Australian Government
Department of Defence
Defence Science and Technology Group

Repair of aircraft components with Additive Manufacturing Laser Cladding Technology – Examples and Modelling

Kevin Walker[1], Qianchu Liu[1] and Tim Cooper[2]

1. DST Group

2. QinetiQ

Presenters : Kevin Walker and Tim Cooper

AA&S Conference

Brisbane, Australia, 19-21 July 2017

Acknowledgements

- Dr Qianchu Liu, Dr Richard Djugum, DST Group
- Professor Milan Brandt and Dr Stephen Sun, RMIT University Centre for Additive Manufacturing
- Mr Neil Matthews, RUAG Australia
- Associate Professor Suresh Palanisamy, Swinburne University
- Hardchrome Engineering
- Mr Noel Goldsmith, DST Group
- Dr J. Lourenco, Rio Grande do Norter Federal Institute of Technology, Brasil
- Drs Anna Paradowska and Mark Reid, ANSTO

Presentation Outline

- Background and Introduction
- Laser Cladding Repairs (Geometry Restoration)
- Certification and Acceptance Strategy (Geometry Restoration Repairs)
- Laser Cladding Repairs (Structural)
- Tim Cooper to present on thermal modelling aspects

Background and Introduction

Why Laser Cladding as a repair technology?

- Makes repair of expensive components possible
- Can repair components when lead-time may be excessive
- Can improve performance of the part

Liu, Q., Janardhana, M., Hinton, B., Brandt, M., and Sharp, P., *Laser cladding as a potential repair technology for damaged aircraft components.* International Journal of Structural Integrity, 2011. 2(3): pp. 314-331.
Liu, Q., Walker, K.F., Djugum, R., and Sharp, P.K., *Repair of Australian military aircraft components by additive manufacturing technology*, in *NATO Specialists Meeting on Additive manufacturing for Military Hardware*. 2016: Tallinn, Estonia.
Liu, Q., Djugum, R, Sun, S., Walker, K., Choi, J., and Brandt, M., *Repair and Manufacturing of Military Aircraft Components by Additive Manufacturing Technology*, in *17th Australian Aerospace Congress*. 2017: Melbourne, Australia.

Advantages of Laser Cladding

- Low dilution and heat input
- Low material distortion
- Low porosity, no micro-cracking, minimal heat affected zone, no or minimal damage to the substrate
- Good metallurgical bond
- Good mechanical properties
- Powder blend and process can be managed to achieve desired mechanical properties

Two categories of repair

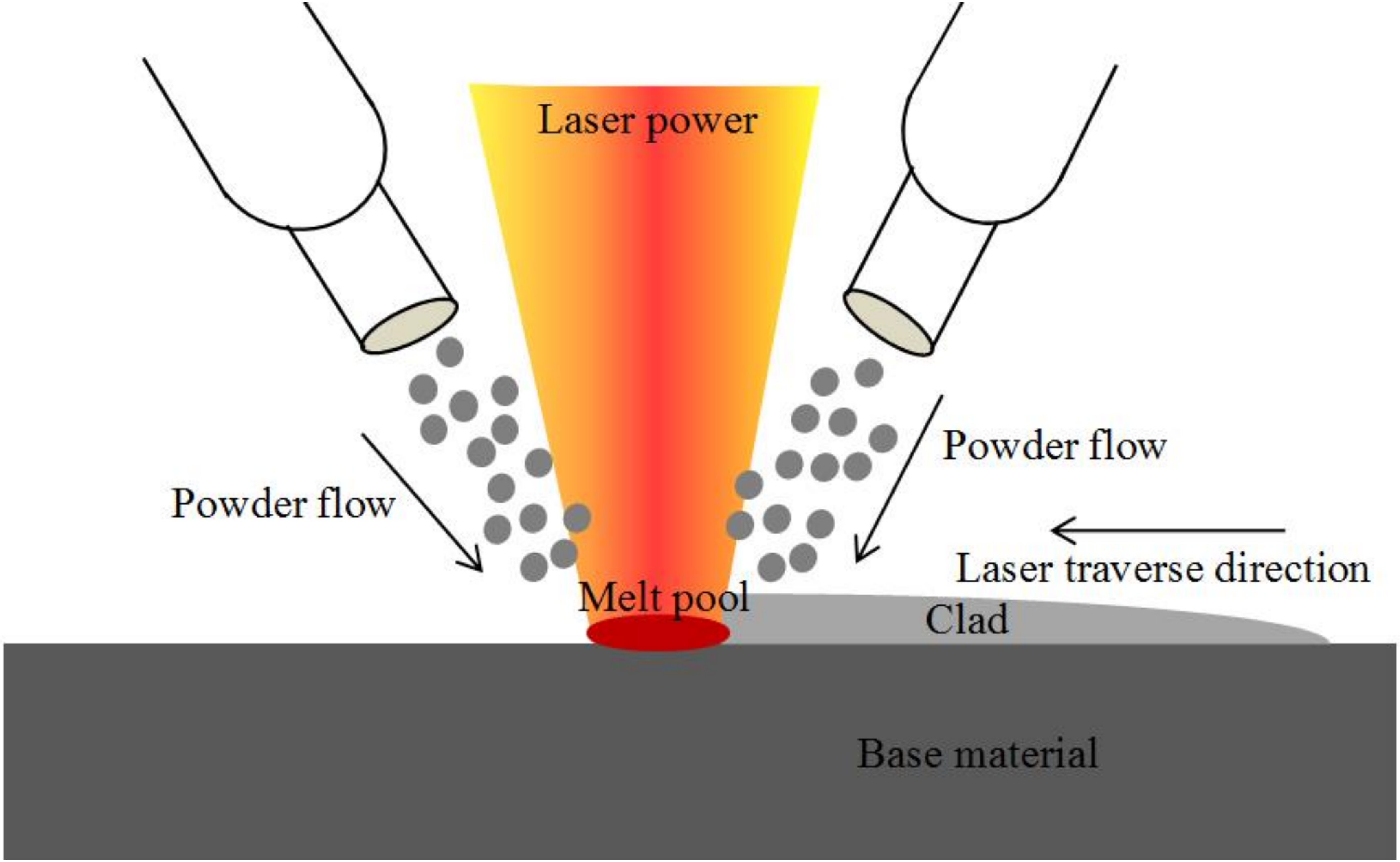
Geometry restoration

- Residual strength and fatigue life not compromised by the damage
- Repair needed to restore:
  - Form, fit and function
  - Corrosion protection
  - Surface finish

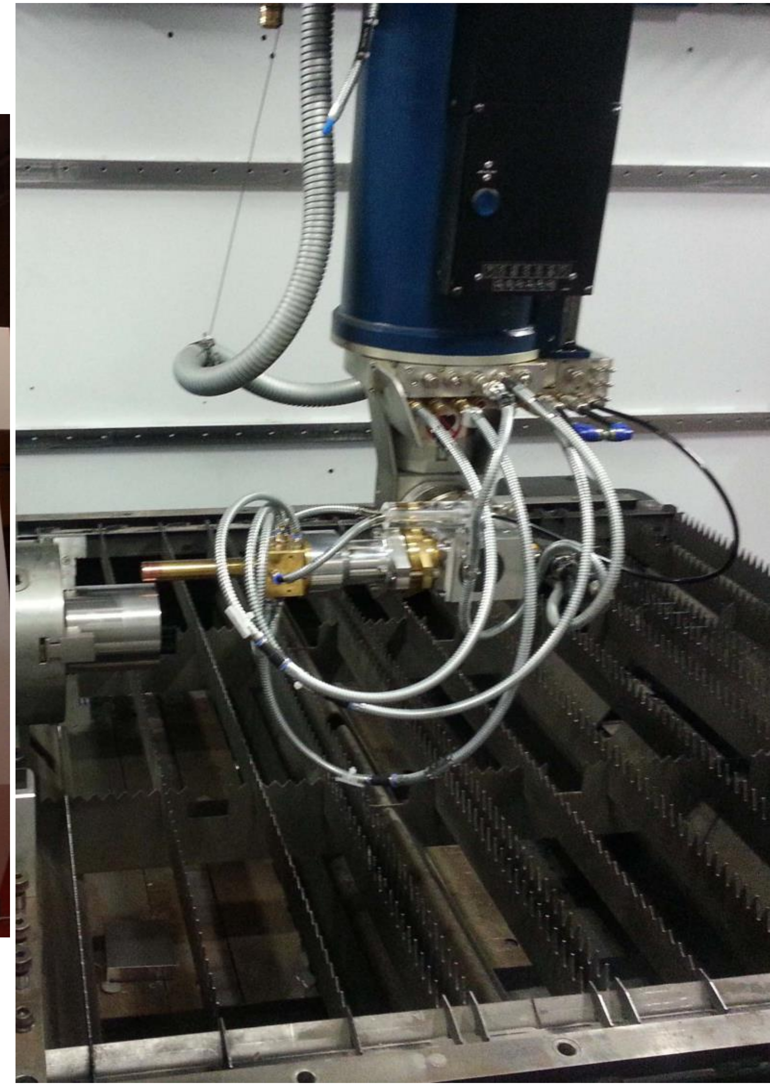
Structural

- Damage is such that static strength and/or fatigue life margins are compromised
- Need to demonstrate that the repair restores structural integrity, in addition to the geometry restoration requirements

