TWI Seminar:
Recent Advances in Surface Engineering at TWI
Jidosha Kaikan, Kudan (Automotive Center), 2nd Floor, Kudan-Minami 4-8-13, Chiyoda-ku, Tokyo, Japan

28 November 2012

09:45 – 10:00	**Coffee/Registration**	
10:00 – 10:05	Welcome and introductory remarks	T Fukuda, UKD
10:05 – 10:20	Introduction to TWI Services	G Wylde, TWI
10:20 – 10:40	Introduction to TWI's Materials, Corrosion & Surfacing Group	D Harvey, TWI
10: 40 – 11:00	Overview of TWI Thermal Spraying & Cold Spraying	D Harvey, TWI
11:00 – 11:10	**Coffee/tea**	
11:10 – 11:40	Introduction to Cold Spray Technology	T Marrocco, TWI
11:40 – 12:00	Laser Surface Engineering	D Harvey, TWI
12:00 – 12:20	Protecting Steel Structures from Corrosion using Thermal Spray Aluminium (TSA)	D Harvey, TWI
12:20 – 12:30	Discussion	
12:30 – 13:30	**Lunch**	

Introduction to TWI

Graham Wylde

November 2012

Your Partner in Technology Engineering

- **A world centre of expertise in Manufacturing, Engineering, Materials and Joining**
- **Dedicated to supporting the needs of our Industrial Membership**
- **Non-profit distributing**

TWI Technology Engineering

TWI in 2012

- £65M of R&D in materials joining and related technologies
- Almost 700 Members operating in over 4500 locations worldwide
- More than 700 staff

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Annual Support for Industry

- More than 8,000 hours of free technical support
- Over 15,000 visitors
- More than 700 Single Client and Group Sponsored Projects
- 70 Core Research Projects
- 65 European Collaborative Programmes
- TWI staff sit on more than 100 Standards bodies
- Over 15,000 people attend our training courses each year

TWI Technology Engineering

Our Support for Industry

Benefits for Members

- Technical helpdesk
- Confidential R&D projects
- Detailed technical discussions
- Access to Core Research Reports
- Access to online technical information
- Discount on training courses
- Networking opportunities
- Help to reduce organisational risk

TWI Technology Engineering

Providing you Information

- Our website
  - Direct access to TWI's expertise via 'Who Knows'
  - Best practice guides
  - Core Research Reports
  - Technical papers
  - More than 1,000 FAQs
  - Knowledge summaries
  - Weldasearch

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Our Expertise

- Joining and welding processes
- Structural performance
- Materials engineering
- Corrosion management
- Modelling/simulation
- Inspection
- Quality and safety
- Surface engineering

TWI Technology Engineering

Services we Provide

- Research and development
  - Consultancy
  - Manufacturing support
  - Fabrication and repair
- In-situ assessment and on-site services
- Failure investigation
- Technology transfer
- Training and certification
- Software

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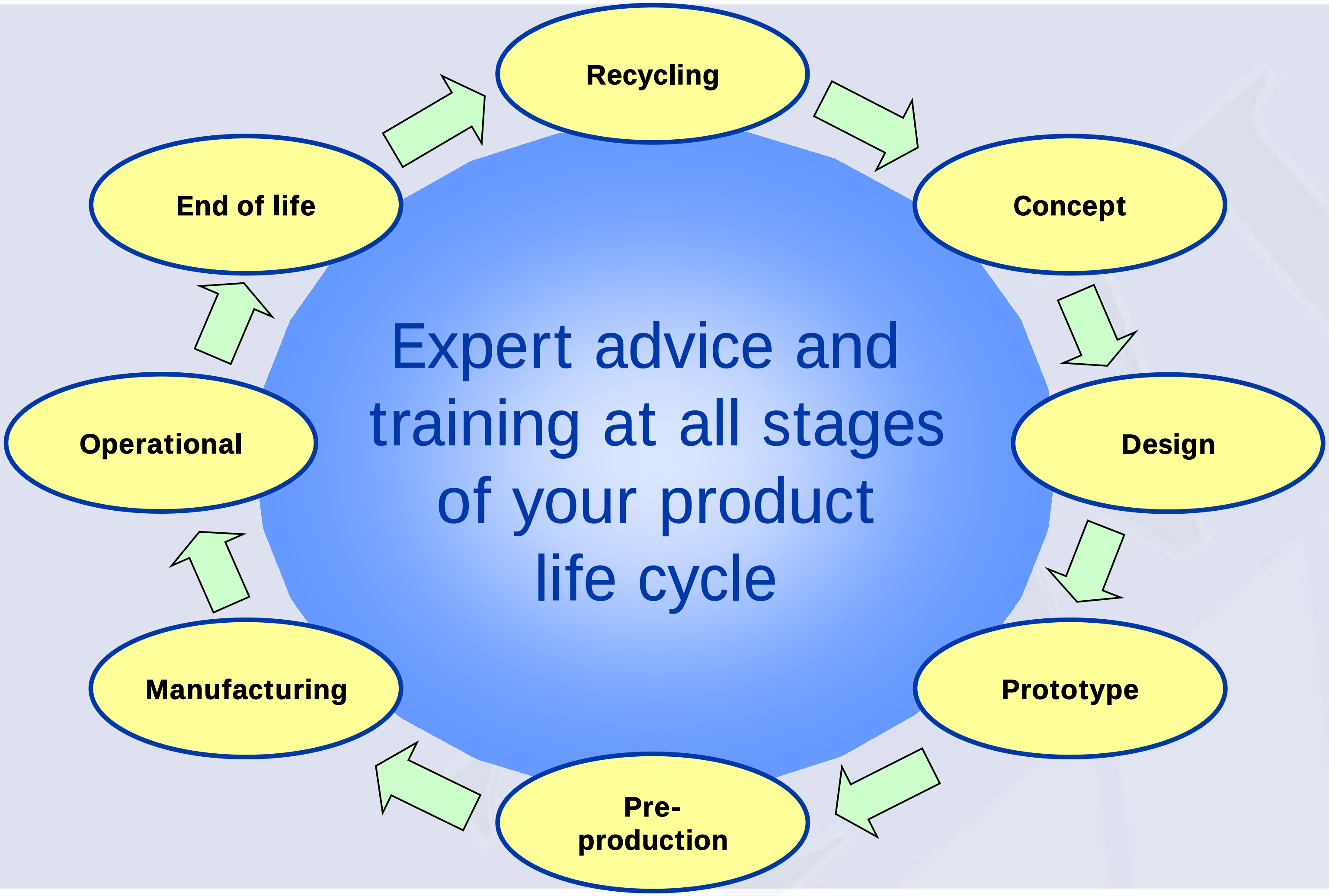
Our Support to You



TWI Technology Engineering

Our Technology Groups

- **Arc welding engineering**
- **Electron Beam, Friction and Lasers**
  - including
    - **Resistance welding**
    - **Mechanical fastening**
- **Advanced Materials**
  - Polymers and Textile joining
  - Composites and Adhesives
  - Ceramics
  - Microtechnology and Electronics

TWI Technology Engineering

Our Technology Groups

- **Metallurgy, Corrosion & Surfacing**
  - **includes spraying technologies**
- **Structural Integrity**
  - **Fatigue Integrity Management**
  - **Fracture Integrity Management**
  - **Asset Integrity Management**
  - **Modelling and Optimisation**
- **Non Destructive Testing**
- **Manufacturing support**
- **Business systems and Software development**

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TWI and Granta Park 2012

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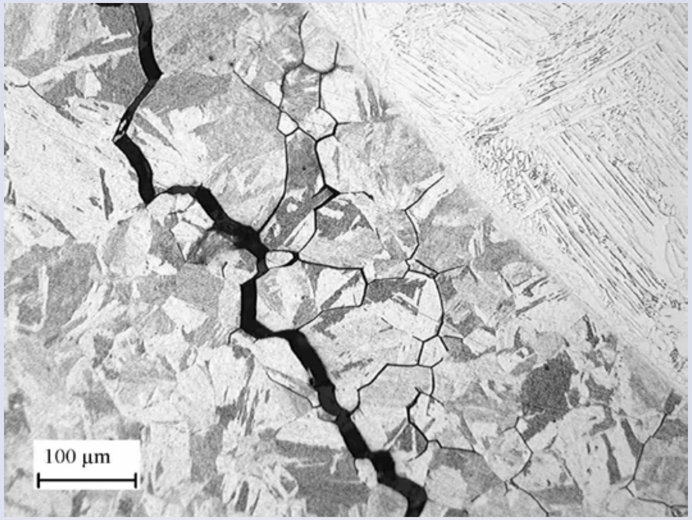
Introduction to TWI's Materials, Corrosion and Surfacing Group

Dave Harvey
Consultant, Surface Engineering



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TWI Technology Groups

- Metallurgy, Corrosion & Surfacing
- Structural Integrity
  - Fatigue Integrity Management
  - Fracture Integrity Management
  - Asset Integrity Management
  - Modelling and Optimisation
- EB, Friction and Lasers
- Non Destructive Testing
- Advanced Materials
- Manufacturing Support
- Business Systems and Software

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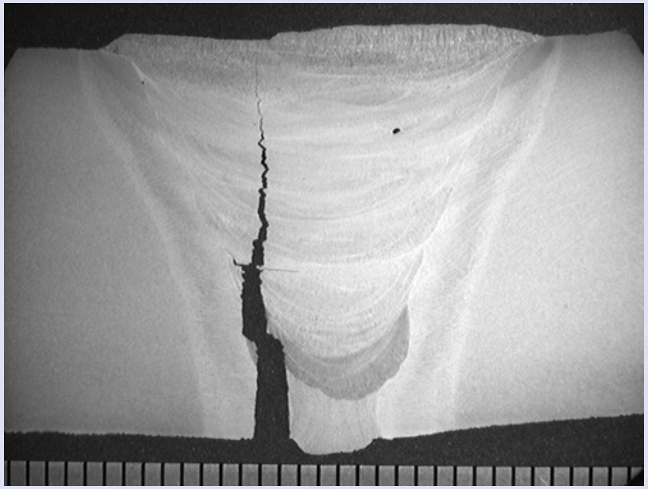
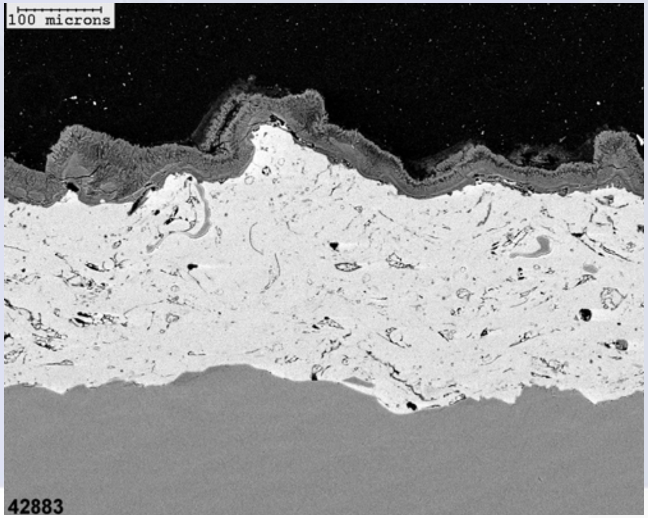
MCS Group Structure

- **Metallurgy, Corrosion and Surfacing**
  - **Ferritic Steels**
  - **Corrosion Resistant Alloys**
  - **Surfacing**

MCS Expertise

- **Weld Metallurgy:**
  - Weld microstructures & flaws
- **Failure mode identification**
- **Environmentally-induced cracking**
  - e.g. H_2 S; $H_{2;}$ Supercritical CO_2
- **Corrosion expertise**
- **Test method development**
  - Large scale or specialist tests
- **Thermal Spray Coatings**
  - Development & testing





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Hydrogen in Steel - Early Years

- The Welding Institute
- HAZ cracking and hydrogen research since 1940s.
- Fabrication Hydrogen Cracking
  - Book, 1973
  - BS 5135, 1974
- Sour service
  - Dedicated laboratory since 1973

