



JOINING
INNOVATION
AND EXPERTISE

TWI view on Cold Spray Technology

AM Sub WG

1710NAS, 12 Nov 2019

Introduction to TWI

- Membership-Based Research and Technology Organisation
- Established 1946
- Fabrication & Integrity of Materials & Structures
- Codes & Standards (>122)

- >800 staff + 50 students
- 700 Industrial Members in 4500 locations worldwide
- Regional Centres: UK & worldwide

Introduction to TWI



WELDING, COATING & PROCESSING

Development of advanced welding / joining / forming / surfacing techniques.



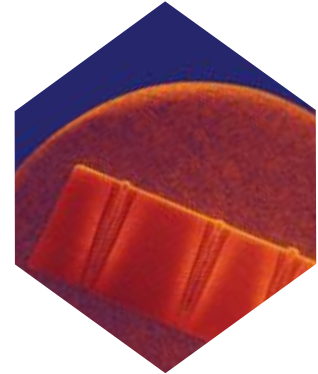
STRUCTURAL INTEGRITY

Strategies to avoid failures
Experts in fatigue and fracture
Fitness-for-service
assessments



NDT & ASSET RELIABILITY

Advanced expertise in non-destructive testing (NDT) and condition monitoring.



MATERIALS PROPERTIES

Microstructure-property
relationships
Analysis and characterisation

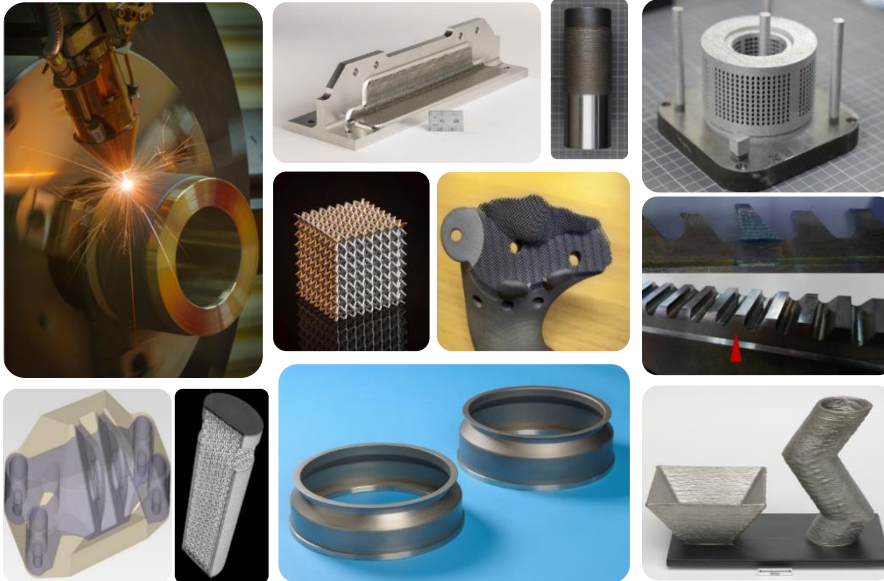
Metal AM Technology Developments

Functional Coatings

Repair & remanufacturing

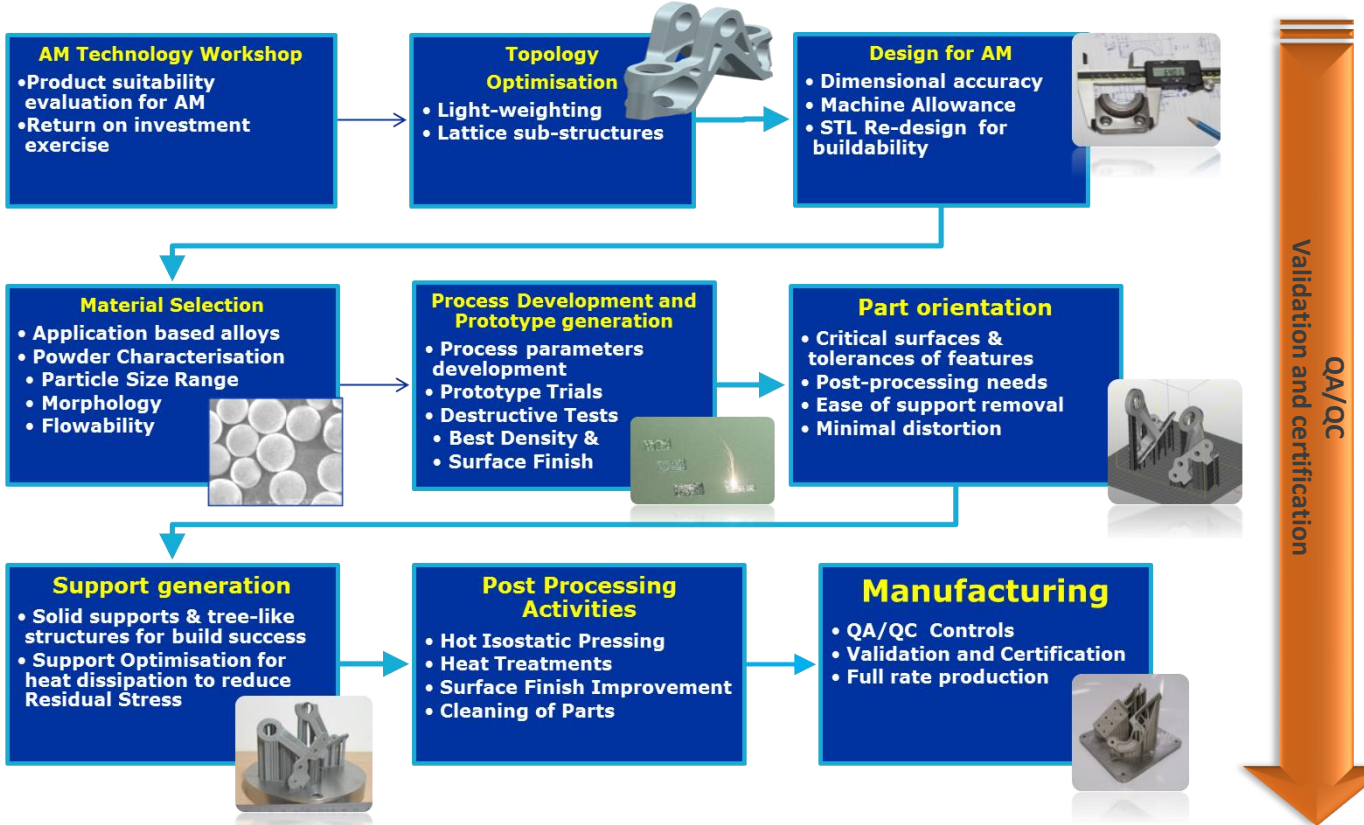
3D freeform manufacturing

Small to large scale (from mm to >1m in any one dimension)



- Laser Metal Deposition
- Selective Laser Melting
- Electron Beam