Laser Cladding Process



Laser Cladding Set-Up



Laser cladding facility at RMIT University, Australia

Laser Cladding Example Cases

Geometry restoration

- F/A-18A Rudder anti-rotation bracket
- F/A-18F AIM-9X Forward Hanger
- C-130J Landing gear shelf bracket
- F/A-18A Engine mount
- First stage compressor blisk

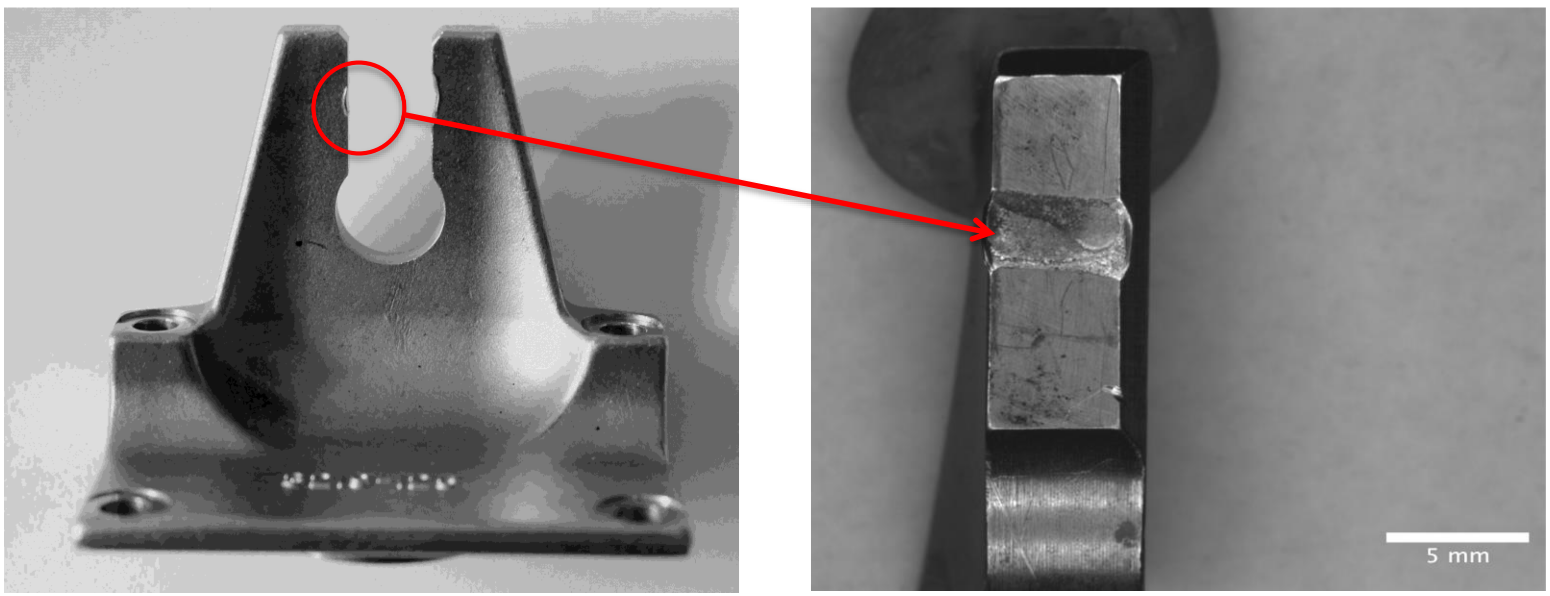
Structural restoration

- Ultra-high strength AerMet®100 steel

Laser Cladding Repairs Geometry Restoration

F/A-18 Rudder Anti-Rotation Bracket

- Unserviceable damage due to wear
- Precipitation-hardened stainless steel 17-4 PH
- Geometrical restoration (No post heat treatment)
- Clad hardness to match component

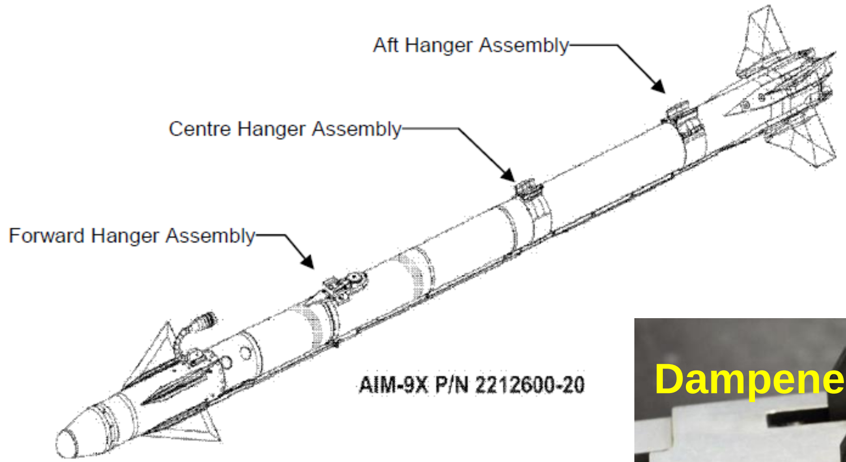


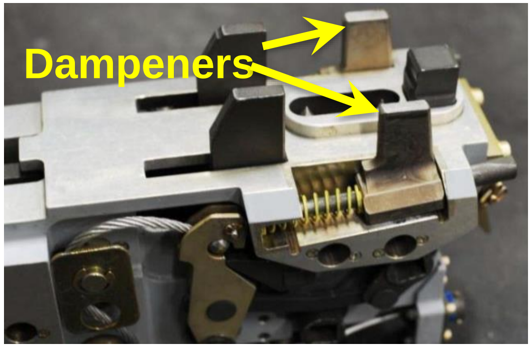
Liu, Q., Brandt, M., Matthews, N., and Sharp, P.K., *Repair of an F/A-18 Rudder Anti-Rotation Bracket using Laser Cladding Technology*, DSTO-TR-2847, 2013, DSTO.

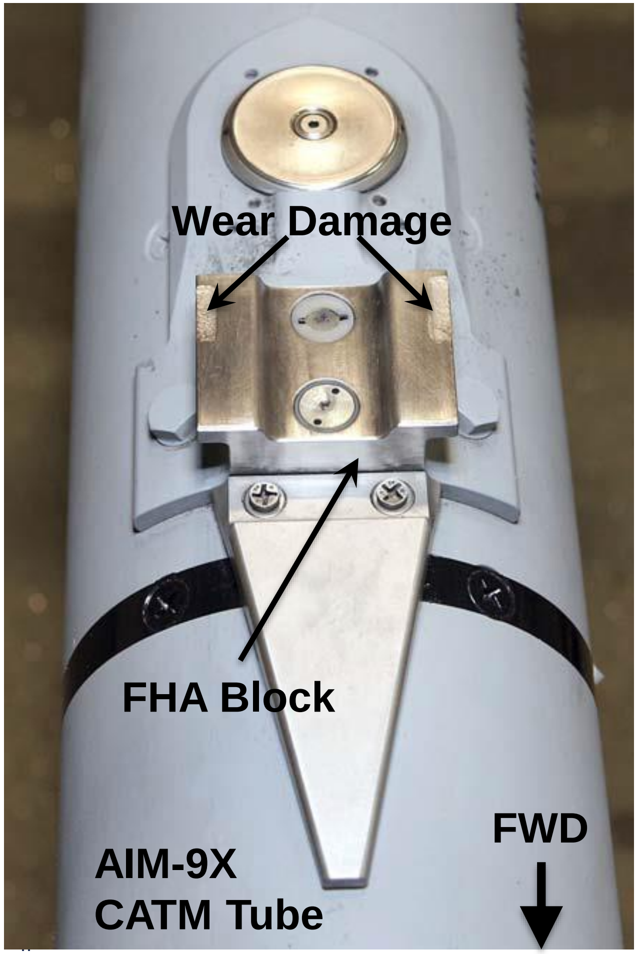
F/A-18 Rudder Anti-Rotation Bracket

- Machine damaged area
- Develop a laser cladding repair (mixed powders)
- 60% 420SS, 40% 316SS
- Clad & machine to tolerance
- TRL 9 (Certification approved, applied to aircraft)