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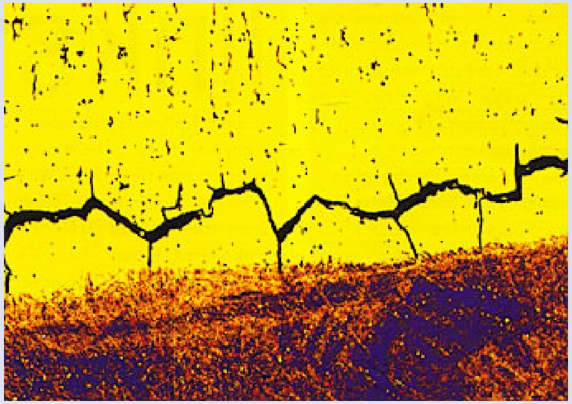
Hydrogen in Steel – More Recent

- Corrosion fatigue (sour)
- Hydrogen assisted cracking of duplex and dissimilar joints (seawater with cathodic protection)
- Performance in high pressure hydrogen gas
- Permeation (polymers)

Breadth of Work on H_2 in Steel

- **Welding**
  - **HAZ hydrogen cracking**
  - **Weld metal hydrogen cracking**
  - **Ambient environment effects**
  - **Evaluation of delay time**
  - **Probabalistic modeling**

- **Hot, high pressure hydrogen**
  - **Disbonding**
  - **Hydrogen attack**



Corrosion / Hydrogen Testing

Aqueous

Sweet (CO_2)/Sour (H_2S) - Oil & Gas Exploration

Saline/Marine - Offshore/Subsea Structures

High pressure

Supercritical CO_2 - CCS/EOR/Oil & Gas Wells

Hydrogen - Hydrogen Storage & Fuel Cells

High temperature

Gaseous/Molten Salt - Boilers/Combustion Plants

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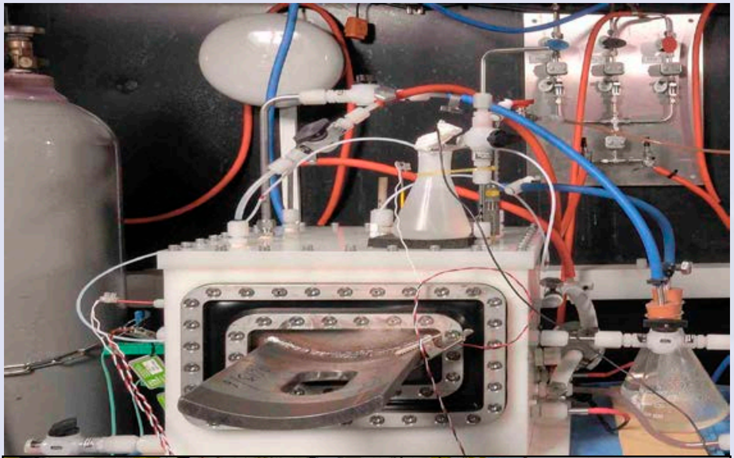
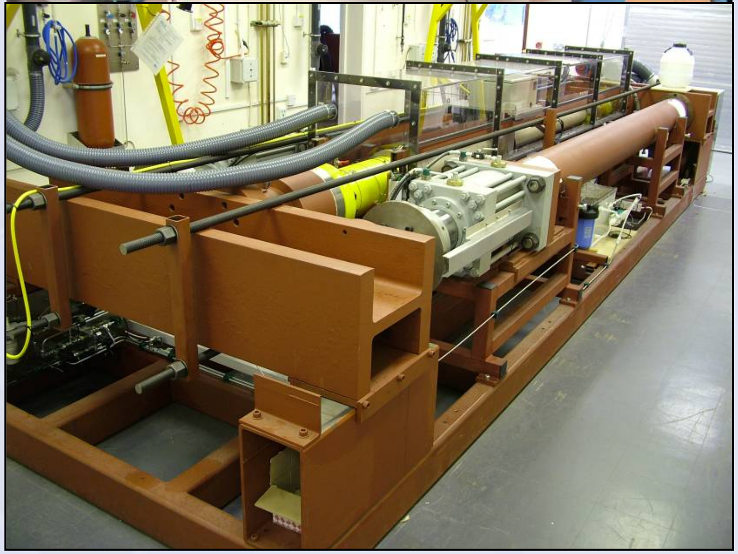
Environmental Testing

- Trevor Gooch Corrosion Laboratory - 1000m^2
- Full-scale and small-scale sour testing
- Corrosion fatigue (endurance and fatigue crack growth rate)
- Static load (bend, tensile)
- Testing standards include NACE TM0177, NACE TM0284, ISO 15156, EFC16 & 17





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Extensive Sour Fatigue Facilities

- **Crack growth rigs**
  - bend specimens
  - 20bar, 200°C
  - 2bar, 100°C
  - crack length monitoring

- **Axial fatigue rigs**
  - large strip specimens from girth welds
  - 80°C, 1bar vessels
  - Environmental control: H_2S, O_2, pH/Fe^{2+}

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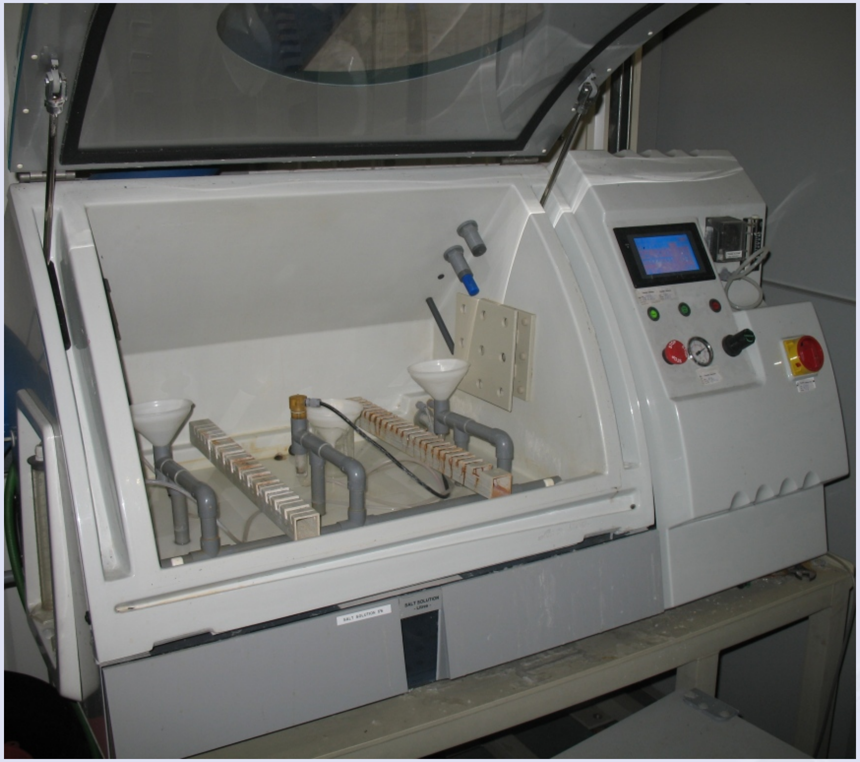
Simulated Offshore Environments



Salt Spray

21 samples
150×100×6mm

4 rigs

Alternate Immersion

6×4=24 samples
75×75×6mm

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Corrosion / Hydrogen Testing

Aqueous

Sweet (CO_2)/Sour (H_2S) - Oil & Gas Exploration

Saline/Marine - Offshore/Subsea Structures

High pressure

Supercritical CO_2 - CCS/EOR/Oil & Gas Wells

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High temperature

Gaseous/Molten Salt - Boilers/Combustion Plants

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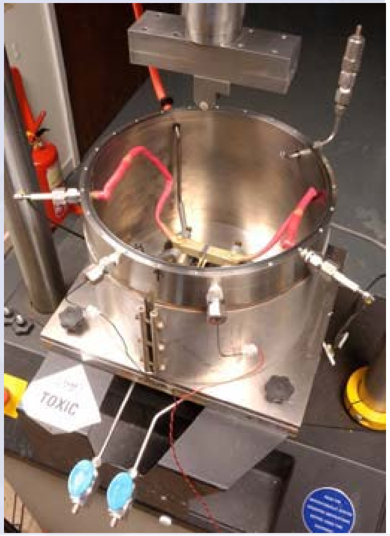
Supercritical CO_2 (with H_2S)

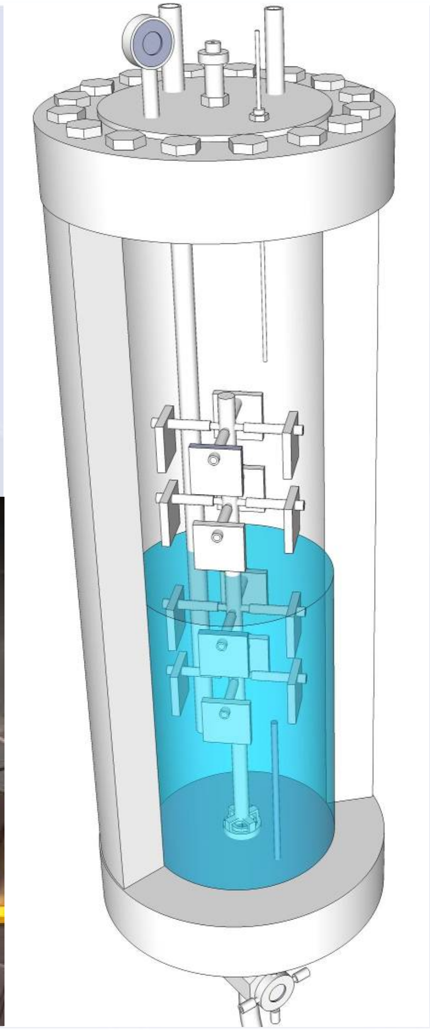
Up to 200 bar in CO_2 (with H_2S up to 200°C).

Autoclaves for testing in high pressure CO_2 only, or with H_2S, H_2O, CH_4, N_2 etc.

Electrochemical monitoring during testing at lower pressure

FCGR, Strip and full scale testing in pressurised sweet and sour environments





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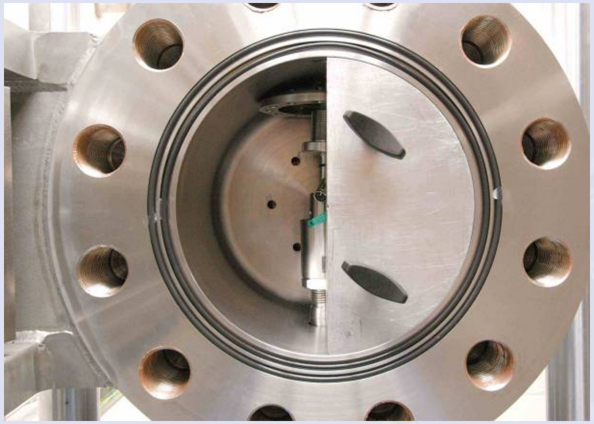
High Pressure Gas Test Facility



- 1000 & 450bar, +/- 100°C vessels on 100kN servo-hydraulic
  - Tensile, fracture & fatigue tests
- Hydrogen economy
  - need to transport and store H_2(g)
- Proposing work for supercritical CO_2/H_2S