- Wire-arc
- Spraying (cold/thermal)

AM Consultancy Service (Workflow)



Open Architecture Additive Manufacturing (OAAM)

- Metallic parts with >1m dimension(s)
- Scalable architecture solution(s), with common CAD/CAM control interfacing (*Autodesk*)
- Develop and deploy 3 AM systems:
 - *Arc-wire / Laser-wire AM @Cranfield and @ Autodesk*
 - *Electron Beam-wire AM @TWI (Cambridge)*
 - *Laser-powder / Laser-wire AM @TWI (Yorkshire Technology Centre)*

AIRBUS

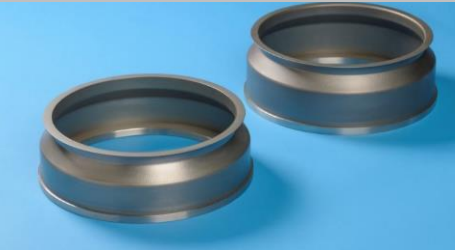


Large Scale LMD at TWI

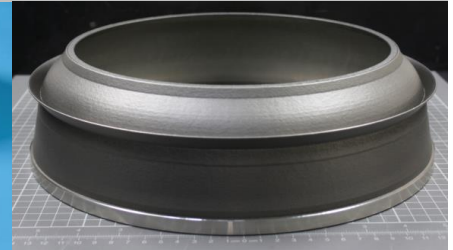
Gas Turbine Casing (1500mm diameter / 1.5mm wall thickness)



Helicopter Casing (300mm Diameter / 0.8mm wall thickness)



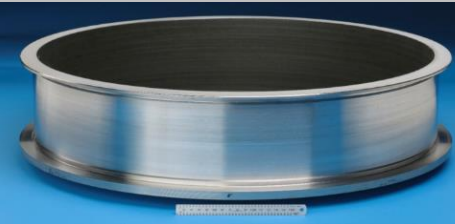
Gas Turbine Demonstrator (600mm Diameter / 1.2mm Wall Thickness)



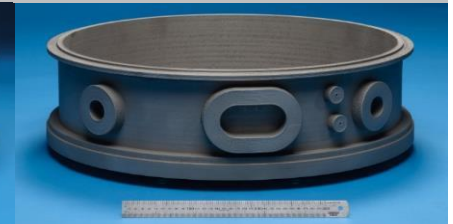
Gas Turbine Casing (600mm diameter / 1.8mm and 6mm wall thickness)



Generic Gas turbine Demonstrator (600-Diameter / 12mm wall thickness)



Aerospace Demonstrator (600mm Diameter)



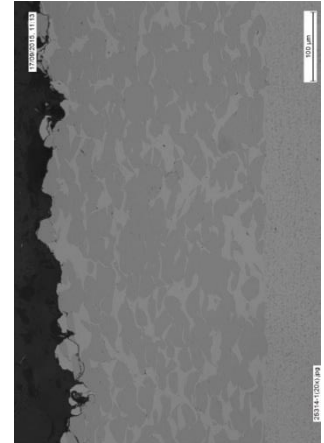
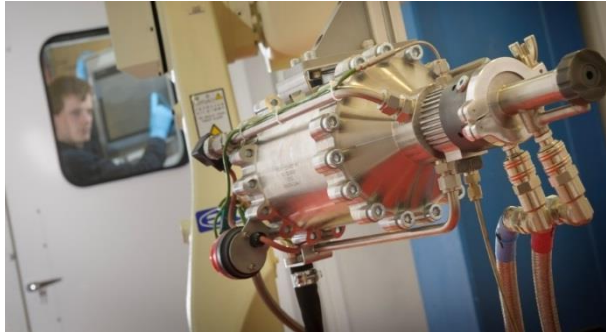
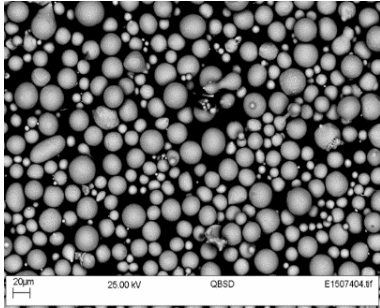
TWI AM Representation at National and International Level