F/A-18F AIM-9X Missile Forward Hanger Assembly



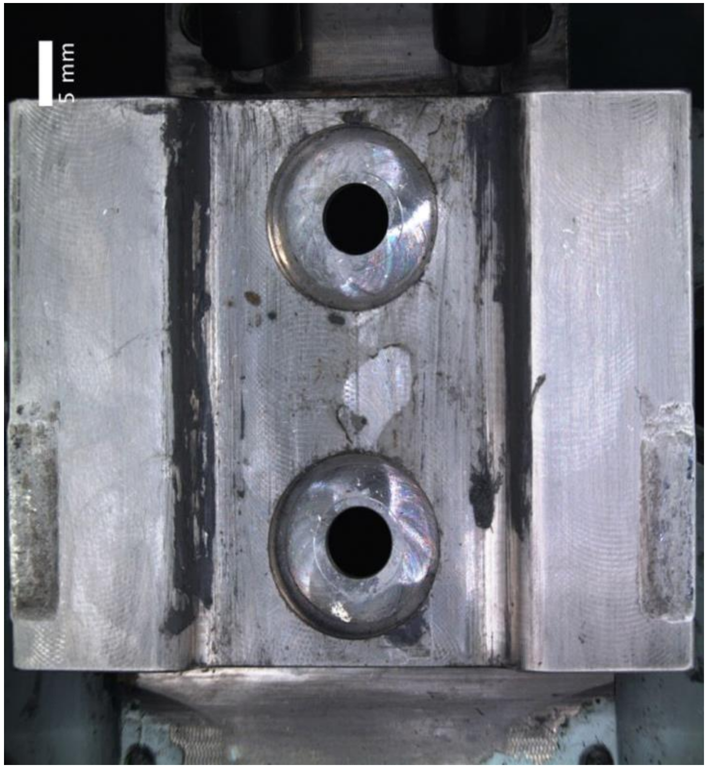


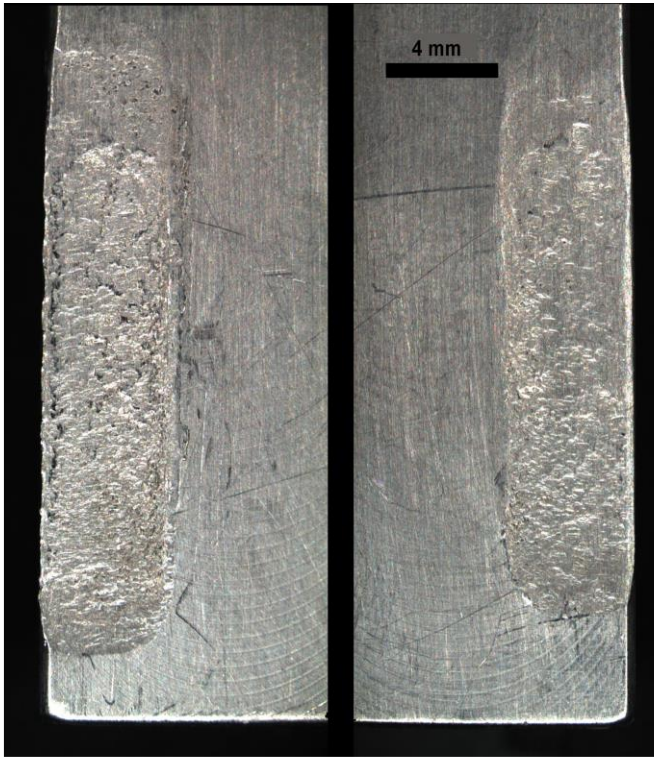


- Unserviceable damage due to wear
- Dampeners causing flange wear damage
- Allowable flange tolerance 0.25 mm
- Geometry restoration

Repair of F/A-18F Forward Hanger Assembly

Damaged by Wear

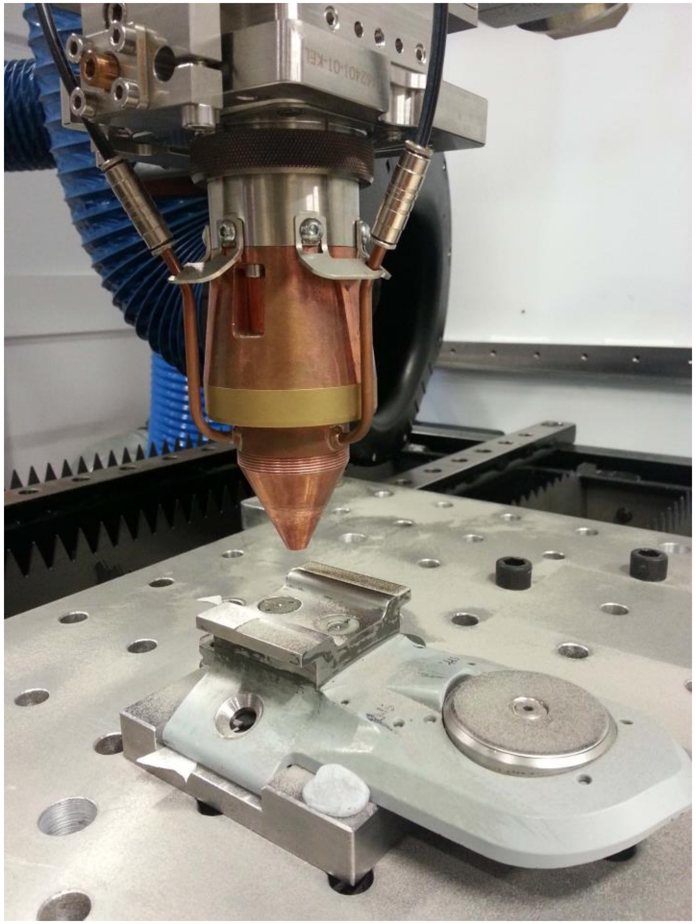


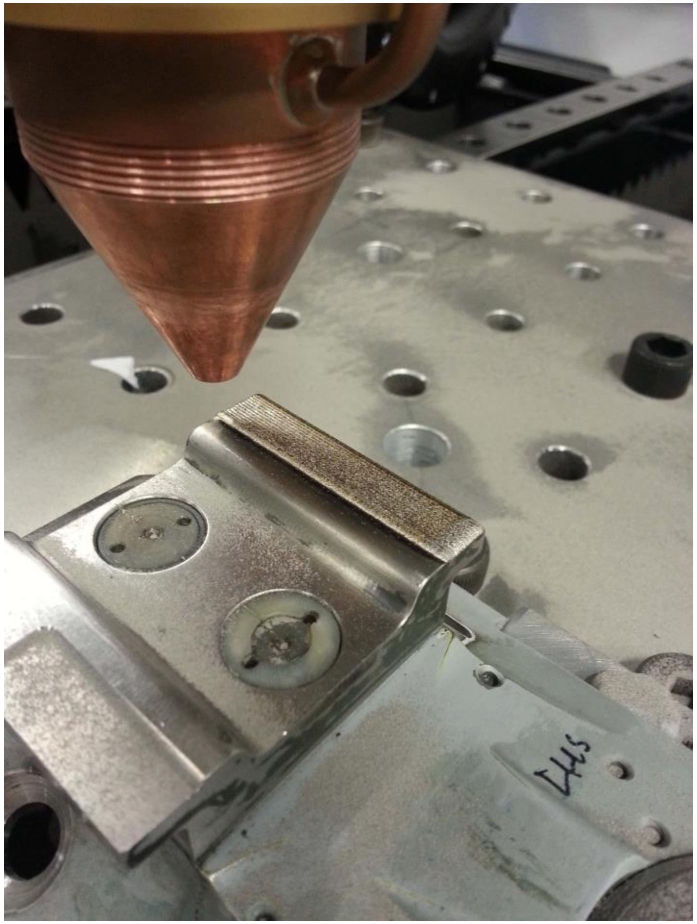


Material: Cast PH13-8 stainless steel

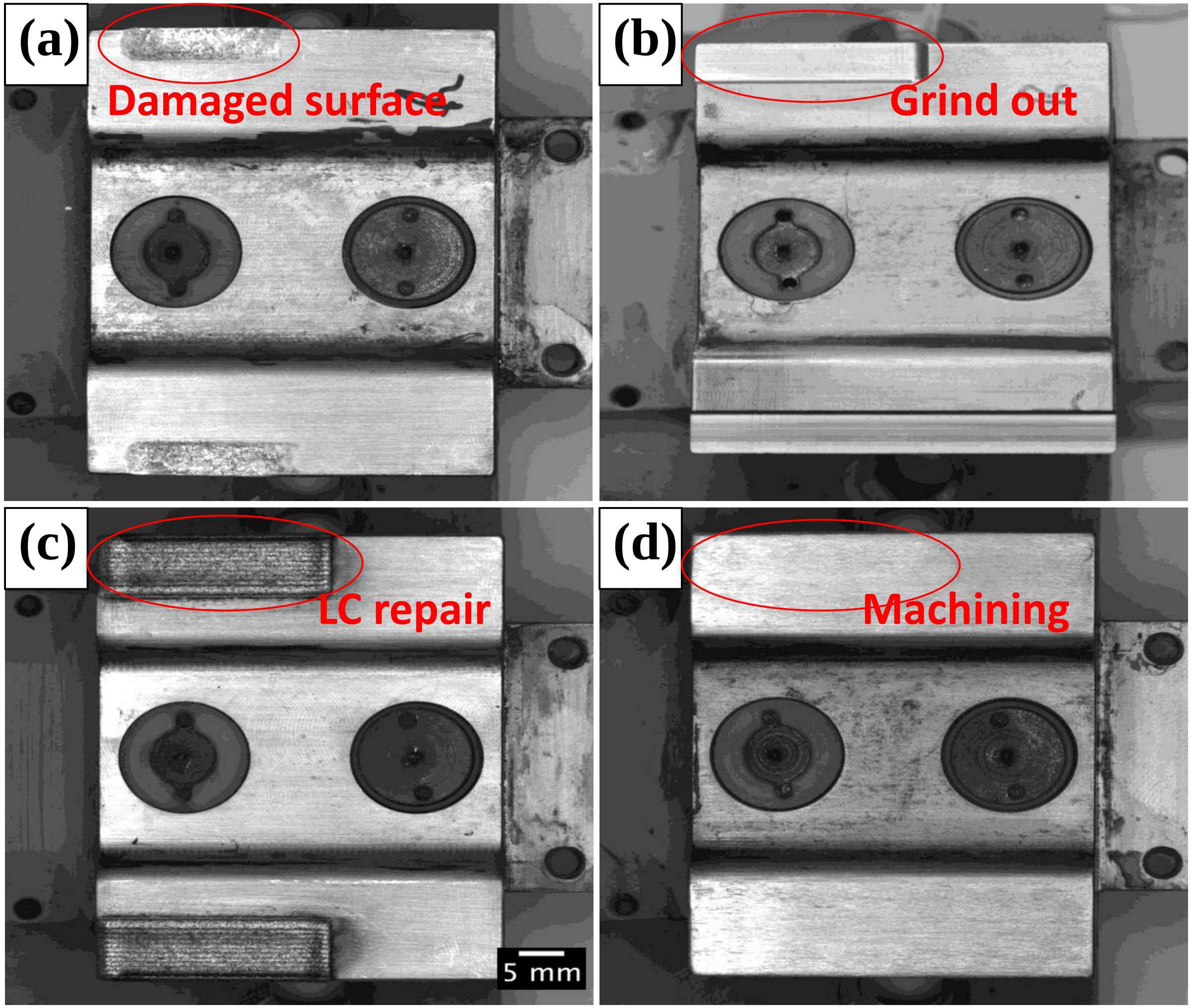
Repair of F/A-18F Forward Hanger Assembly