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High Pressure Hydrogen

400bar, RT to ~100°C

1000bar, -50°C to ~100°C

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Corrosion/Hydrogen Testing

Aqueous

Sweet (CO_2)/Sour (H_2S) - Oil & Gas Exploration

Saline/Marine - Offshore/Subsea Structures

High pressure

Supercritical CO_2 - CCS/EOR/Oil & Gas Wells

Hydrogen - Hydrogen Storage & Fuel Cells

High temperature

Gaseous/Molten Salt - Boilers/Combustion Plants

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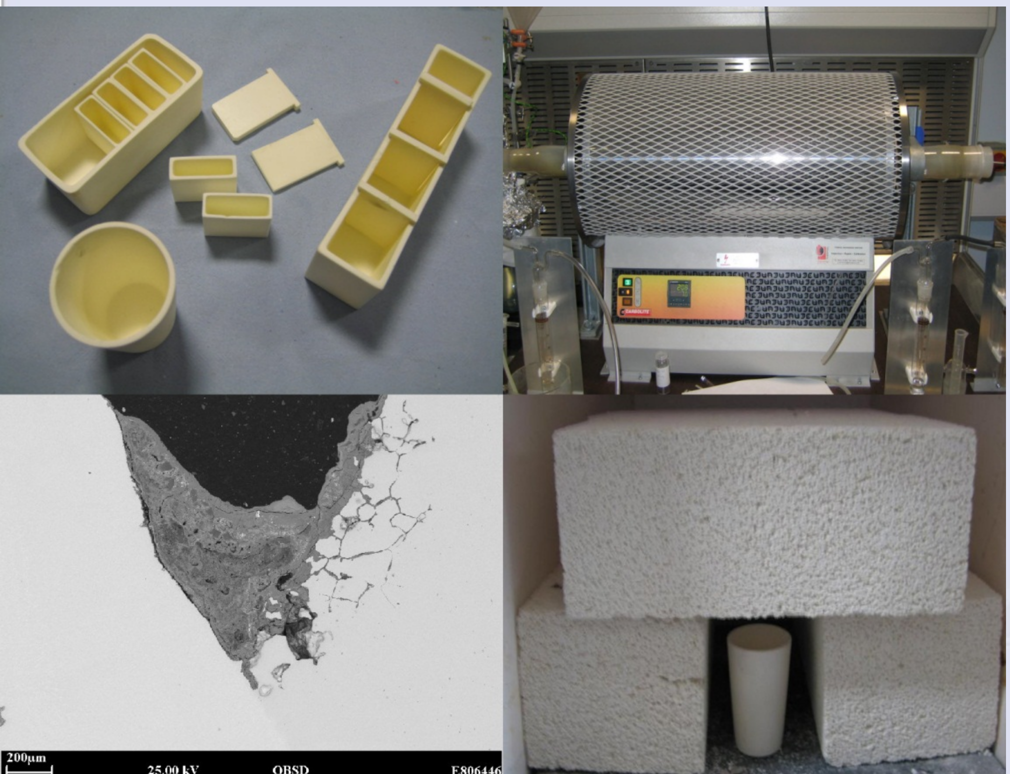
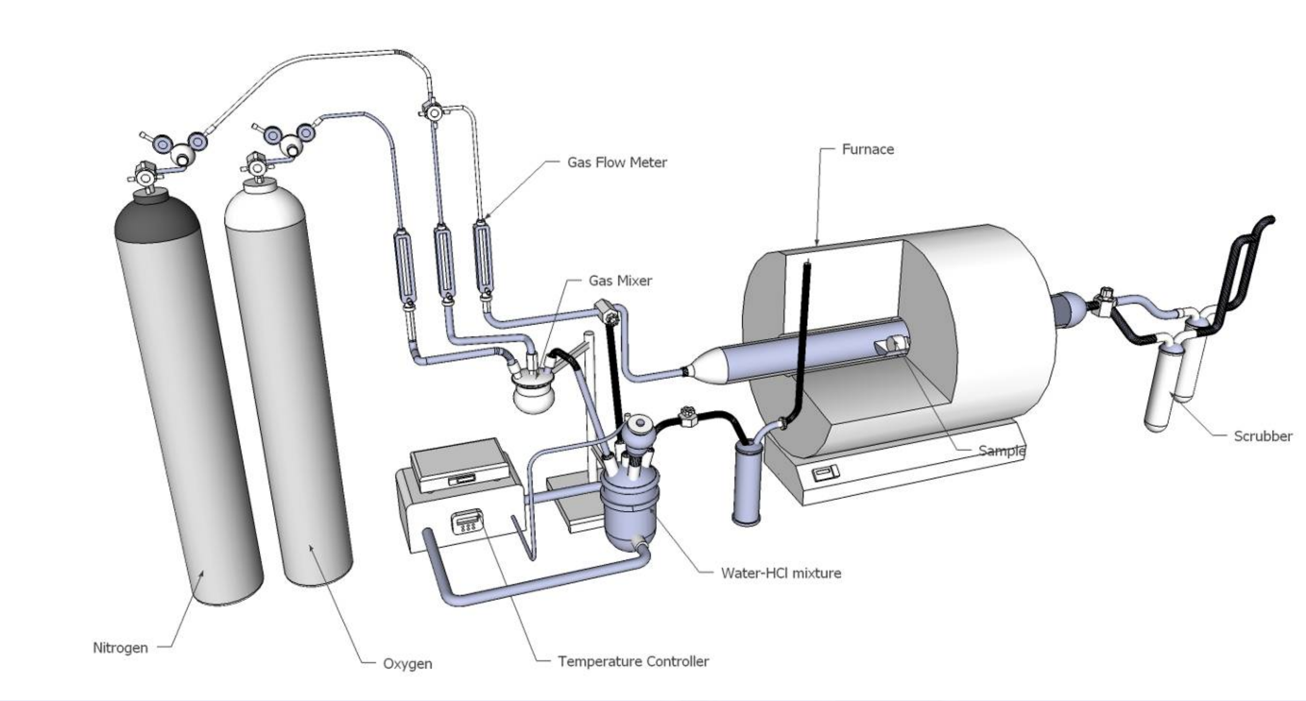
High Temperature Corrosion at TWI



- Gaseous Corrosion Cells
- Supports a variety of gases and flow rates (e.g. HCl, CO_2, air, steam)
- Up to 6 samples at once
- No cross-contamination
- Testing at up to 1100°C for extended durations
- Modular – can be reset for other experiments
- Maximum sample size 40x40mm

High Temperature Corrosion Facility



Conditions

RT-1000°C

- O_2, N_2, HCl, H_2O
- Salt Mixtures

* CO, CH_4, SO_2

Applications

- Dry & wet Oxidation
- Chlorine-assisted corrosion
- Molten Salt Corrosion

* Metal dusting etc.

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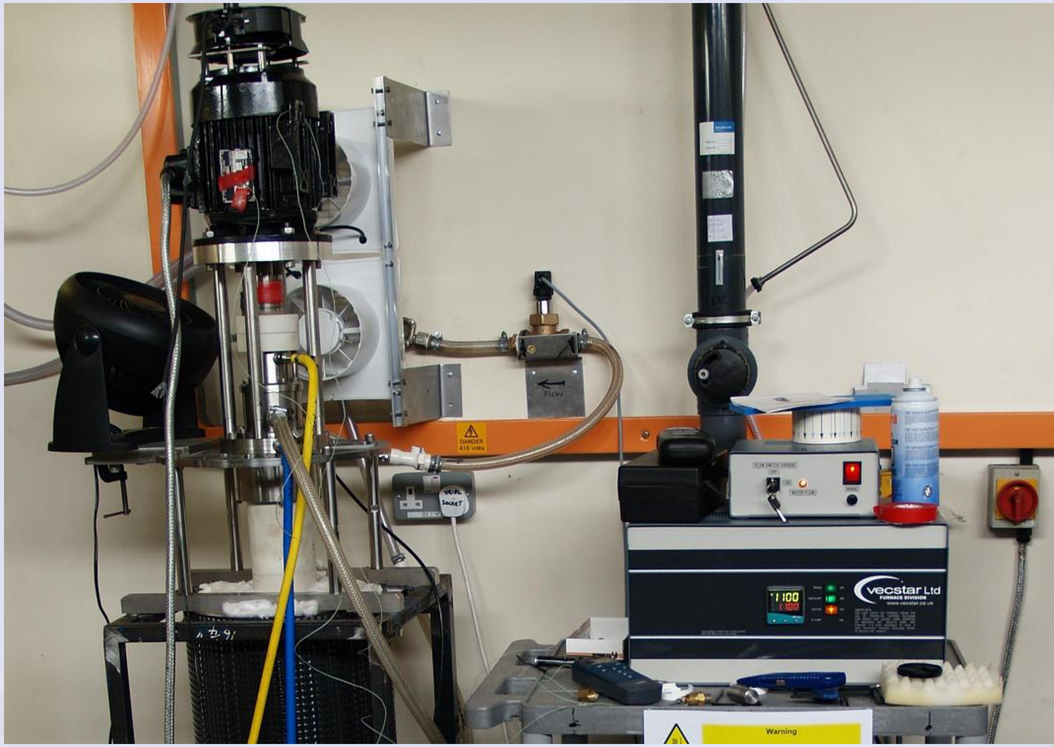
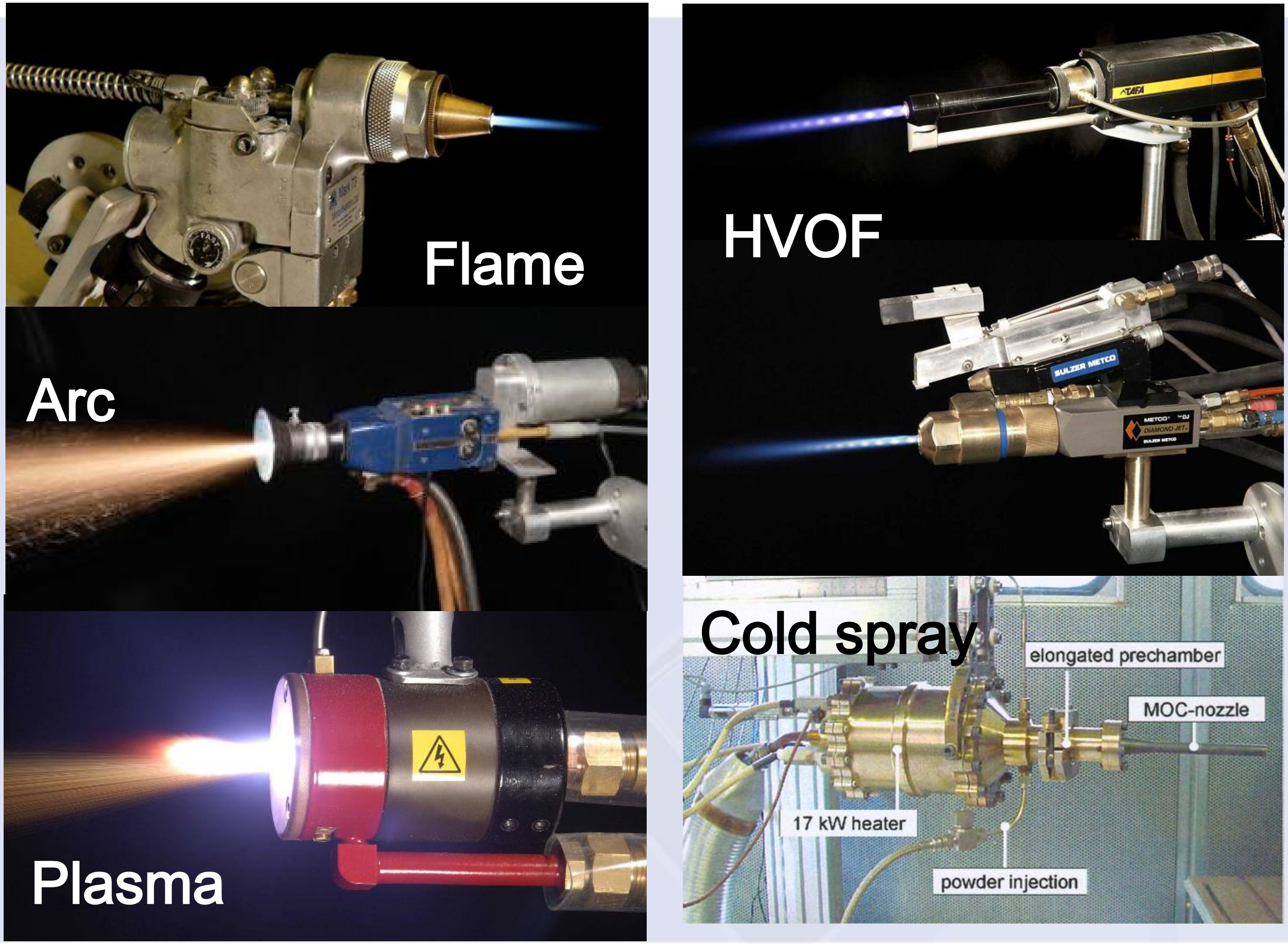
Molten Salt Erosion-Corrosion at TWI

- Erosion-Corrosion Cell
- Spins samples at up to 1200rpm in molten salts
- Temperatures up to 1100°C under argon
- Suitable for chlorides, hydroxides, carbonates
- Modular – can be reset for other experiments
- Maximum sample diameter 10mm



Thermal & Cold Spraying Systems



TWI Surfacing Section

- **Process technologies:**
  - HVOF (Top Gun® / Diamond Jet ® / JP5000 ® / HVT wire)
  - Air Plasma Spray (APS)
  - Twin wire arc spray, wire & powder flame spray
  - Cold Spray
- **Services offered:**
  - Coatings development (fundamental R&D)
  - Coating applications development
  - Consultancy:
    - Materials selection
    - Failure investigations
    - Coating characterisation and testing.