- TWI leads the AM group at Nadcap (since 2014) and has developed an audit checklist with and for industry for laser and EB powder bed techniques
- TWI helped to develop the MASAAG Paper 124 Issue 1 document on “Guidance Note on the Qualification and Certification of Additive Manufactured Parts for Military Aviation” with DSTL & 1710 NAS (Oct 2018)
- TWI sits on the ISO TC 261 JWG10 committee to develop joint AM standards with ASTM F42:
 - 2 laser powder bed fusion specs will be published in Q2,2020
 - Working on 4 new ISO specs over next 2-3 years (wire + laser beam, arc + wire, laser blown powder and EB + wire)
- TWI is Vice-Chair of the “Additive Manufacturing UK National Strategy 2018 – 25” steering group

Cold Spray

Cold Spray Process

Solid state deposition / powder consumable

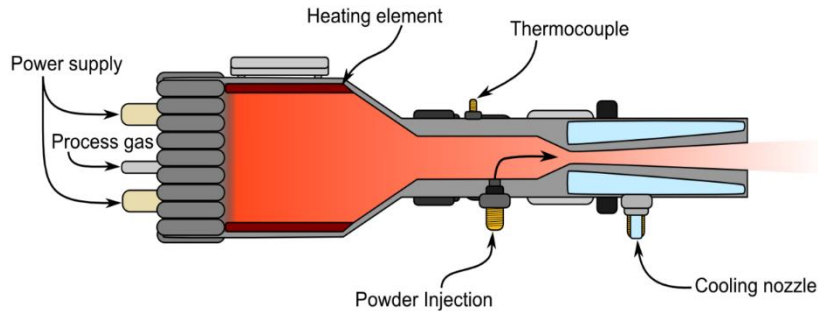
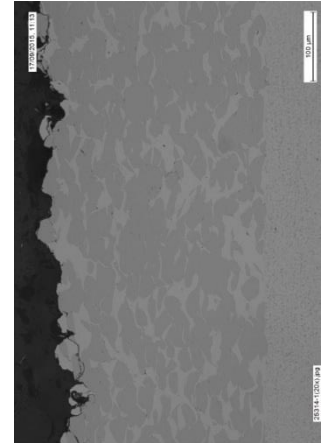
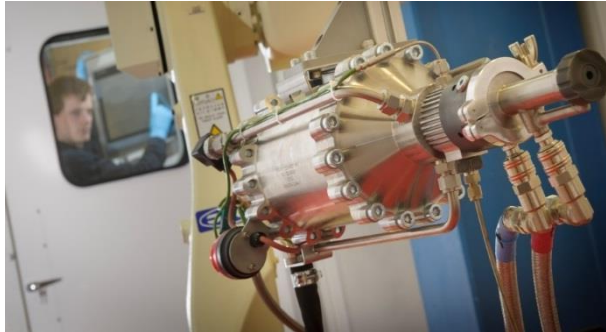
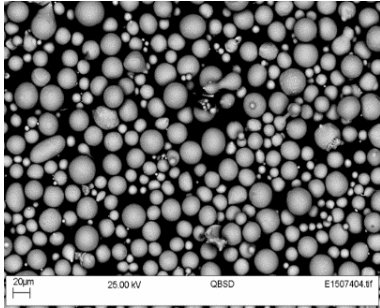


Metallic powders propelled by high pressure supersonic He or N₂ gas stream to reach a critical velocity

Solid particles propelled on to substrate where they impact and plastically deform to form a coating

