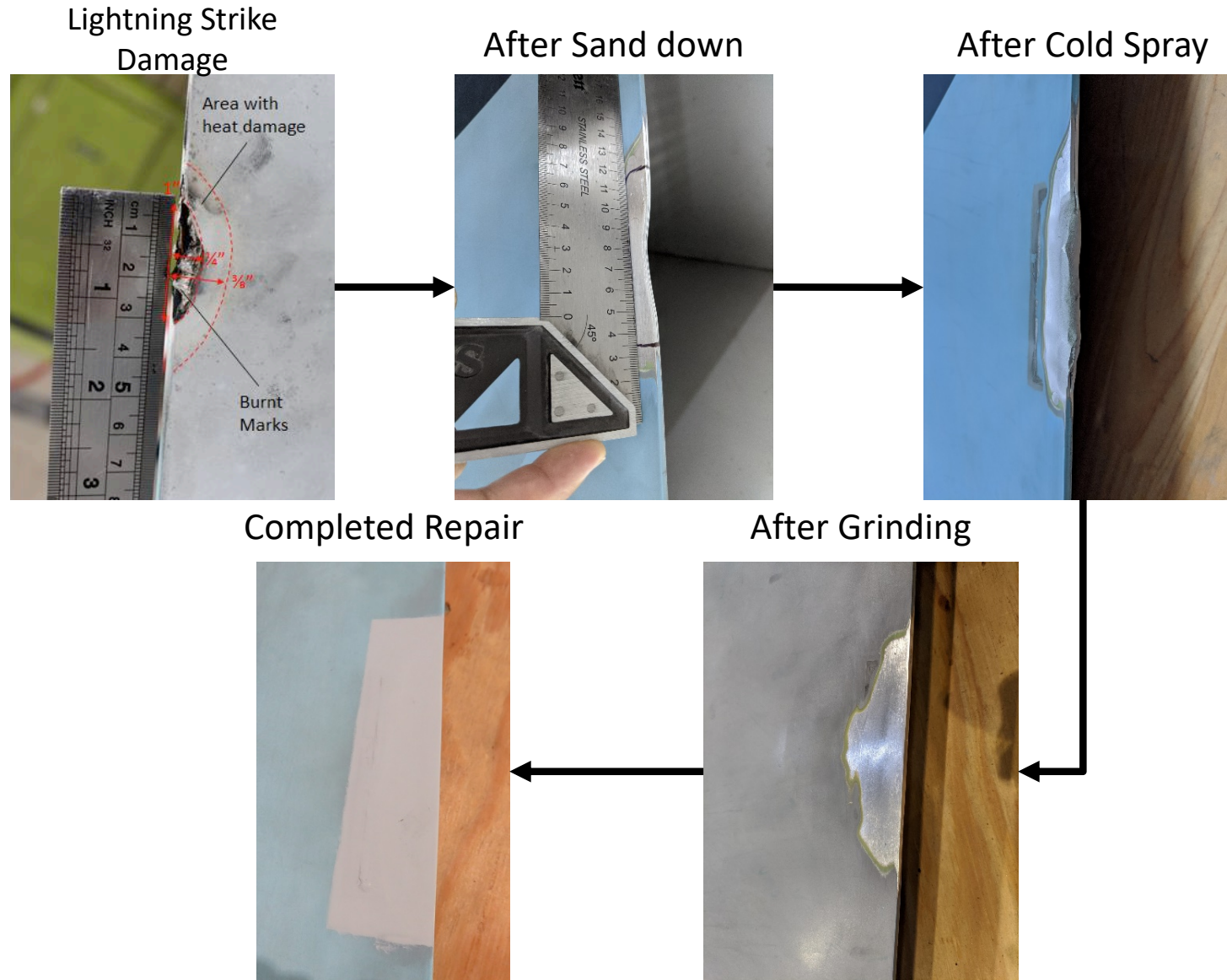
- G550 aircraft (A/C 010) experienced a lightning strike in flight.
- The entry and exit points of the lightning were determined post-flight at the LH winglet, based on the burnt mark.
- The burnt mark on the winglet is approximately 1" length by 1/4" depth.



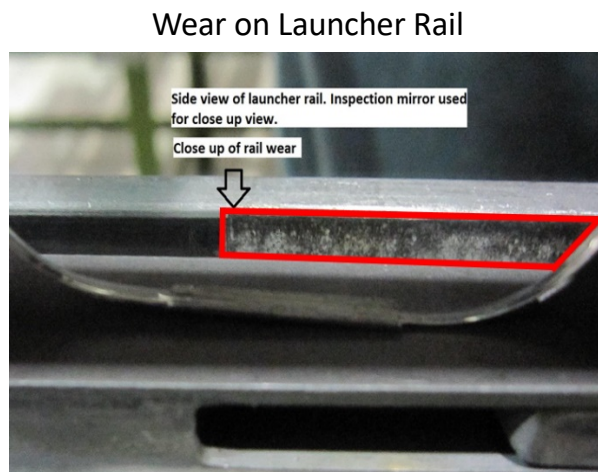
G550 Winglet damaged by lightning.



Cold Spray Application



Cold Spray Application



Conclusion

- Cold Spray is an emerging technology that addresses the shortcomings of more traditional coating processes.
- Exciting prospects for cold spraying is its use as a selective technology for very controlled application of materials requiring very high purities and superior physical properties.
- Key challenges remain but if these are overcome it could open up new applications.



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