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Overview of TWI Thermal Spraying & Cold Spraying

Dave Harvey

Consultant, Surface Engineering

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TWI Surface Engineering Section

Heidi Lovelock
Section Manager

David Harvey
Technology Consultant

Dr Melissa Riley
Senior Project Leader
(Thermal Spray Coatings Technology)

Dr Tiziana Marrocco
Senior Project Leader
(Cold Spray Coatings Technology)

Dr Shiladitya Paul
Senior Project Leader
(Coatings and Corrosion)

Gary Muggridge
Senior Cold Spray Technician

Andrew Tabecki & Frank Nolan
Senior Thermal Spray Technicians

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TWI Surface Engineering Section

- **Process technologies:**
  - HVOF, plasma, twin wire arc, flame spray (Cambridge).
  - Cold gas dynamic spray (Sheffield).
  - Three 6-axis robots with thermal spray programming.
- **Main services:**
  - Applications development.
  - Fundamental R&D.
  - Consultancy services and materials selection.
  - Coating failure investigations.
  - Coatings characterisation and testing.

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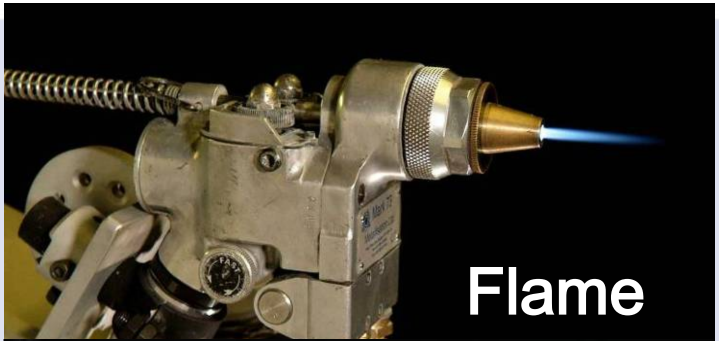
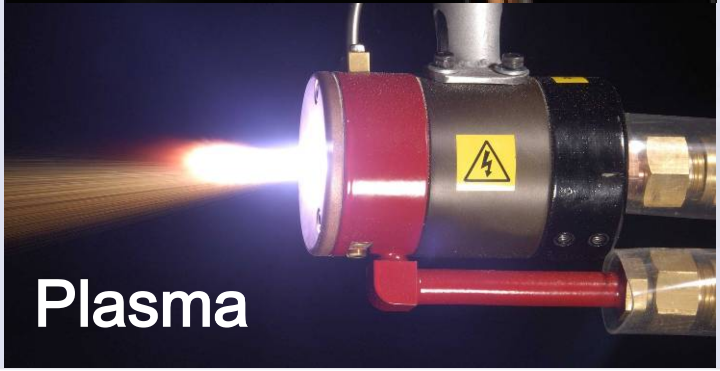
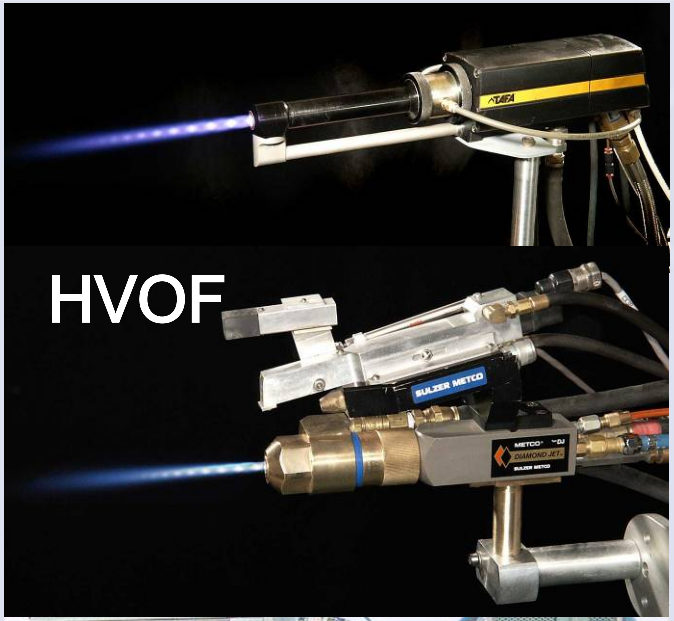
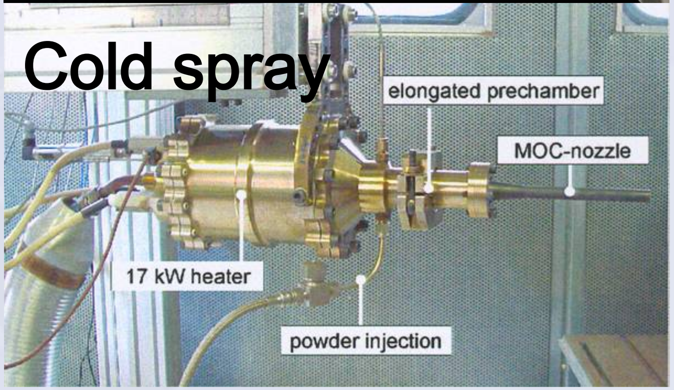
Thermal & Cold Spraying Systems









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TWI Thermal Spraying Facility

- 3 sound attenuated booths (Cambridge 2, TWI Yorkshire 1).
- 4 HVOF systems (TopGun / DJ / JP5000 / HVTwire).
- Plasma spray & arc spray.
- Wire and powder feed flame spray.
- Cold spray (TWI Yorkshire).

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TWI Cold Spray System

- **Kinetiks 4000/47 cold spray system**
- **CGT commercial system - (now Sulzer Metco)**

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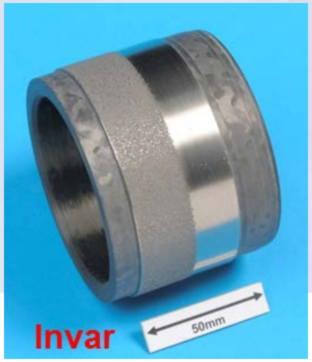
TWI Surface Engineering Group-Sponsored Projects (GSP)

Improved splash and tidal zone coatings for a 40-year design life (oil & gas, wind power).

Development of coating technologies for corrosion mitigation in biomass, waste-to-energy and other process plants (power generation).

CompoSurf™ coating technology for increased functionality of composite materials (aerospace).



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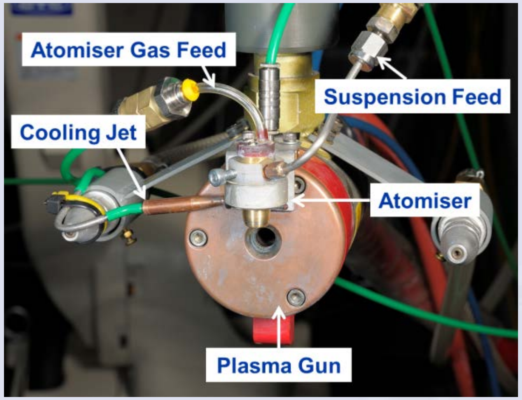
TWI Surface Engineering Collaborative Projects

Development of photo-catalytic coatings for splitting H_2O (renewable energies).



Cold spray Al-boron carbide coatings for neutron capture (nuclear power).

Automated application of 40-year life coatings for wind turbine structures (wind power).

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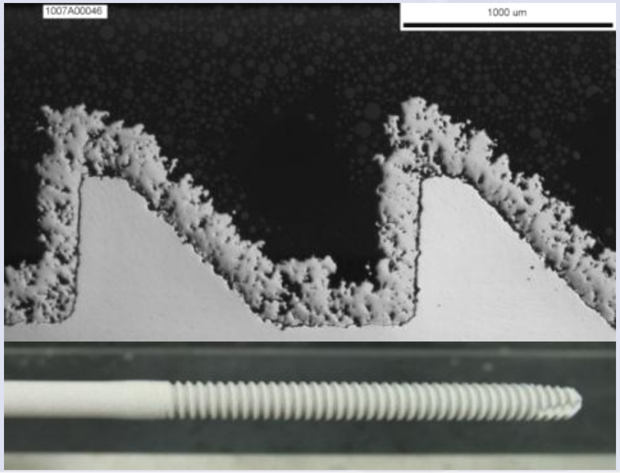
Other TWI Surface Engineering Projects

- Cold spray repair of Ti, Mg, Al alloys (aerospace).
- Cold spray electronic (Al, Sn) and biomedical (Ti) applications.
- Environmental hydrogen embrittlement testing of Cd-plating alternatives (aircraft landing gear).
- Protection of polymer composites e.g. lightning strike dissipation, thermal protection.
- Surface engineering of offshore drilling tools.



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New Core Research Programme 2012-2015 CRP

Automated surface preparation methods for thermal spray coating (grit blasting)

Further development of Cold Spray process - deposition of more challenging coating compositions (Ti64, Ni718, Al7075)

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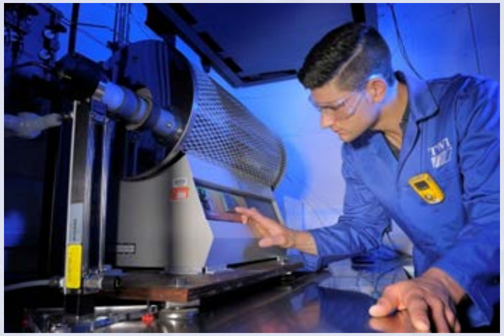
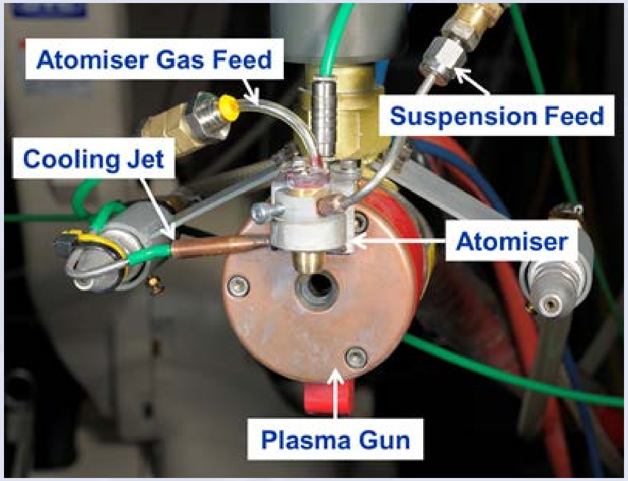
New Core Research Programme 2012-2015 CRP

High temperature corrosion testing (including metal dusting)



Development of a suspension spraying capability (nano-scale powders)



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Introduction to Cold Spray Technology