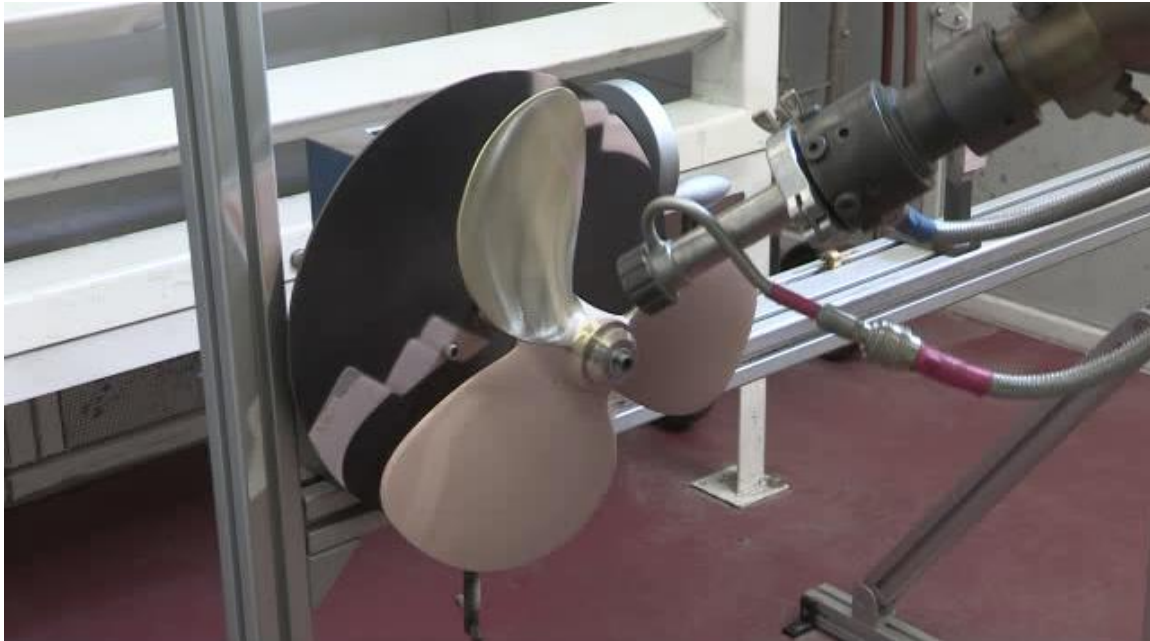
Cold Spray Process

Solid state deposition / powder consumable



Gas heated to accelerate gas and spray particles - some softening of particles can occur & can be beneficial

Cold spray deposition of anti-fouling coating on marine propeller



Note – coating deposited onto as-machined surface

Contrast with thermal spray where substrate is prepared by grit blasting

Cold Spray System Category

- Low Pressure Cold Spray:
 - Manual / portable systems
 - Limited range of coating materials
 - Limited gas heating $\sim 200\text{ }^{\circ}\text{C}$
 - e.g. Dycomet, SST, Tessonics
- High Pressure Cold Spray:
 - Mechanised systems
 - Wider range of materials
 - Gas heating up to $1100\text{ }^{\circ}\text{C}$
 - e.g. Impact Innovations, Plasma Giken
- Hybrid system:
 - Manual, portable up to 900°C , 70 bar
 - e.g. VRC Metal Systems, Impact Innovations (tbc)

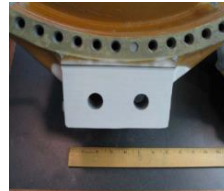
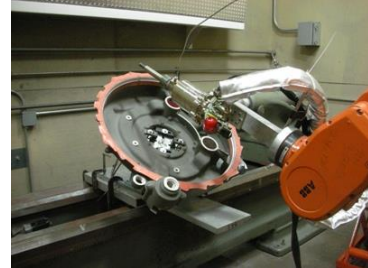


Suppliers of low pressure and high pressure portable cold spray systems



Cold spray repair of high value Al & Mg alloy components – developed by ARL since 2008

- Repair (or coating) by solid metal powder deposition
- UH-60 Blackhawk Mg gearbox repair
- C-160 Al propeller repair
- Al nose wheel steering actuators

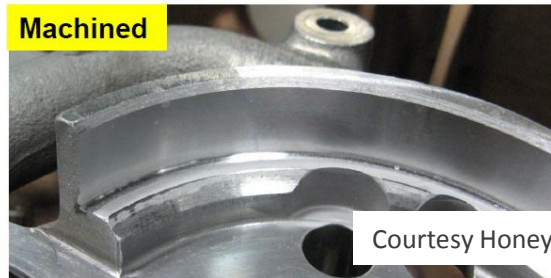
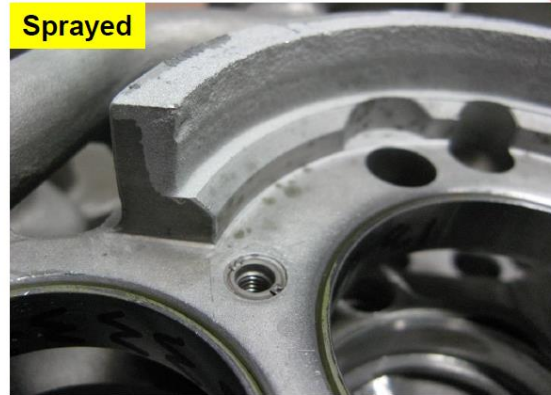
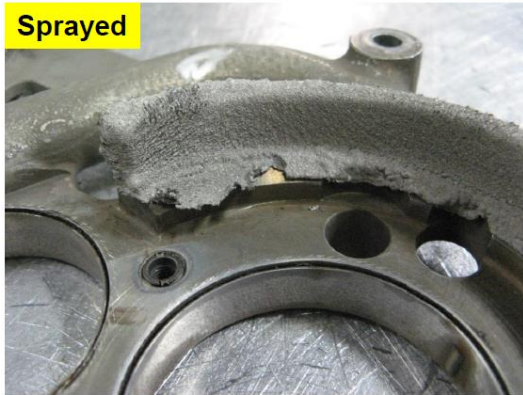


Cold spray - repair process benefits over thermal spray

Thermal spray

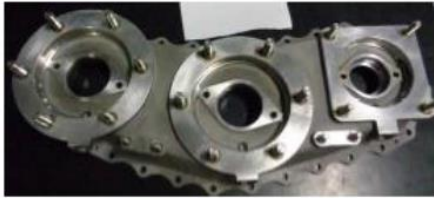
vs

Cold Spray



Courtesy Honeywell

Typical cold spray repairs – gearboxes



3060810-1



3071321-4



3862287-6



3810123-8



3071382-4



3862699-3



3862780-4



3863163-8



3863426-3

Honerwell

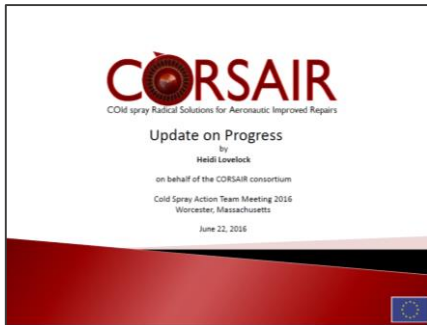
Repair of aircraft skin corrosion / erosion