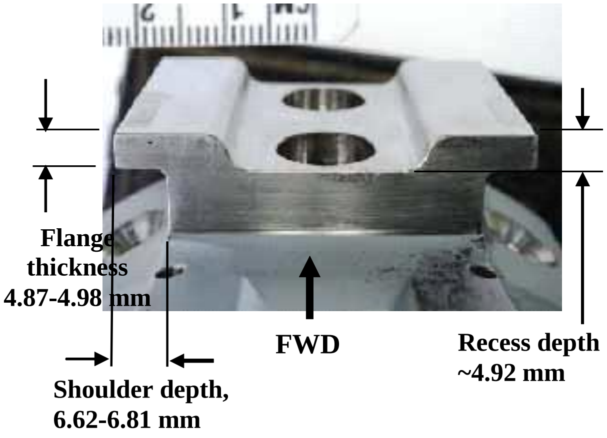
During Repair





Repair of F/A-18F Forward Hanger Assembly





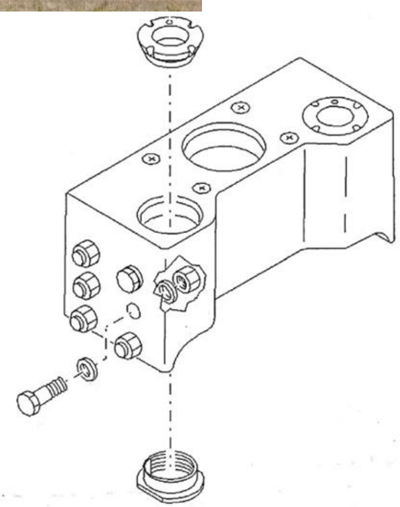
Process developed:

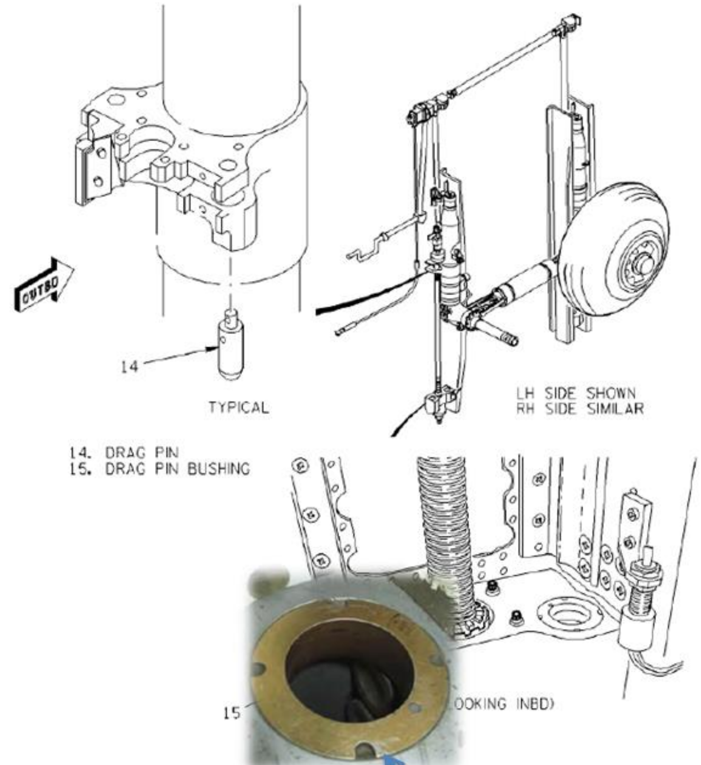
* Matched on hardness

* Awaiting certification

Introduction

Laser Cladding Repair C-130J Landing Gear Shelf Bracket Corrosion

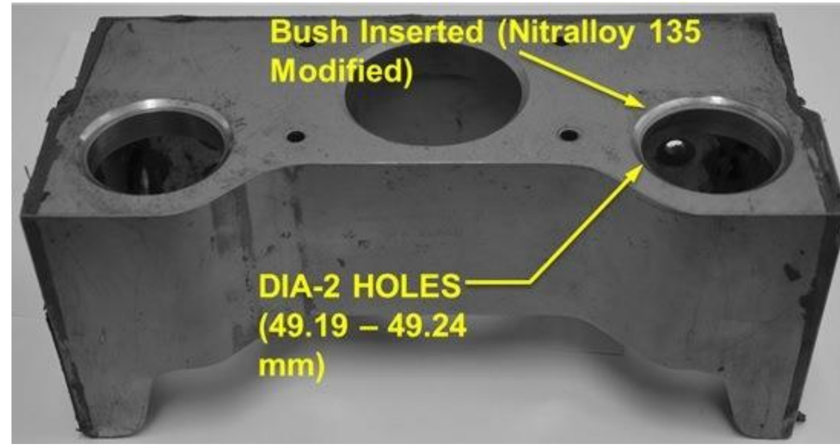


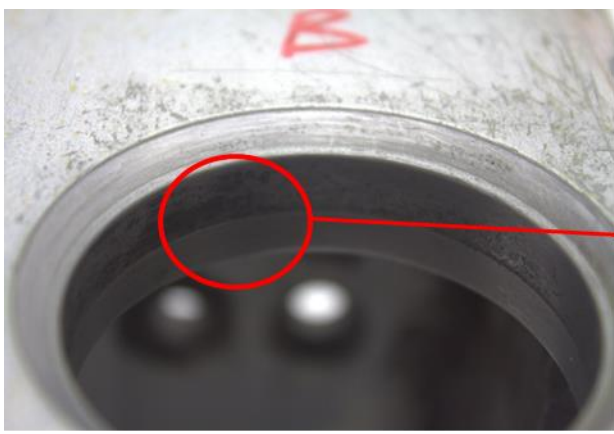


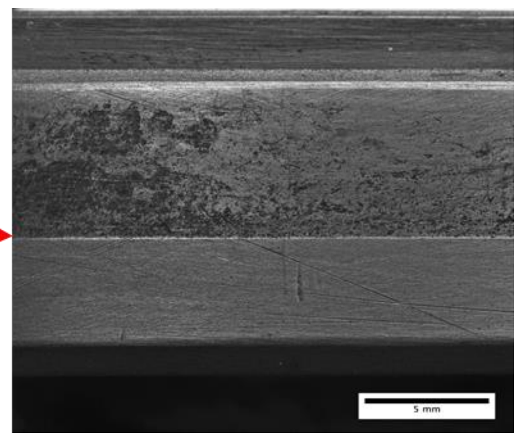
Bushing Inserted (Nitralloy 135 Modified)

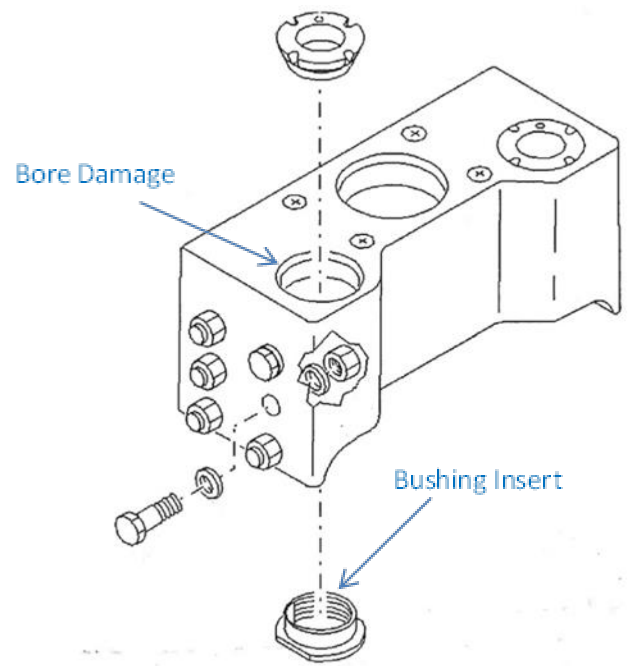
C-130J Landing Gear Shelf Bracket Details

- 4140 steel forging
- Corrosion in drag pin holes
- Corrosion damage depth limit is very conservative – maximum allowable depth 12 µm, 0.0005 in
- Typically find 3 out of 4 brackets need to be replaced at 6 yearly depot servicing