Tiziana Marrocco

Senior Project Leader

TWI

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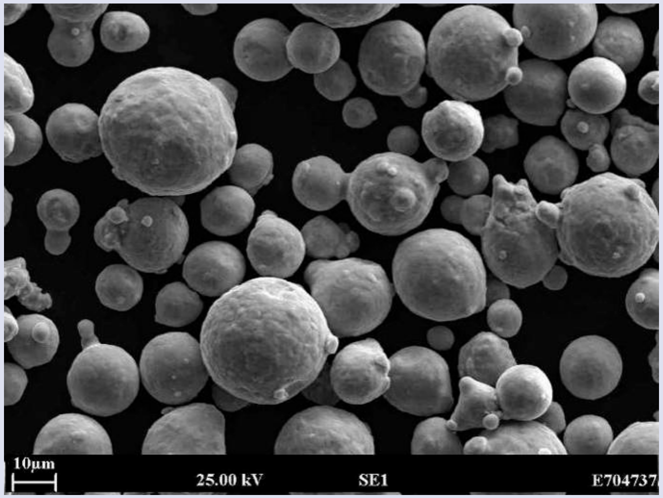
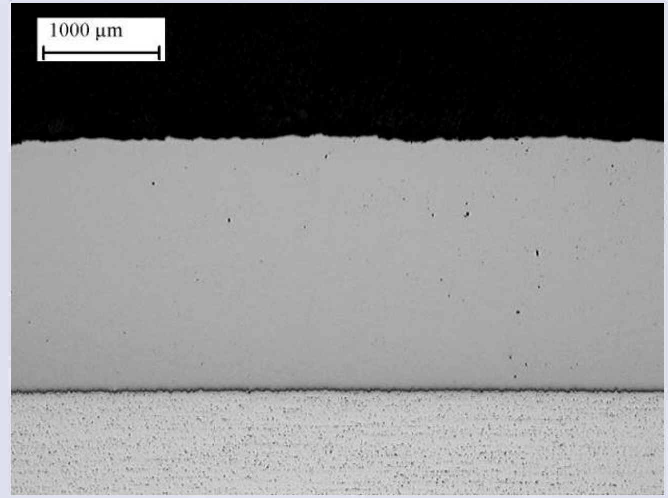
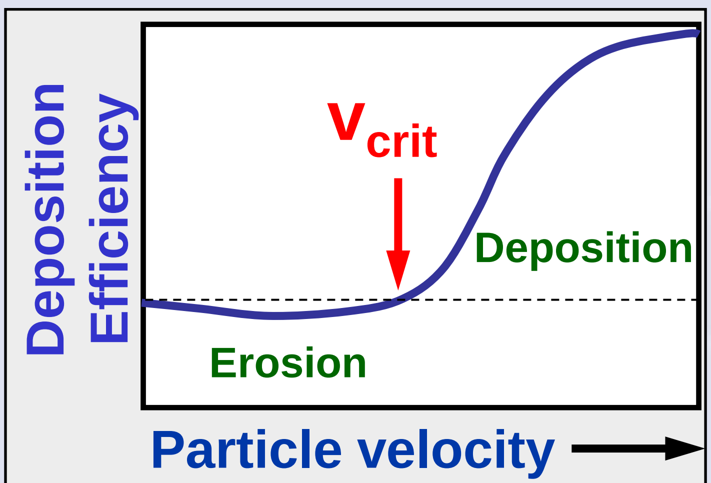
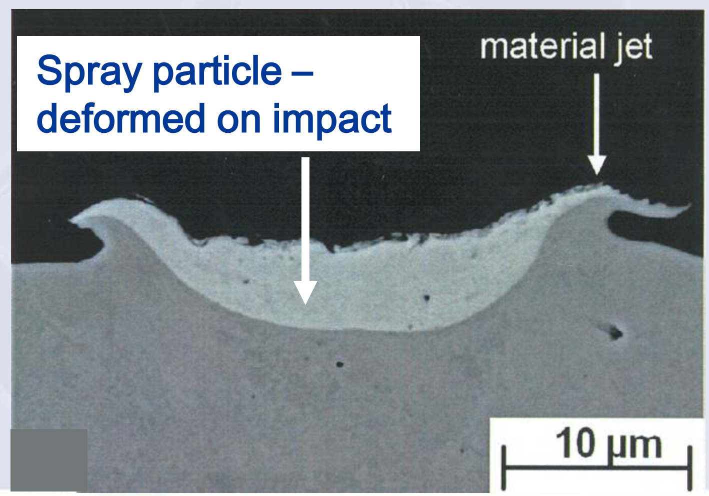
Cold Spray – Coating Formation









Cold Sprayed Cu-Sn on Al

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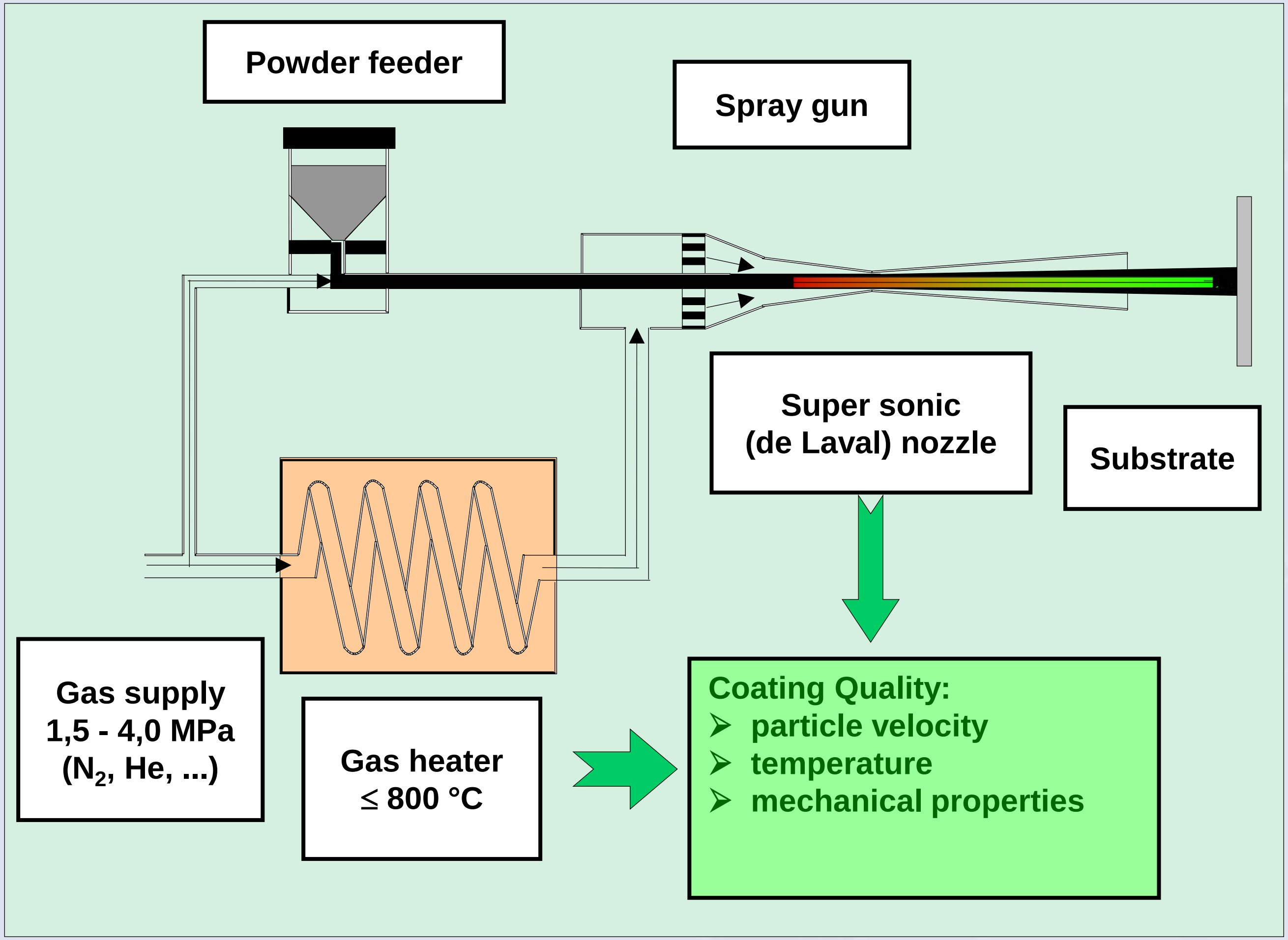
Cold Spray – The Basics



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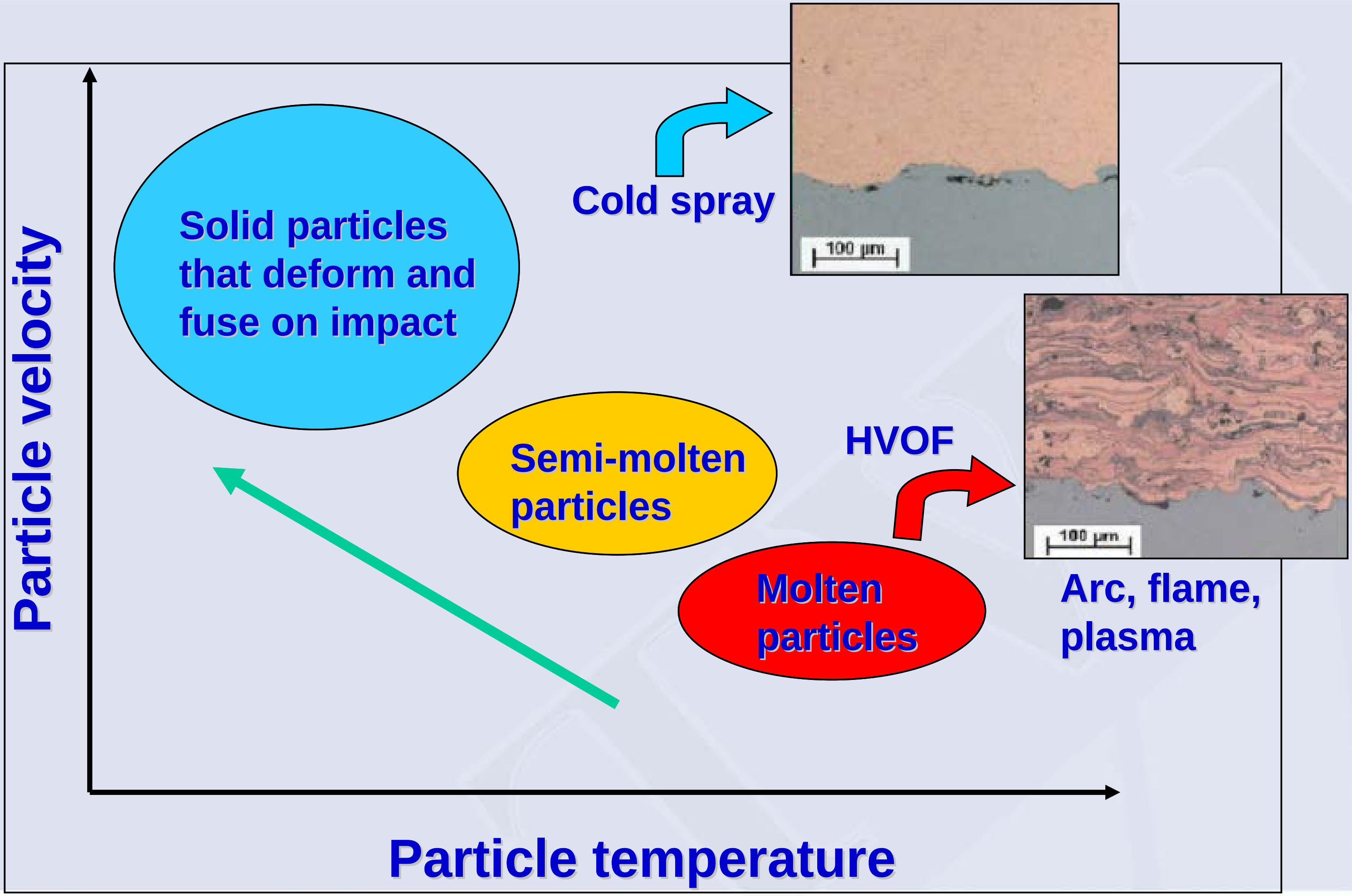
Technology Position – Thermal Spray and Cold Spray