- US Air Force has qualified cold spray repair of B1 bomber skin panels
- Developed by VRC Metal Systems / US Army Research Laboratory
- VRC Metal Systems is located at the entrance to Ellsworth AFB (B1 base)



Cold Spray Action Team (CSAT)

- <https://www.coldsprayteam.com/>
- Annual DoD-sponsored 2-day workshop in Worcester (MA) open to civilians (including non-US citizens)
- Driven by Vic Champagne, Army Research Lab (ARL)
- TWI has presented at 3 workshops (2016, 2017, 2019)



TWI Capabilities

- 11 thermal and cold spray processes in-house
- 4 spray booths (two of which can combine to a single, large facility 7.5 x 6 x 4m)
- State-of-the-art characterisation facilities and bespoke test setups
- Offline programming capabilities and mechanized surface preparation



Mechanised cold spray systems at TWI

CGT Kinetiks 4000/47
40 bar / 800°C max



Impact Innovations 5/11
60 bar / 1100°C max

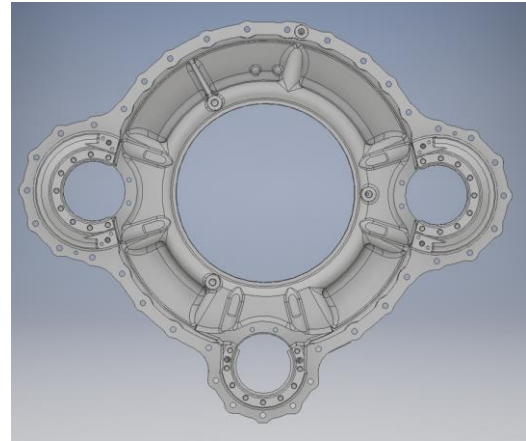
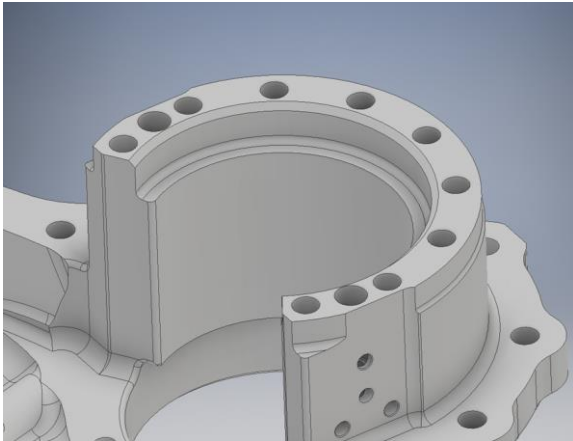


Primarily run using N₂ as cold spray process gas

TWI Cold spray repair of Mg alloy component

– courtesy of Leonardo Helicopters

- Cold spray repair



TWI has applied for DASA Rapid Impact project funding to develop technology with Leonardo to TRL7