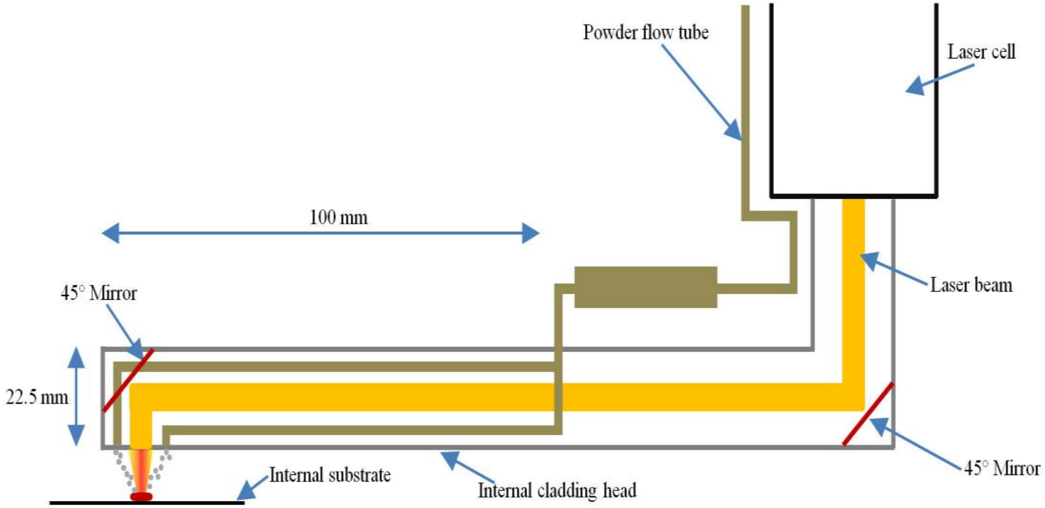


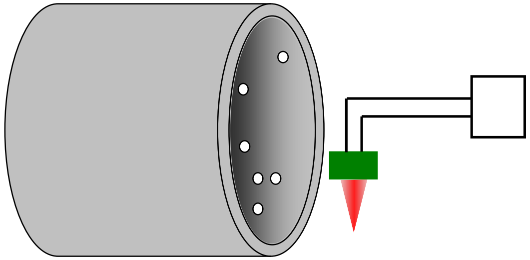


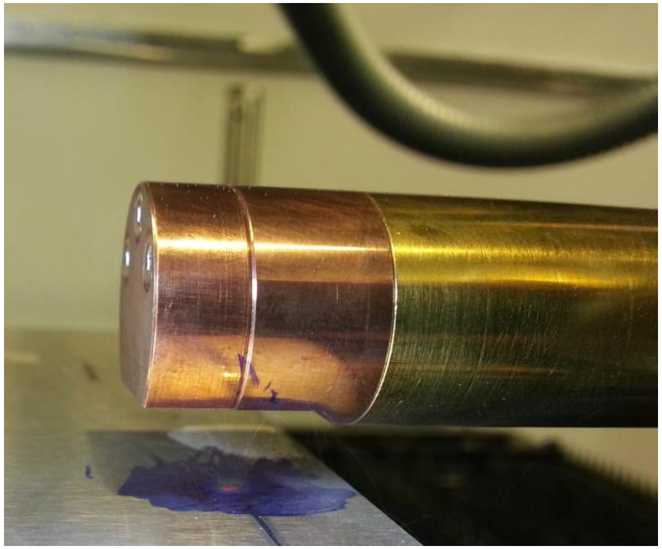


Walker, K.F., Liu, Q., Brandt, M., and Sun, S., *Repair of a Critical C-130J Landing Gear Component with Additive Manufacturing Laser Cladding Technology*, in *ASIP Conference*. 2016: San Antonio Texas USA.

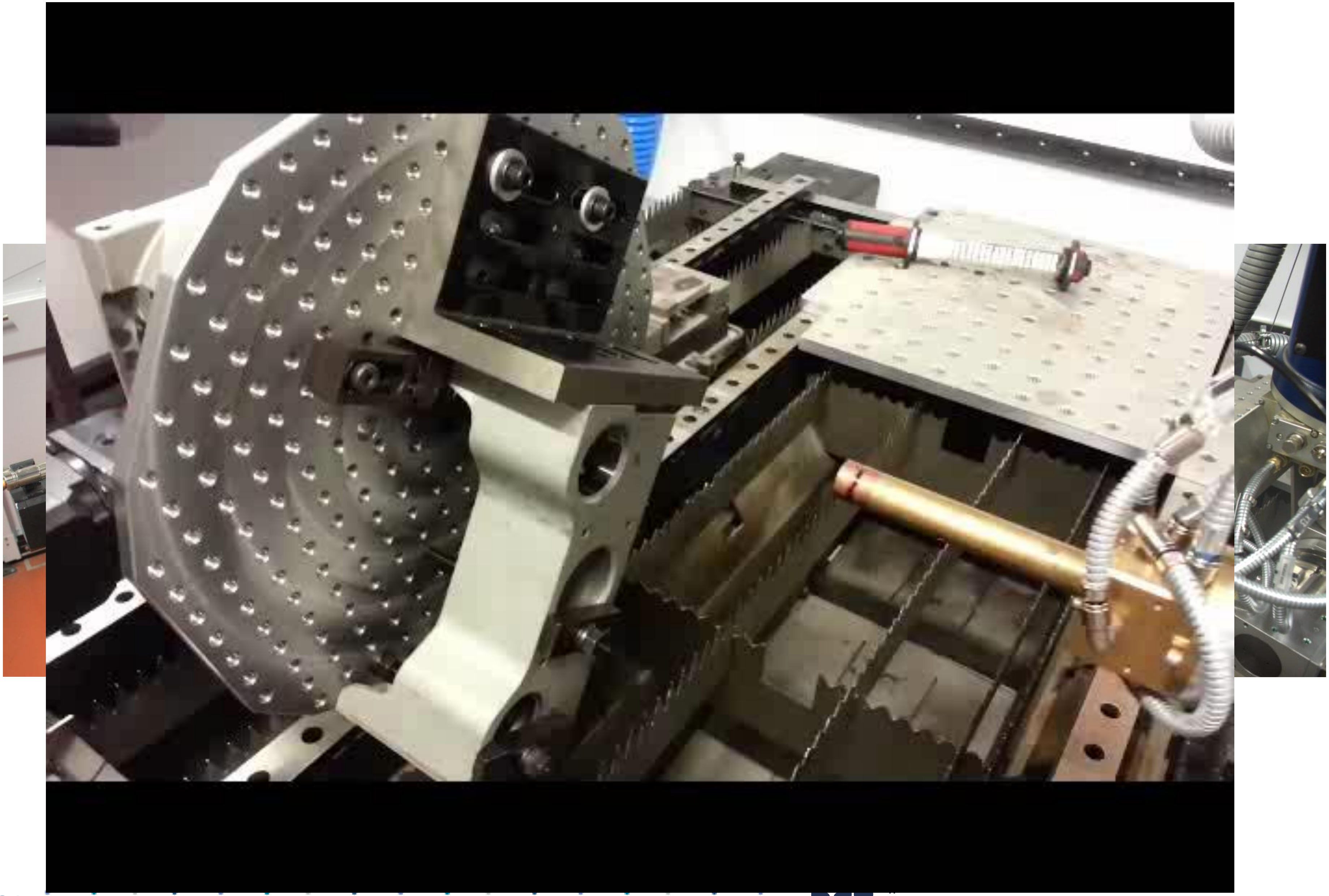
Internal Cladding System





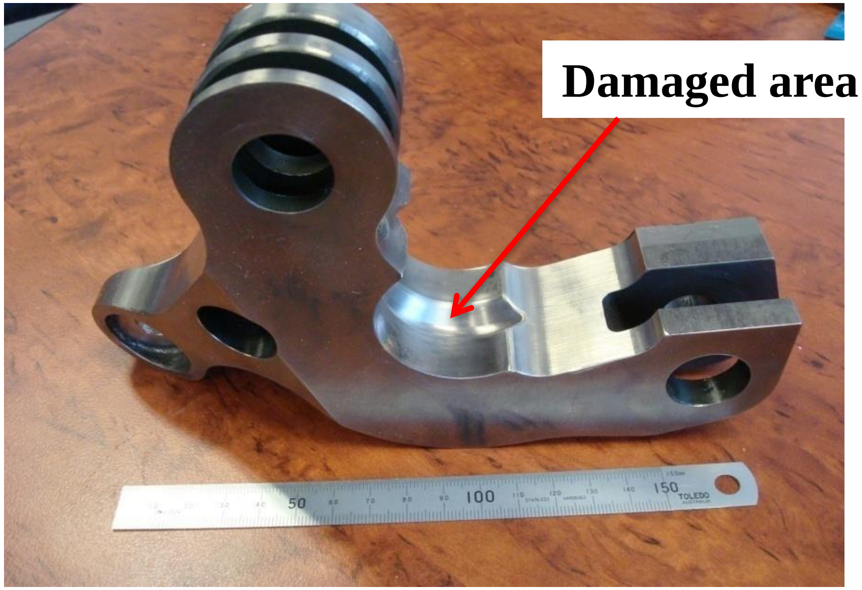


Schematic of a cladding nozzle for the internal repair, designed by Fraunhofer Institute of Laser Technology