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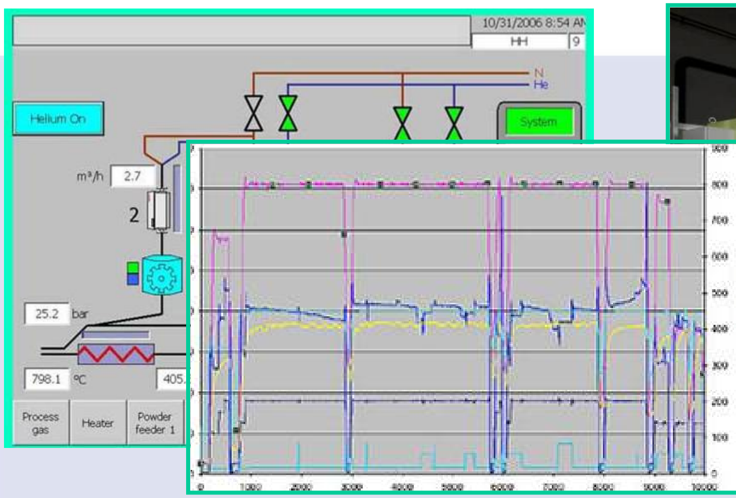
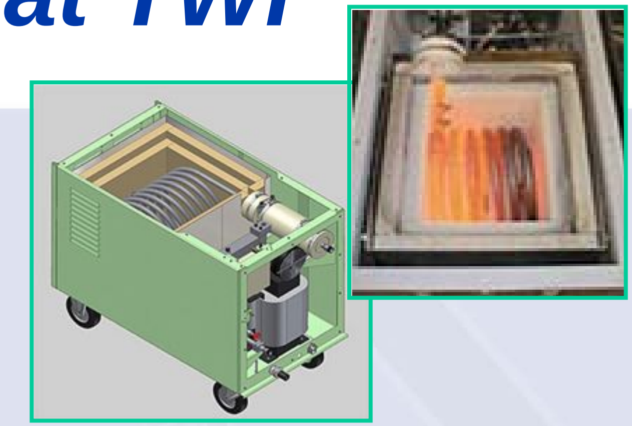
Cold Spray System at TWI



Live process parameters control & recording

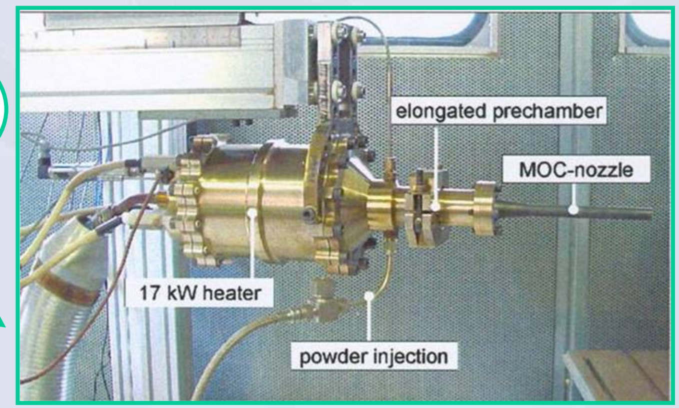
Gas control system (uses N_2 and/or He)



30kW resistance heater to accelerate cold gas

Kinetiks 4000/47®

Dual powder feeding unit



6-axis robot-mounted spray gun (17kW filament heater to heat powder)

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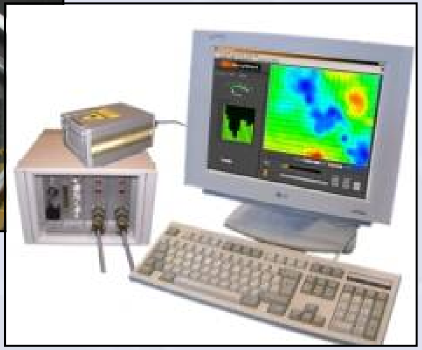
Cold Spray Facility at TWI

Waste particle collection unit



Laser-assisted diagnostic system

Sample setting flexibility

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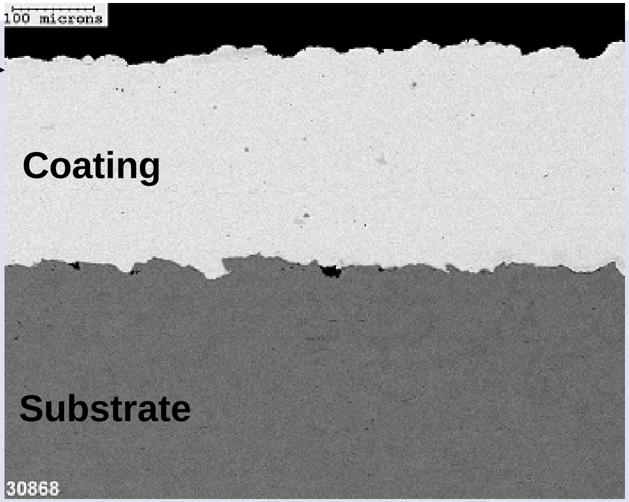
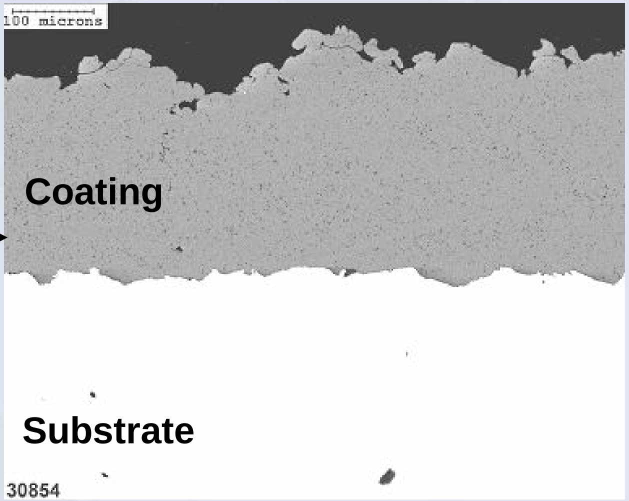
Typical Cold Spray Coating Microstructures

- Cu coating
- Oxygen level, wt%
  - Powder 0.05
  - Coating 0.05



- Cold spray does not oxidise metal powders during spraying

- Al coating
- Oxygen level, wt%
  - Powder 0.20
  - Coating 0.20



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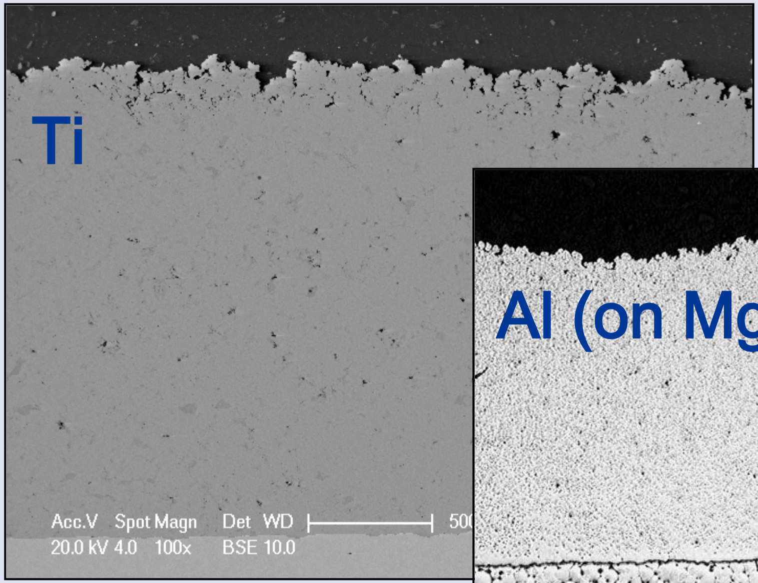
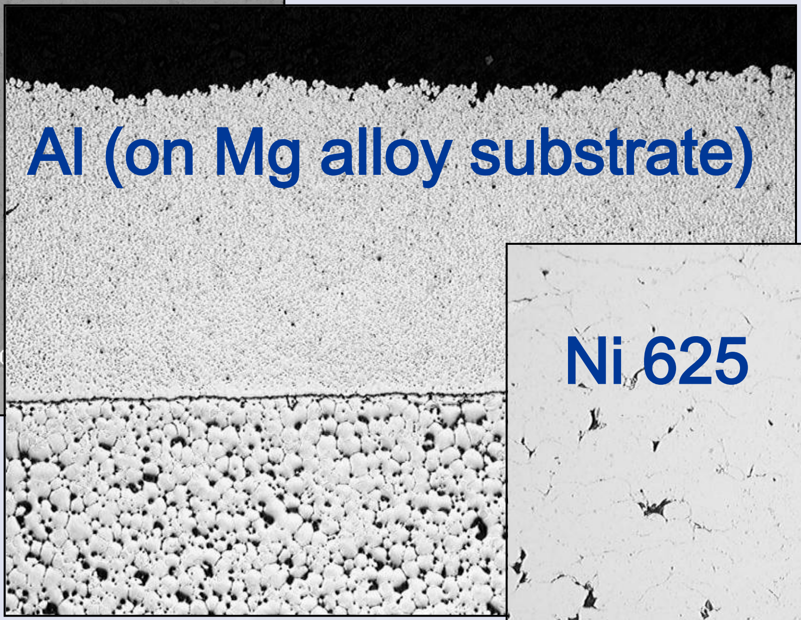
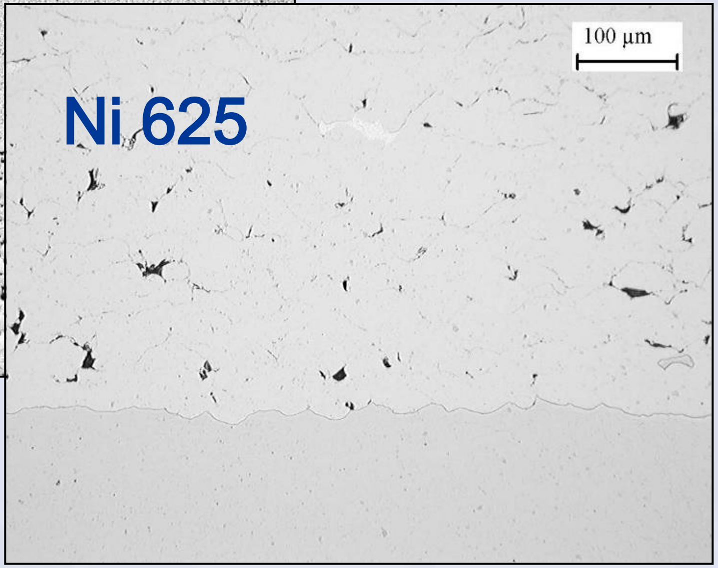
Typical Coating Microstructures