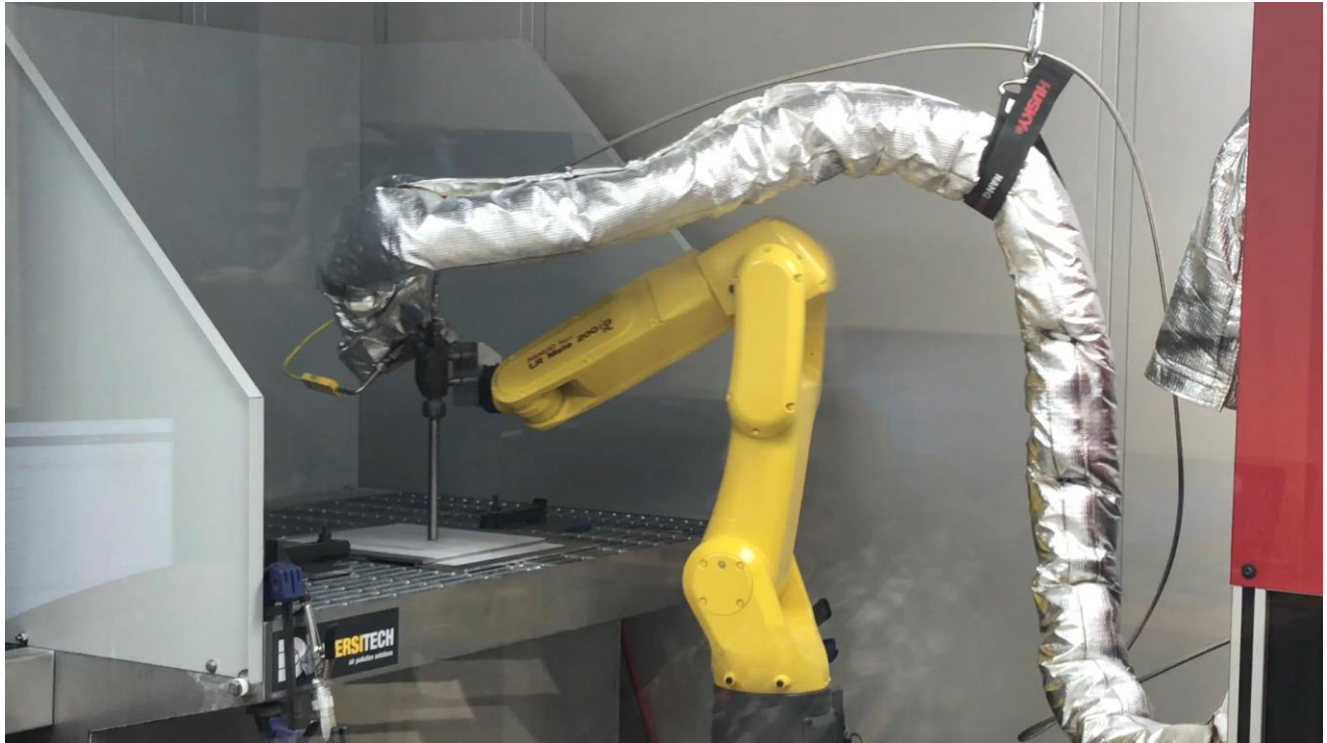
TWI Project for MoD

Evaluation of Cold Spray Technology

- Mitigation of structural steel corrosion with wear resistance
- Two portable / manual cold spray systems selected:
 - Dycomet low pressure system
 - VRC Gen III high pressure system (functionally equivalent to Dragonfly)
- Process and operator factors: P, T, stand-off, spray angle

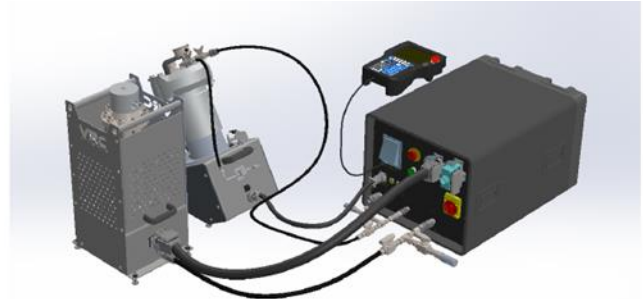


VRC high pressure cold spray system (TWI project for MoD)



CS repair – Dragonfly “hatchable” cold spray

- High pressure, portable, manual shipboard system developed for US Navy during 2019
- System specification:
 - Deposit efficiency of Al6061 70-80%. CP Al higher?
 - Throughput 20 g/min = 1.5m²/hour
 - Target adhesion >2000psi (13.8MPa).
 - Extraction 1000 cfm.
- Has achieved ETL certification (CE marking next).
- To be displayed at ITSC conference / exhibition in June 2020
- Subject to confirmation - to be demonstrated at TWI & Naval base the following week

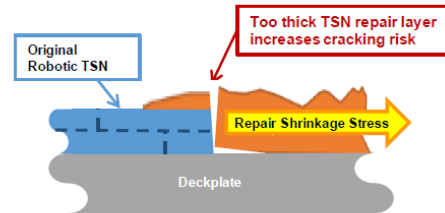


Repairing flight deck TSA – US experience

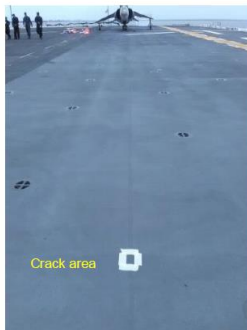
New TSN Standard Item 009-BB TSN Repair Performance

TSN REPAIR PERFORMANCE CHARACTERISTICS:

- Corrosion Control / Adhesion
 - TSN applied to deck as liquid metal droplets that shrink as they cool. Increased layer thickness increases stress and risk of edge cracking/delamination.
 - Robot applies TSN in overlapping, staggered layers to resist cracking.



ISSUE: Small crack observed in TSN after installation.



Epoxy primer
repair!

Potential
application for
cold spray?

Crack inspected and found no loose material. Most likely related to inadequate surface profile on weld.

Cut edges of crack away with small rotary power tool. Aluminum-based TSN does not feather effectively.

5 in² weld exposed and applied epoxy primer to seal area.

NAVSEA cold spray repair example

- NORFOLK NAVAL SHIPYARD, Portsmouth, VA.
- “The number one priority for innovative technologies for Naval Sea Systems Command is bringing cold spray technology to the fleet. With a team effort from Norfolk Naval Shipyard (NNSY) employees and a partnership with Penn State Applied Research Laboratory (ARL), Cold Spray has officially surfaced at America’s Shipyard.”
- Hydraulic actuator not repairable by traditional methods and the lead-time for a replacement was in excess of 10 months from the vendor



<https://www.navsea.navy.mil/Media/News/SavedNewsModule/Article/1956373/eye-on-innovation-the-coolest-team-brings-cold-spray-to-nnsy/>

US Naval Base Puget Sound – Cold Spray Repairs

- <https://www.coldsprayteam.com/3%20Stamey%20%20Presentation%20PSNS%20OCSAT%202018%20Approved.pdf>

Cold Spray Case Studies and Implementation

Tom Stamey
PSNS & IMF, C/260M



Case Study: Swing Check Valve



Body

- VRC Gen III cold spray system
- CuNi 70/30 substrate
- Praxair Ni-914-3 (Ni 99.0 min)