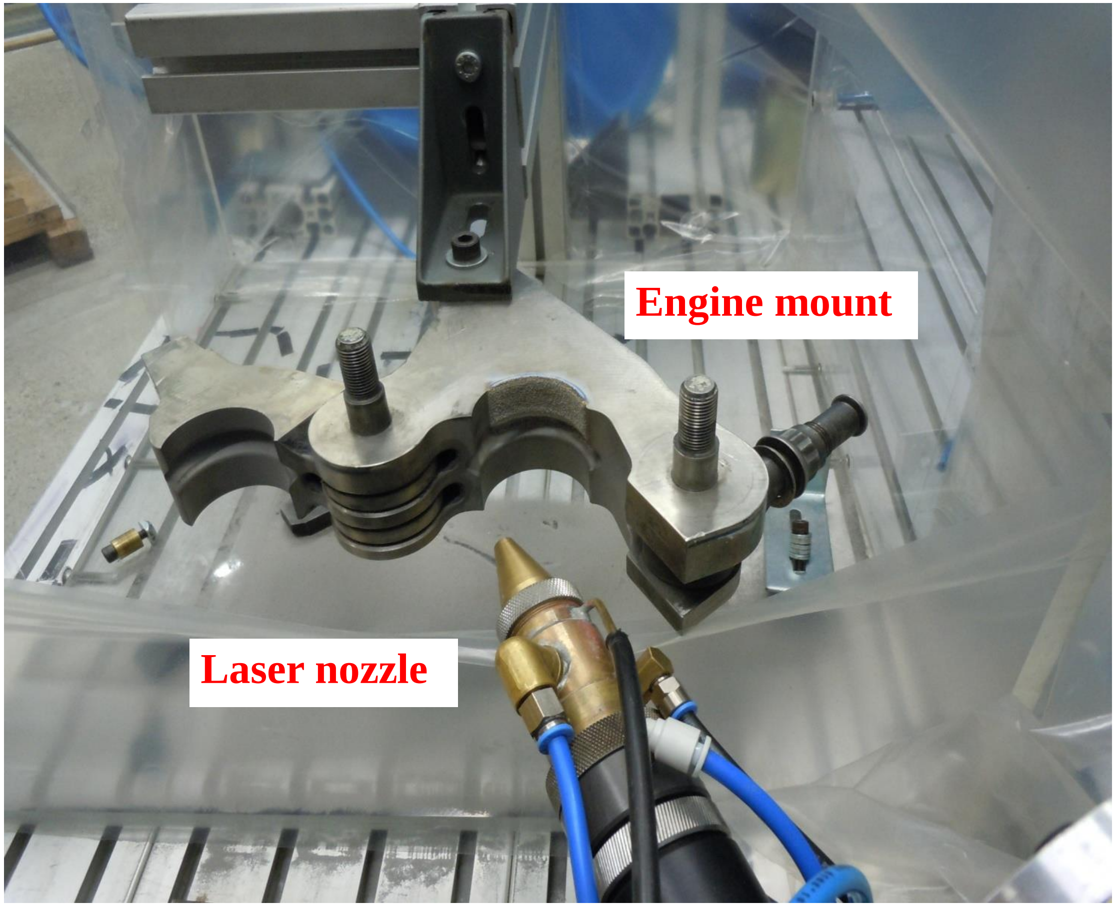


Repair of F/A-18 Engine Mount

- Unserviceable damage due to wear
- Titanium Alloy (Ti-6Al-4V)
- Geometrical restoration (No post heat treatment)

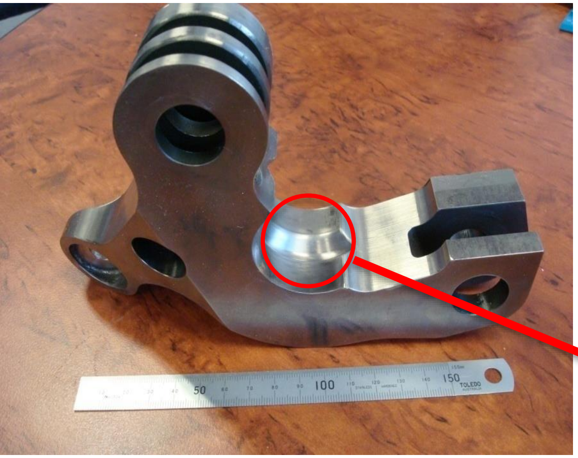


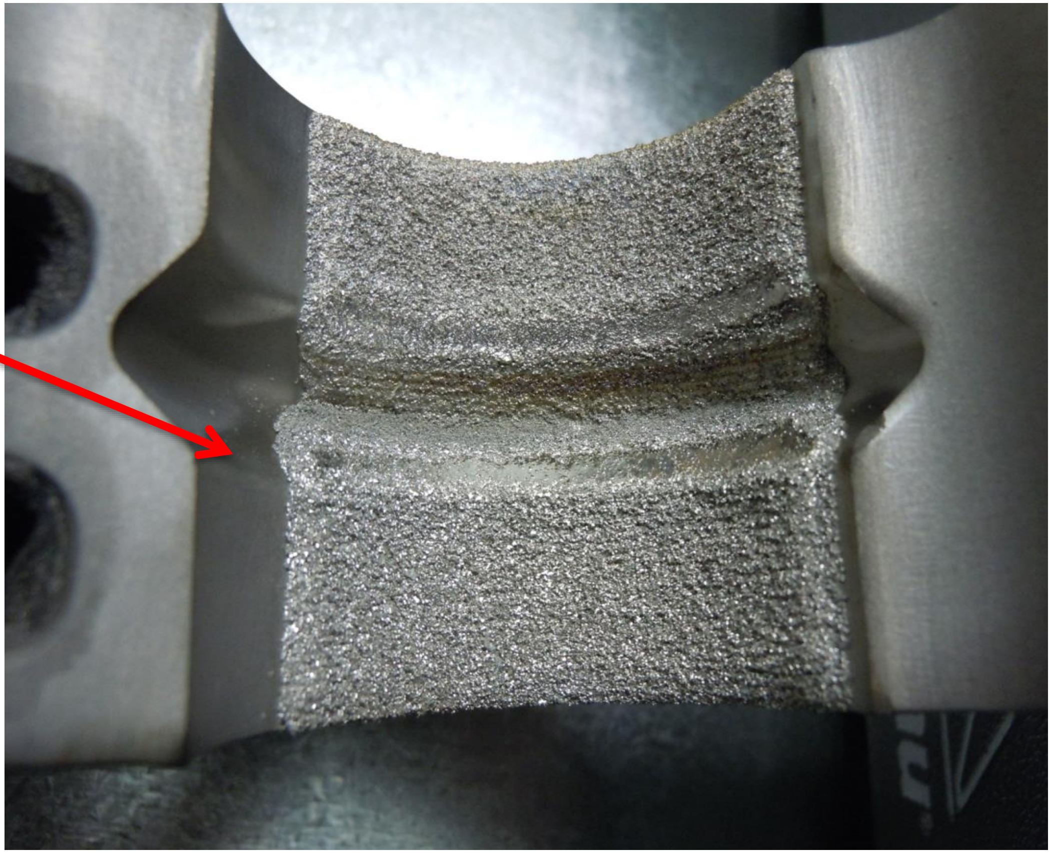
Repair of F/A-18 Engine Mount



Set-up for repair at Swinburne University

Repair of F/A-18 Engine Mount

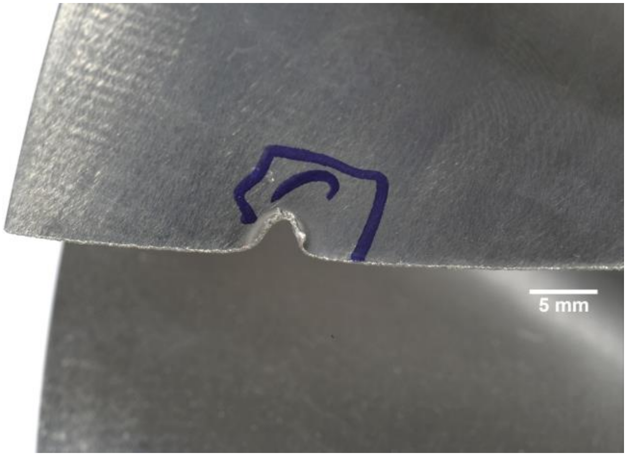




Repaired area in Engine mount (at Swinburne University)