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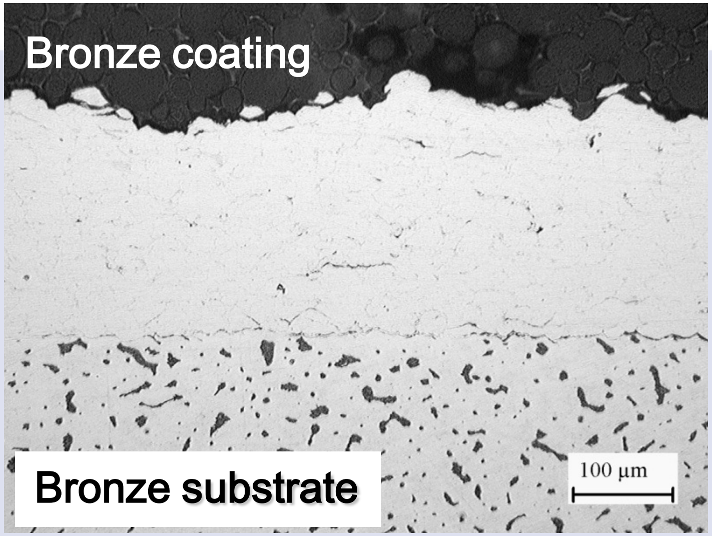
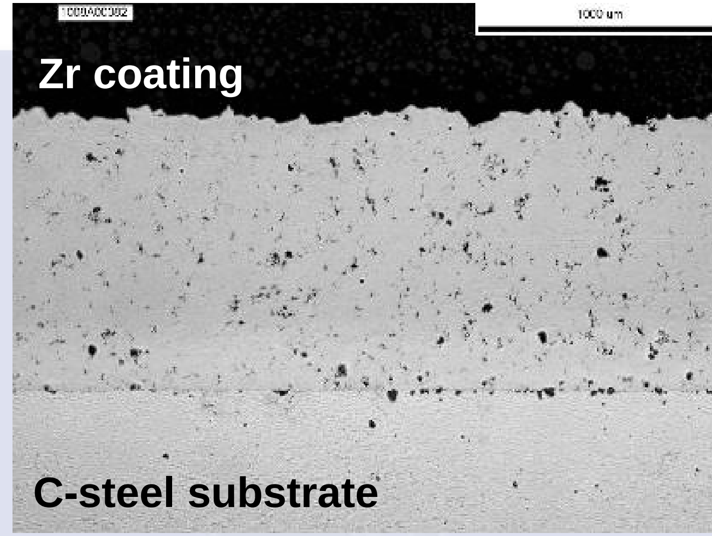
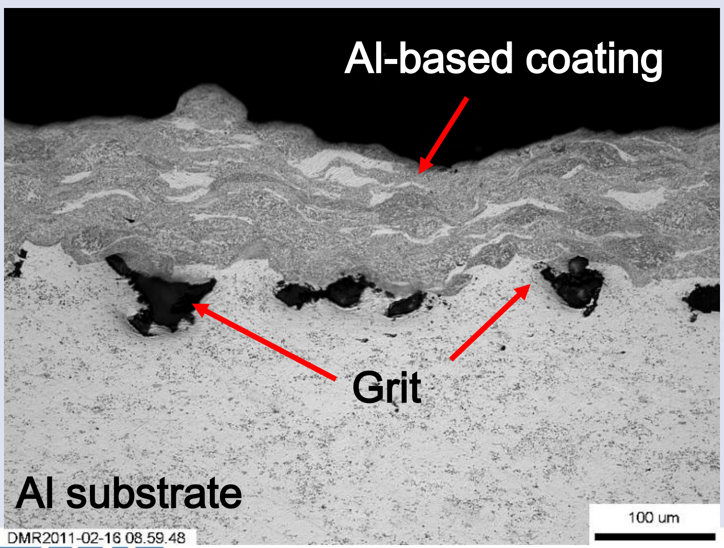
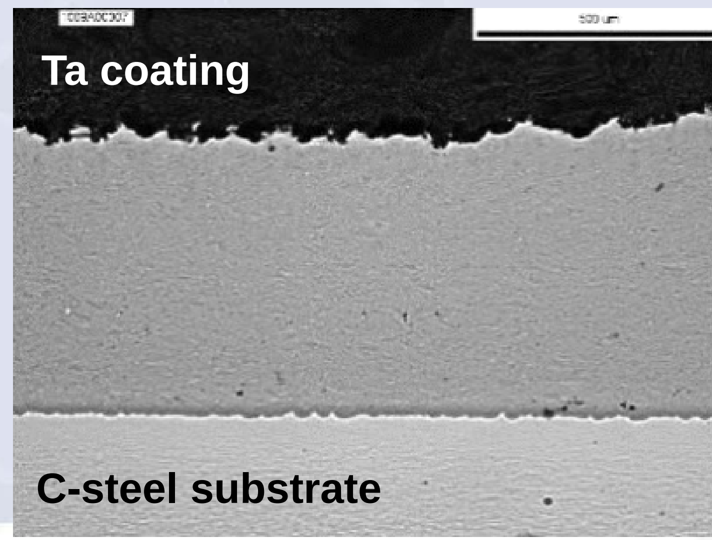
Typical Coating Microstructures









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Cold Spray Application Developments

- Repair of Mg and Al alloy components:
  - Four coating contractors being established in USA
- Deposition of Ni superalloy and MCrAlY coatings for gas turbines:
  - GE, MTU both have CGT Kinetiks 4000/47 systems.
- Coatings for electrical and electronic devices:
  - ASB, OBZ coating contractors supplying products
- Cd-plating alternatives:
  - Being evaluated by Boeing
- Spray-forming and direct manufacturing:
  - CSIRO has filed for Ti pipe manufacturing patent.
- Repair of Al coatings:
  - Boeing close to qualifying CS for IVD, Alclad etc

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Cold Spray Repair of Rotorcraft Components

- US Army / Australian Navy projects
- Reclamation of high value Mg components
- Military helicopters eg Apache, Chinook
- Many high value components otherwise scrapped due to severe corrosion and / or wear

Helicopter gearbox repaired with CP Al

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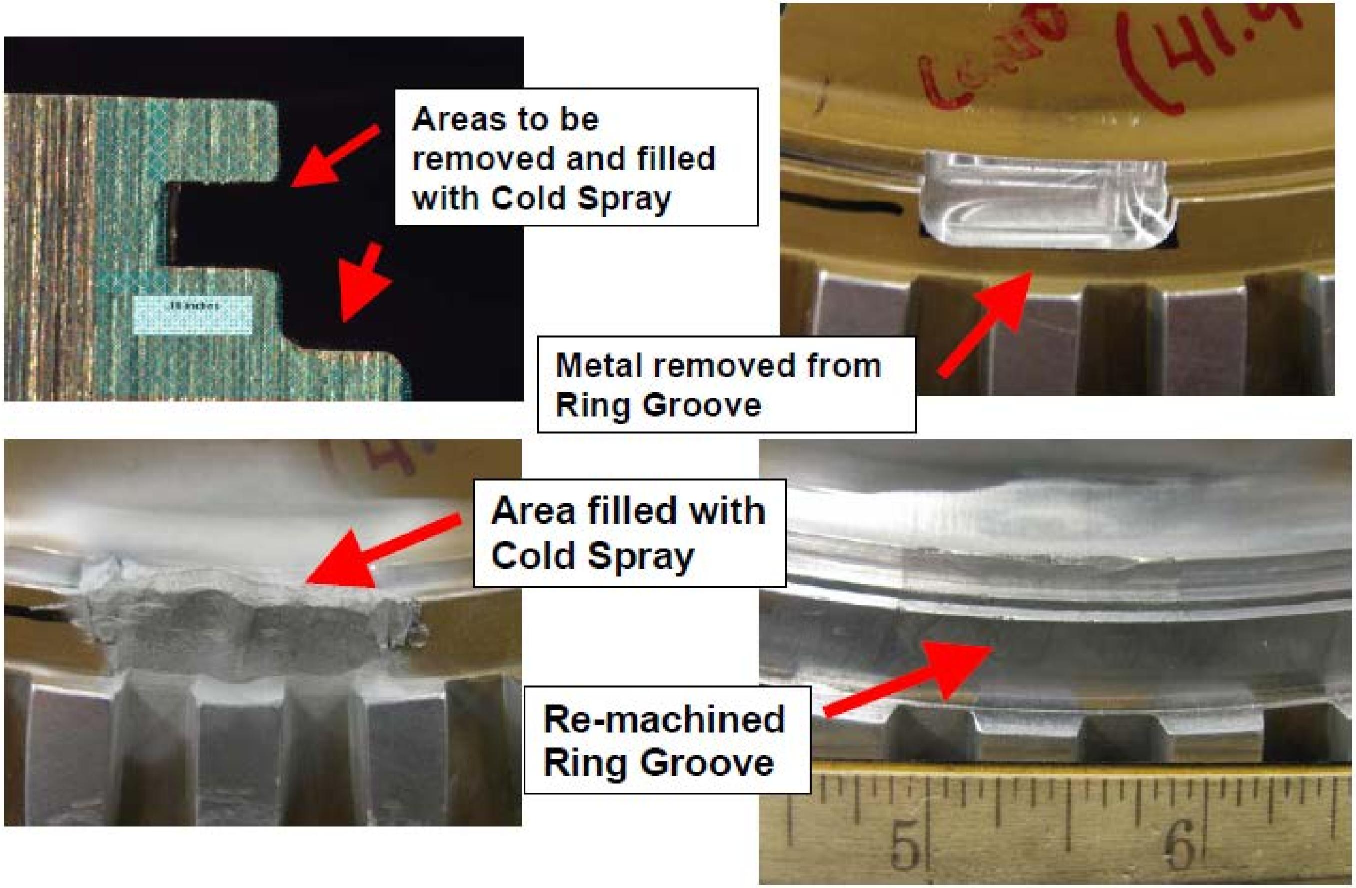
Mechanical Damage Repair – Snap Ring Groove



6061-T6 Al Alloy repaired with CS Al

Courtesy ARL

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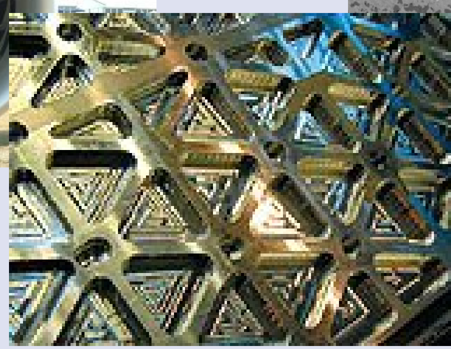
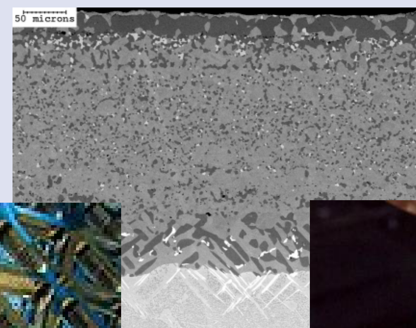
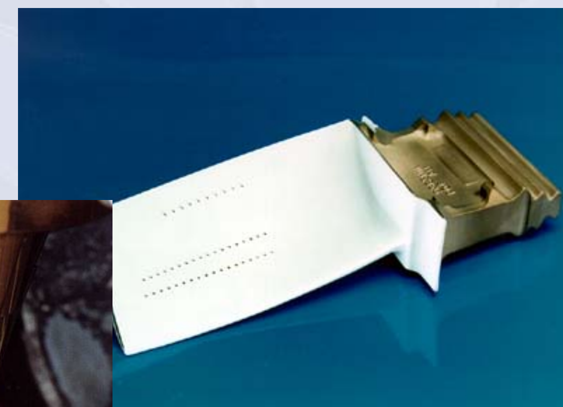
Engine (Repair) Applications

- **Repair of Mg alloy components**
- **CoNiCrAlY coatings for high temp corrosion and thermal barrier bondcoat**
- **Component repair, fabrication (blades, vanes, seals) with Ni superalloy compositions (eg IN718)**

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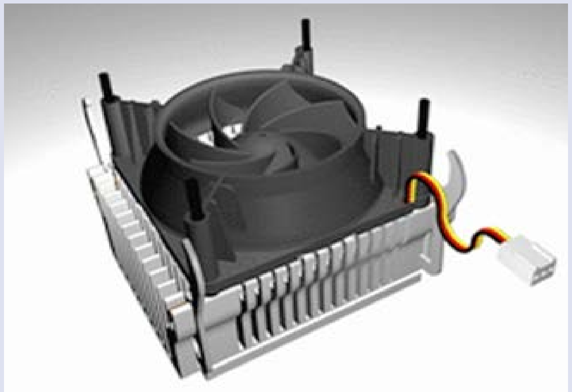
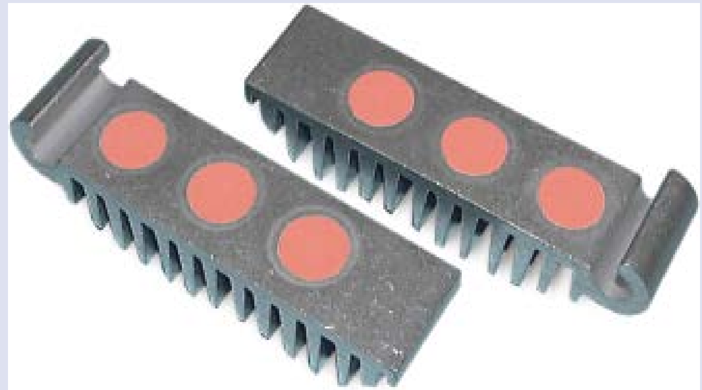
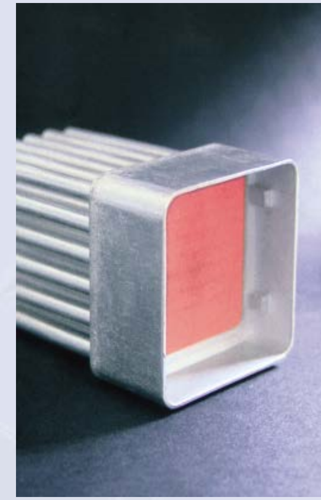
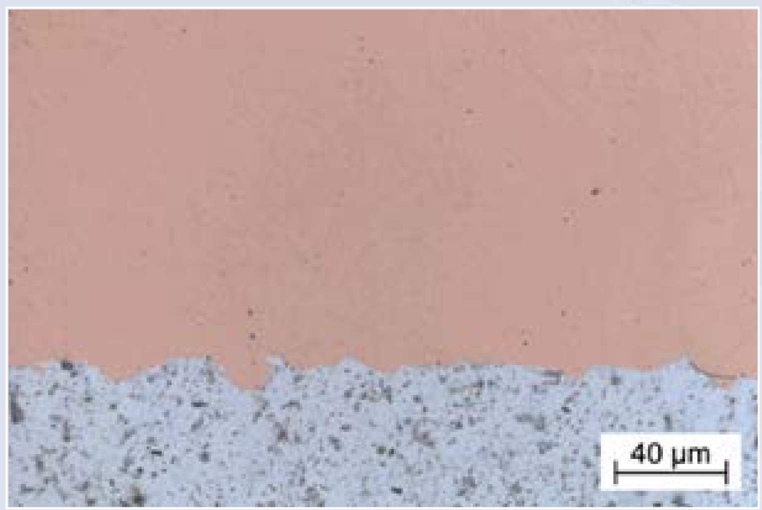
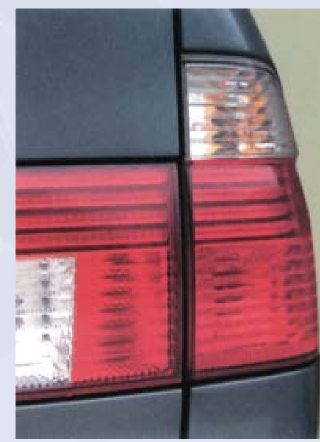
Heat Sinks for Electronic Components