Case Study: Swing Check Valve



Spraying the Mockup

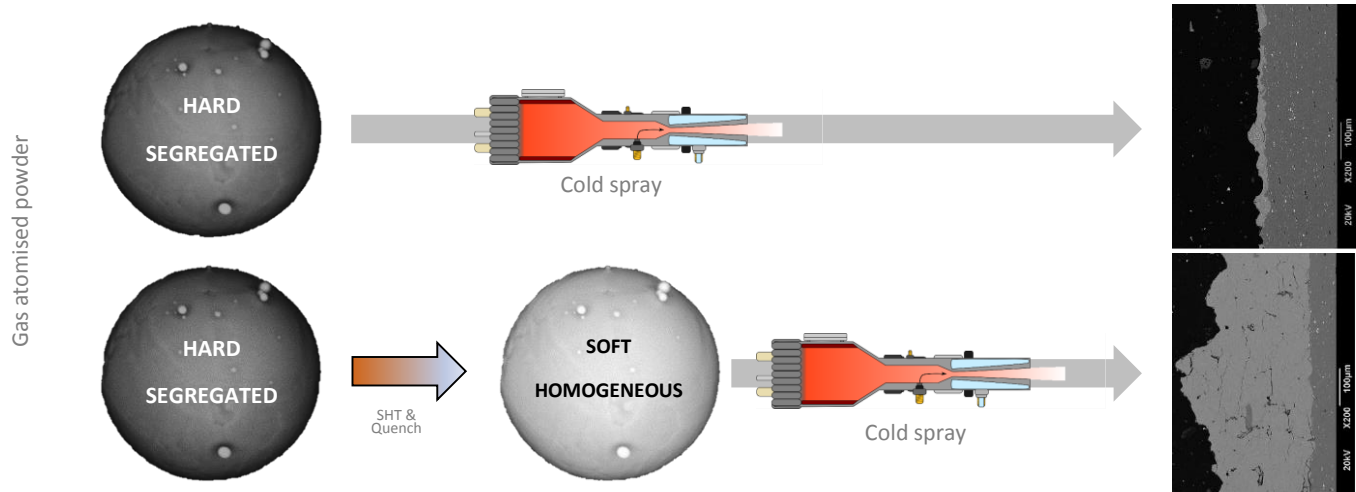


Mockup
Upper sleeve removed

Al feedstock development – route to load-bearing repairs

Innovate UK project (TWI, PSI, Alphatek, BAE Systems)

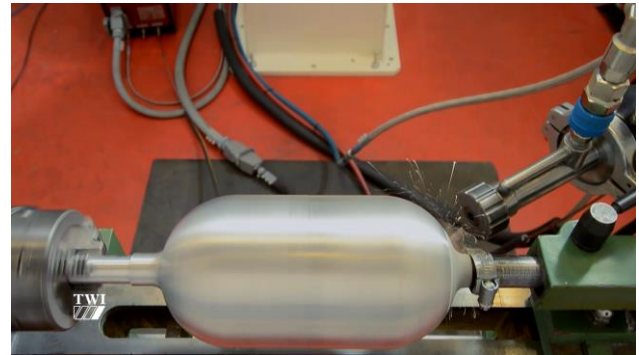
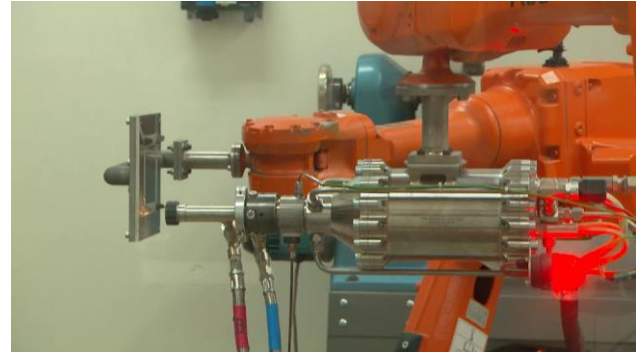
- Precipitation-hardenable Al alloys (2XXX, 6XXX, 7XXX, etc) can be difficult to deposit by cold spray
- It is possible to tailor properties by heat treatment prior to spraying



Sabard, A., de Villiers Lovelock, H.L. and Hussain, T., 2018. Microstructural Evolution in Solution Heat Treatment of Gas-Atomized Al Alloy (7075) Powder for Cold Spray. *Journal of Thermal Spray Technology*, 27(1-2), pp.145-158.

Cold Spray Additive Manufacture (CSAM)

- ‘Freeform’ deposition – like more conventional laser DMD approaches:
 - Co-operative robot deposition
 - Control systems for powder switching at corners
 - Limited resolution
 - Limited complexity from line-of-sight deposition & self-supporting
- ‘Template’ deposition onto substrate that can be removed:
 - Suited to alloys where conventional processing routes are expensive and difficult (e.g. Ti)
 - Can achieve very high build rates
 - May require support to be removed (melting, dissolving, machining)

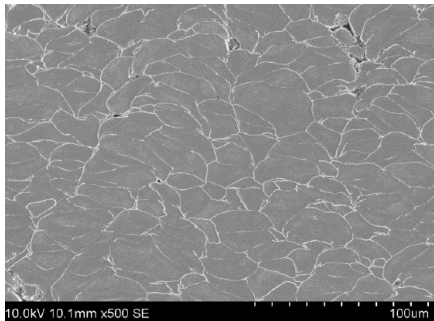


Cold spray forming of Ti-6Al-4V propellant tank

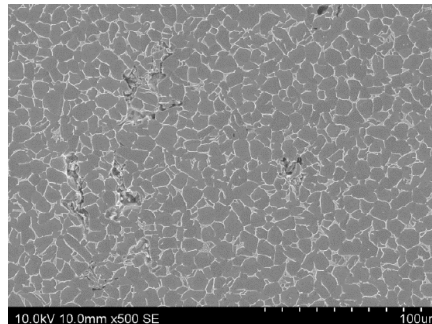
Ti-6Al-4V has been successfully spray formed to a variety of shapes.