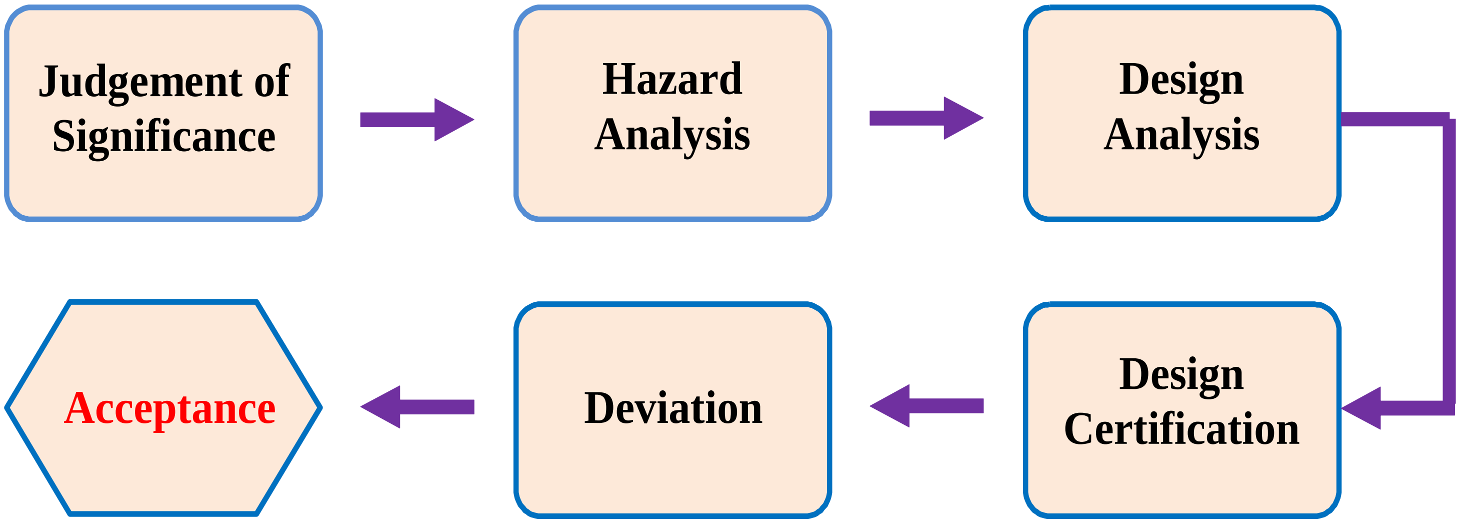
AM Repair of Dynamic Engine Components

- FOD impacts to integrally bladed engine compressor rotors can render these high-value components unserviceable.
- Impact damage can be repaired by two methods – subtractive and additive.
- Subtractive repair involves grinding out and blending the damaged area. This can affect the high-cycle fatigue response of the component.
- Additive repair uses laser powder deposition to rebuild the damaged area, restoring it to its original geometry.
- Challenges for AM repair of dynamic components, such as Ti-6-4 rotors, include the effects of heat affected zones, achieving desirable microstructures in the repair material, and defects such as porosity.



Certification and Acceptance
Laser cladding repairs (Geometry Restoration)

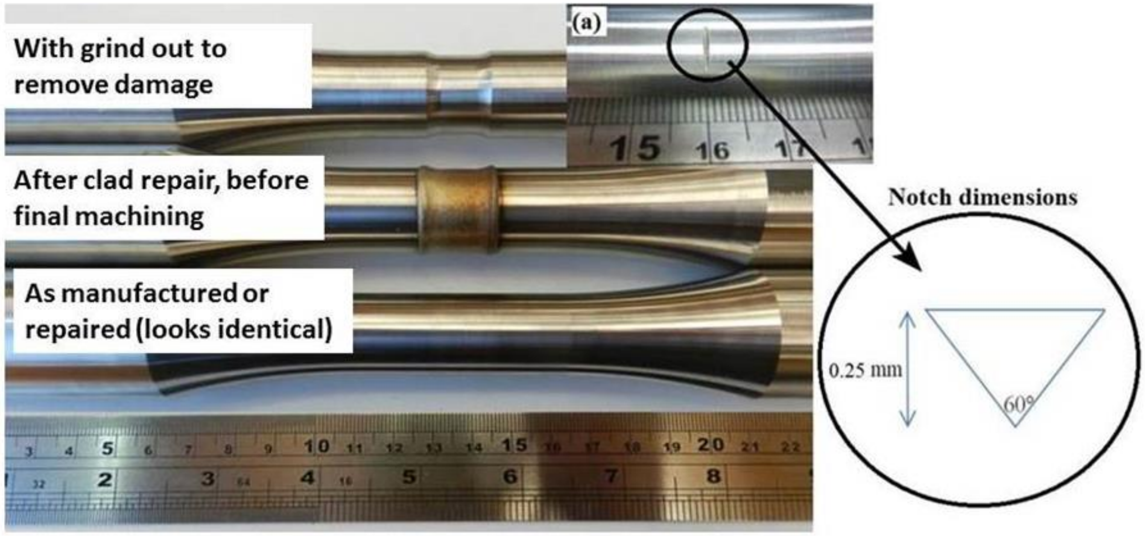
Certification and Acceptance Strategy – Geometry Restoration Repairs Only



Laser Cladding Repairs Structural

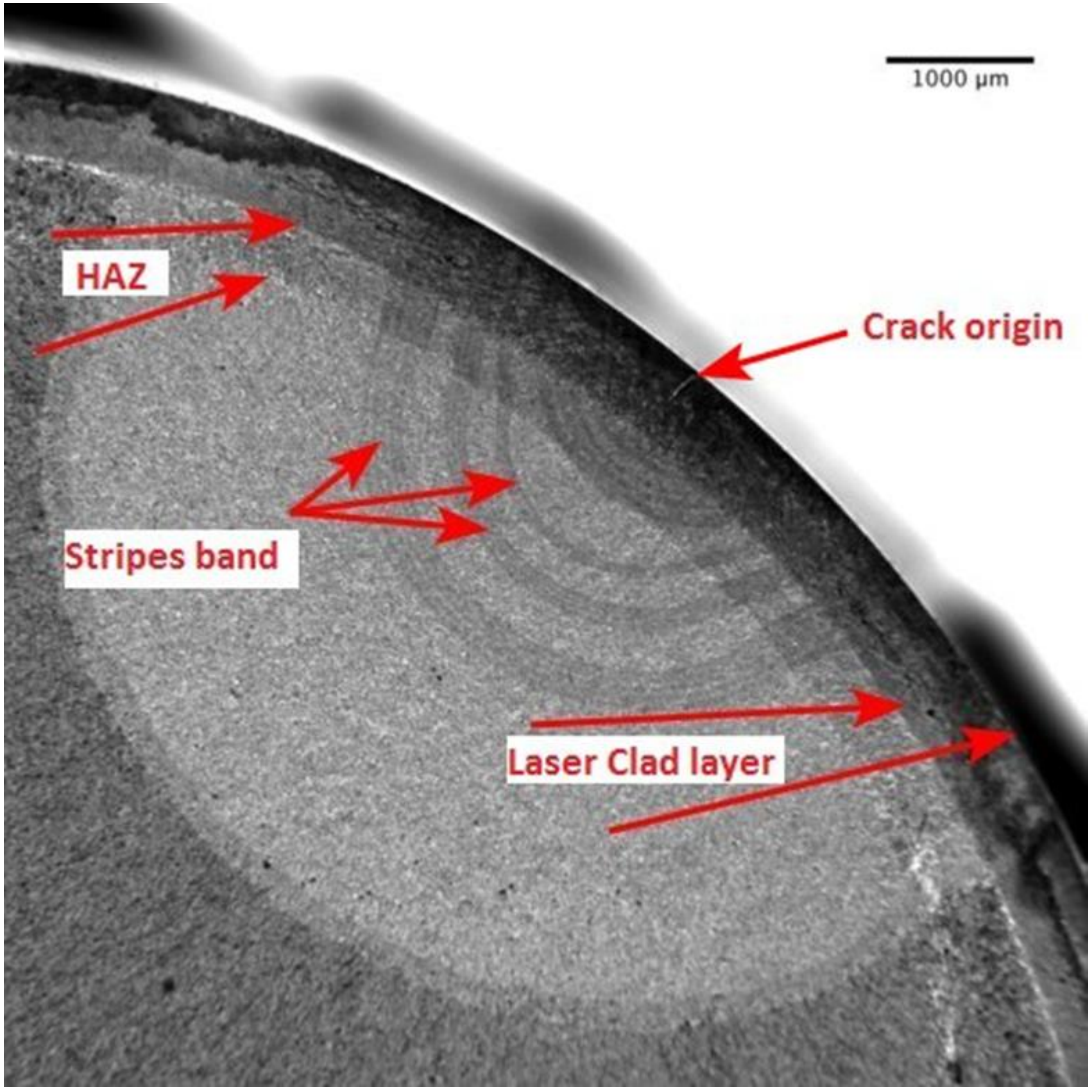
Structural Repair of AerMet®100 Steel

- AerMet®100 32/20 mm dia round bar samples
- 0.25 mm deep crack starter
- 0.5 mm deep, 10 mm long groove, repaired by cladding with TRUMPF TrueLaser Cell 7020 System