Coating properties

- Deposition efficiency >90%
- Density >98%
- Hardness \approx 350-450Hv as-deposited (depending on parameters used)
- UTS (As deposited) \approx 225 Mpa
- UTS (heat treated) \approx 819 MPa



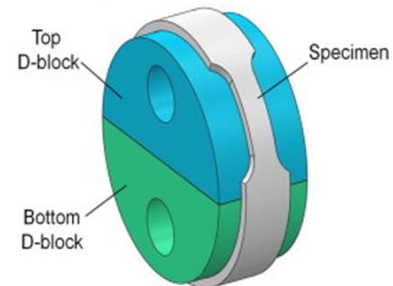
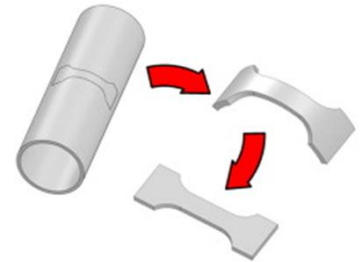
Ti-6Al-4V coating – as-sprayed



Ti-6Al-4V coating – heat-treated

Ti alloy propellant tank – development

- Current project “Mechanical properties of Ti alloy AM components manufactured by cold spray forming”
 - TWI – manufacture cylinders, heat treatment / HIPing, tensile testing (longitudinal & ring hoop tension test)
 - ESTEC / Harwell – NDI / X-ray CT, SCC
- Next step (2020, Q1-Q3) ⇨ Discovery Project / Technology Research Programme
 - Manufacturing / deposition strategies
 - Metallurgical issues – optimise heat treatments
 - Test and qualify properties strength, ductility, fatigue, toughness
 - Include an aluminium layer for de-misability?



Cold Spray Additive Manufacturing (CSAM)

- Worcester Polytechnic Institute (WPI) Receives \$25m to Bring Cold Spray 3D Printing Techniques to the Battlefield:
 - \$25m award from U.S. Army Combat Capabilities Development Command Army Research Laboratory (CCDC-ARL)
 - <https://www.wpi.edu/news/wpi-receives-25-million-award-bring-cold-spray-3d-printing-techniques-battlefield>

Outline proposal for a UK Cold Spray Centre for the Defence Sector

■ Cold Spray Centre stakeholders / steering committee

- MoD representatives including Abbey Wood / Dstl / DST
- Representatives from each service (air, land & sea)
- Industrial representatives, such as Leonardo, Rolls-Royce, BAE Systems, Babcock

■ Centre deliverables (TWI)

- Defence Standard for portable / manual cold spray application.
- Defence Standard for mechanised cold spray / load-bearing application.
- MoD-dedicated, mobile (in a container) manual / portable cold spray system for on-site demonstration and trials.
- MoD-dedicated cold spray cell at TWI compliant with Industry 4.0 'Factory of the Future' requirements for mechanised and portable demonstration and application development.
- Development and qualification of cold spray repair applications for MoD and its prime contractors.
- Technology transfer, such as support is setting up cold spray repair facilities at MoD sites, prime sites or qualified cold spray coating vendors.
- PhD and MSc projects to underpin technology with good science.

Standards (1)

- DEF STAN 02-828 Issue 3, 2013: Requirements for Thermal Spray Deposition of Metals and Ceramics for Engineering Purposes
 - Under revision by TWI, does not include TSA (refers to BS EN ISO 2063)
 - Revision will not include cold spray

- BS EN ISO 14921:2010 Thermal spraying — Procedures for the application of thermally sprayed coatings for engineering components
 - Includes cold spray (but not load-bearing)

- BS EN ISO 2063:2017 Thermal spraying - Zinc, aluminium and their alloys
 - Part 1: Design considerations and quality requirements for corrosion protection systems
 - Part 2: Execution of corrosion protection systems
 - Does not include cold spray

Standards (2)

- MIL-STD-3021, 2015 - Manufacturing Process Standard Materials Deposition, Cold Spray
 - No BS EN ISO equivalent to MIL-STD-3021
 - Includes load-bearing repairs

- MIL-DTL-32495, 2018 - Detail Specification for Powders for Cold Spray Deposition
 - No BS EN ISO equivalent to MIL-DTL-32495

- Arguably, there is a case for producing two standards for cold spray:
 - Cold spray – Procedures for the application of cold sprayed coatings for engineering components (to accommodate the option for load-bearing repairs).
 - Cold spray – Al, Zn and their alloys – Design considerations, quality requirements and execution of corrosion protection systems.



Eur Ing David Harvey

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Cold spray 3D printing