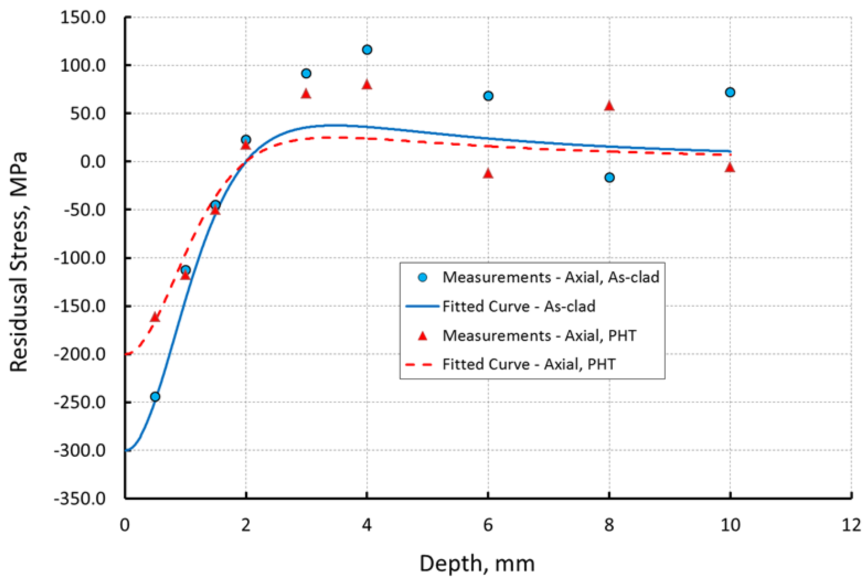


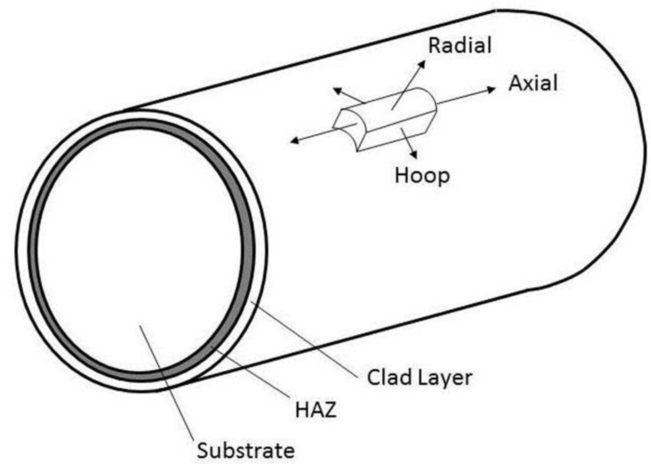
Walker, K.F., Lourenco, J.M., Sun, S., Brandt, M., and Wang, C.H., *Quantitative fractography and modelling of fatigue crack propagation in high strength AerMet100 steel repaired with a laser cladding process.* International Journal of Fatigue, 2017.

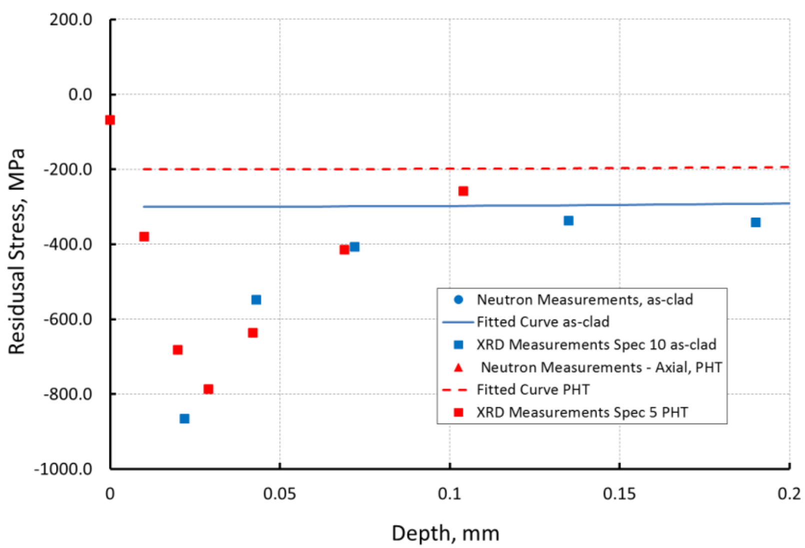
Test Results : As-clad



Residual Stress Measurement





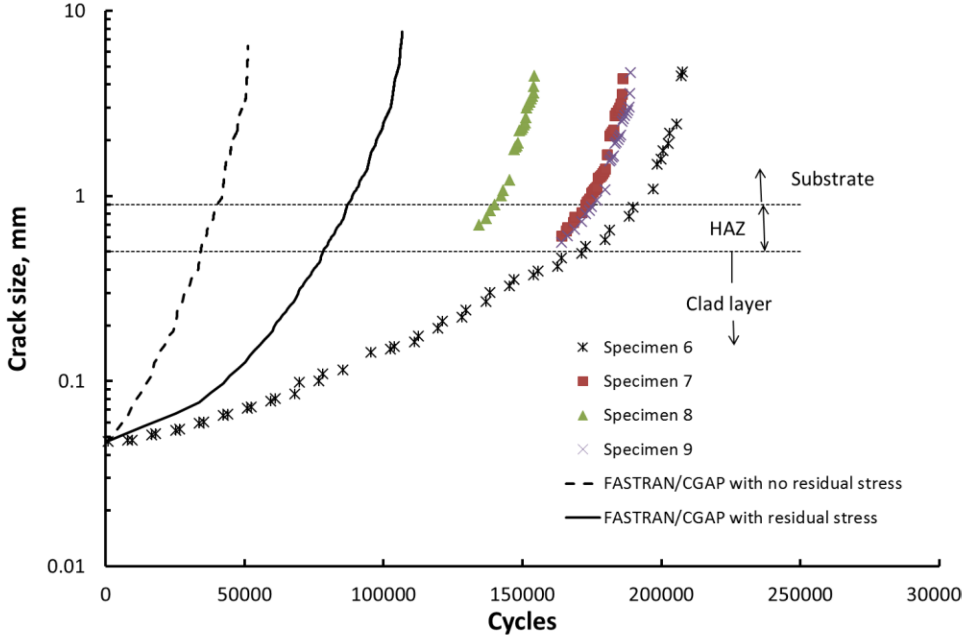


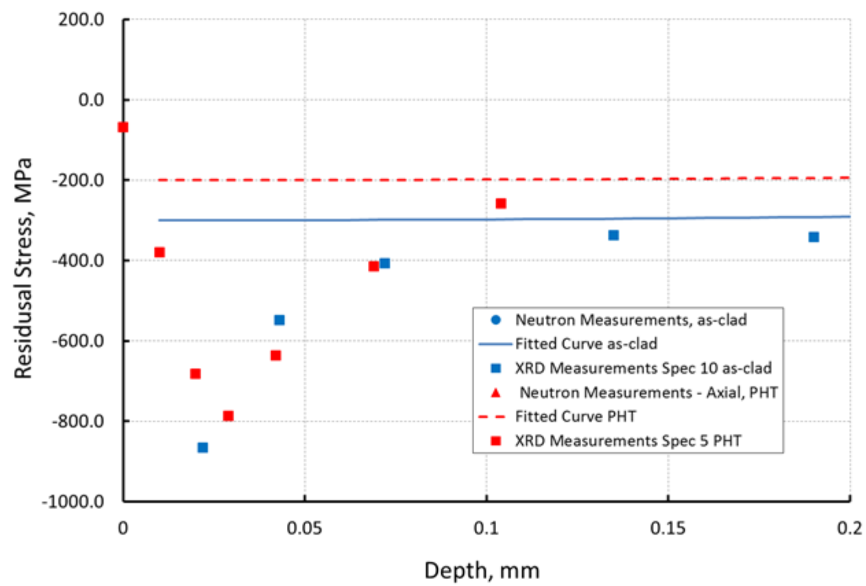
$$\sigma_R(z) = \sigma_{R,\max} \frac{1-(z/d)^2}{\left[1+(z/d)^2\right]^2}$$

Satisfies the zero net force condition

$$\int_0^\infty \sigma_R(z)dz = 0$$

Crack Behaviour & Prediction:





- Slow fatigue crack growth due to the compressive residual stress in clad layer
- Ability to restore strength and fatigue life is very promising
- Crack growth modelling being updated with recent X-Ray diffraction results – expect an improvement
- Ability to model the residual stress behaviour will greatly improve our capability to design these structural repairs – to be discussed next by Tim Cooper

Tim Cooper – Modelling of the thermal effects of the Laser Cladding Process

Back Up Slides

Laser Cladding Details

- AerMet®100 steel powder, Sandvik, gas atomized, particle size range 45-75 µm, mean size 60 µm
- TRUMPF TrueLaser Cell 7020 system with 3.0 kW fiber laser and coaxial laser cladding head
- Helium carrier gas, Argon shielding gas

	C	Mn	Ni	S	Cr	Si	Mo	Fe	Co
AerMet®100 steel substrate	0.23	0.01	11.13	0.001	3.0	0.02	1.17	bal.	13.43
AerMet®100 steel powder	0.24	0.86	11.3	0.00	3.1	0.96	1.21	bal.	13.4

Laser power (W)	Number of pass	Laser spot size (mm)	Transverse speed (mm/min)	Powder flow rate (g/min)	Step-over width (mm)	Carrier gas flow (L/min)	Shielding gas flow (L/min)
800	1	1.3	1400	5.15	0.6	10	16

Judgement of Significance

- Addresses the consequence and risk of incorporating the proposed repair.
- The scope of the proposed laser cladding repair is determined to be geometrical only.
- The effect of the design change in terms of form, fit or function is also assessed and possible failure of the component is considered.

Hazard Analysis

- Investigates the risk associated with laser cladding repairs as opposed to replacing the component. Any hazard description, effects, risk and risk mitigation are addressed.
- For example, dimensional tolerance is restored, structural integrity is not compromised, material hardness remains the same, quality control of the process and powder used is established and the consequence of failure is no worse than leaving the component in its current worn stage.

Design Analysis

- Investigates the in-service loading conditions acting on the repaired region and its structural integrity due to material loss.
- Repair criteria are established in which the maximum allowable or acceptable damage is identified.

Design Certification

- Formal approval or acceptance of the repair is established based on the three preceding criteria.

Deviation

- The repair method or standard operating procedure documentation is established for conducting future repairs.