Courtesy FST

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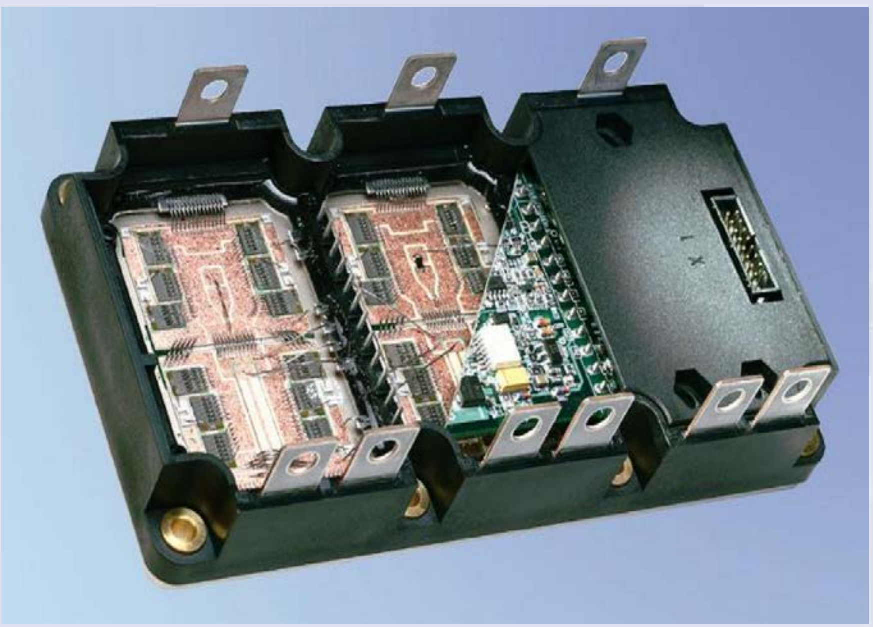
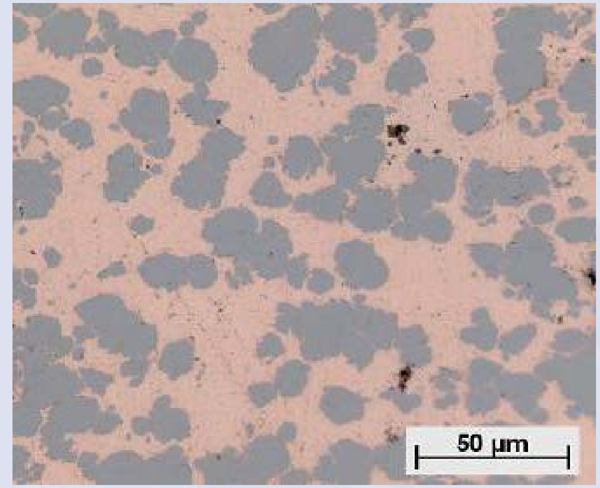
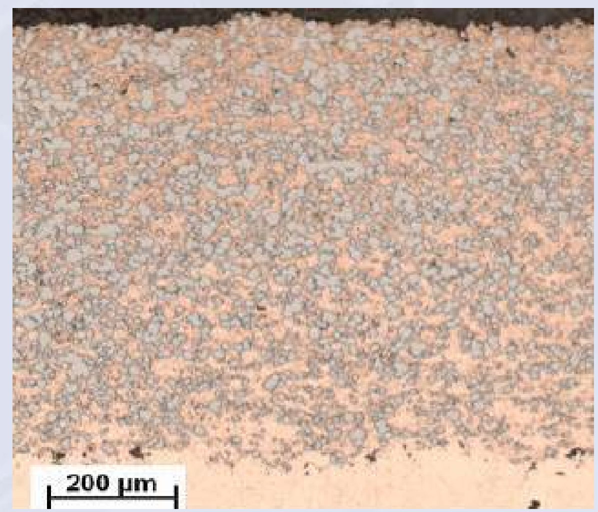
Improved Power Module Design

- CS Cu-W layer.
- Reduce CTE mismatch.
- Good thermal conductivity

CTE = coefficient of thermal expansion







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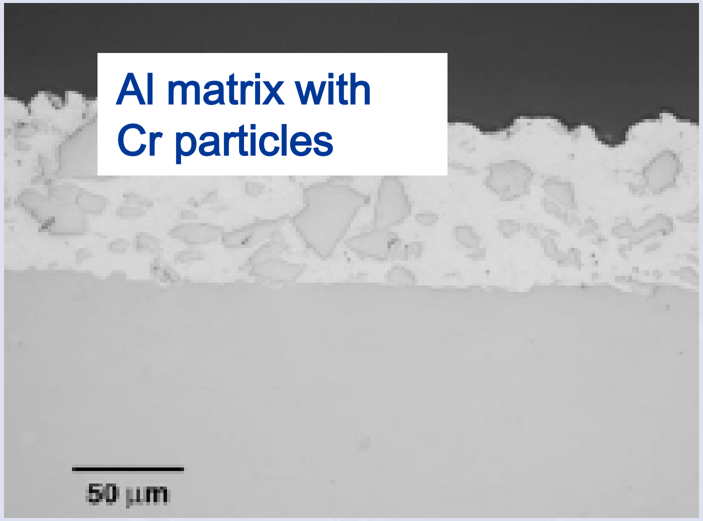
Courtesy Danfoss

Cd Plating Alternatives using Al-based Coatings

- **Challenges:**
  - Cd-plating toxicity
  - Plating processes H_2 embrittling
  - High strength steels
- **Cold spray process:**
  - Non H_2 embrittling process
  - Excellent adhesion.
  - Excellent corrosion resistance



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Spray-Formed Ti

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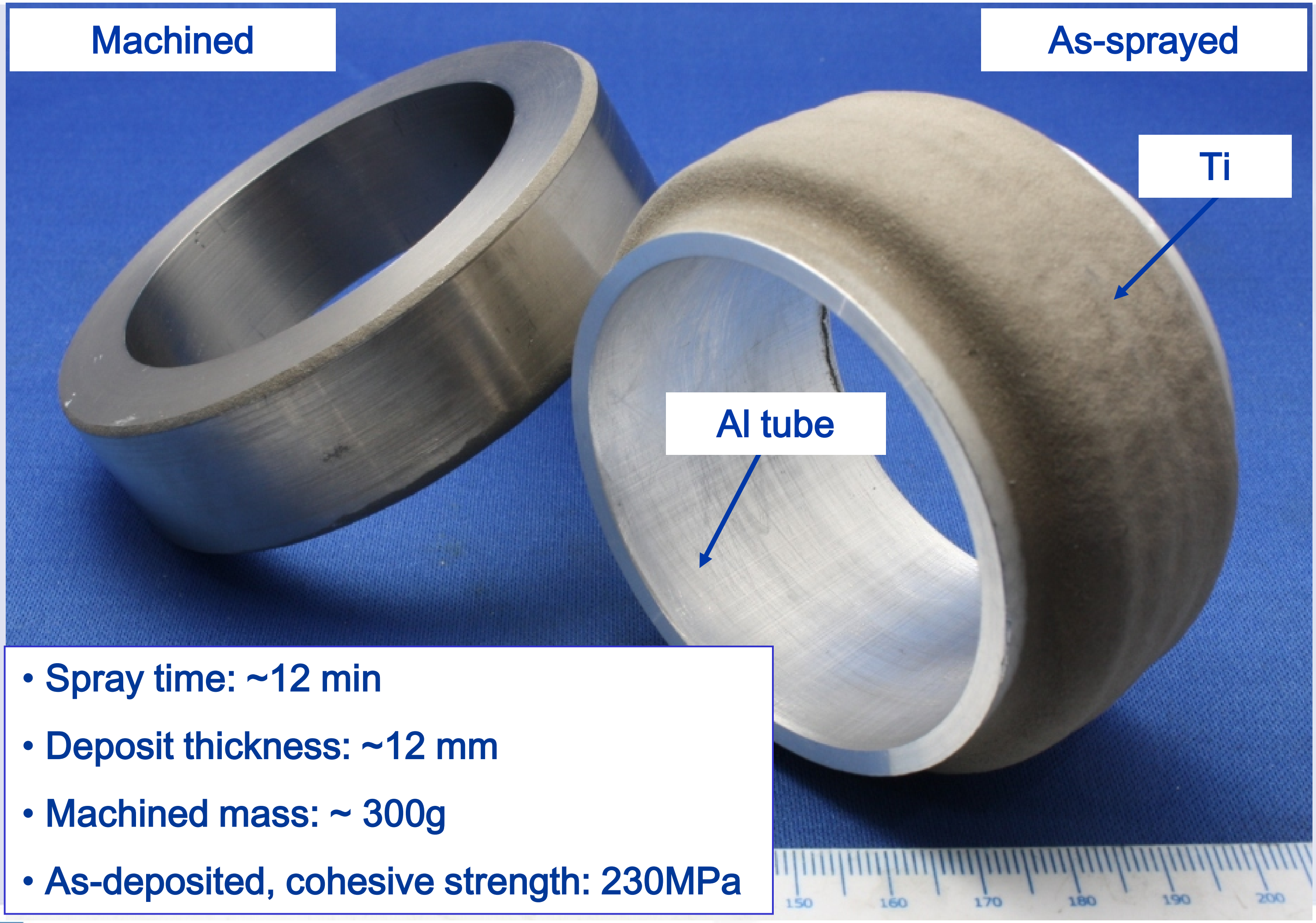
Spray-Formed Ti



- Spray time: ~12 min
- Deposit thickness: ~12 mm
- Machined mass: ~ 300g
- As-deposited, cohesive strength: 230MPa

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Commercial Status

- Originally developed in 1980s (Russia)
- CGT has sold >40 units worldwide → acquired by Sulzer Metco in February 2012.

- Impact Innovations (established by former CGT staff).
- Plasma Giken (Japanese manufacturer with US facility).
- CenterLine (specialises in sub-sonic cold spray).
- Inovati (kinetic metallization process).

- MIL-STD-3021, US DoD Manufacturing Process Standard – Materials Deposition, Cold Spray (published 4.8.2008).

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Commercial Systems (Supersonic)

Impact Innovations

Inovati Kinetic Metallization

CGT Kinetiks

Plasma Giken

Cold Spray System Specifications

Manufacturer	System Name	Max T (°C)	Max P (bar)
CGT (now Sulzer Metco)	Kinetiks 4000/47	800	40
	Kinetiks 8000/87	1000	40
Plasma Giken	PCS-1000	1000	50
Impact Innovations	Impact 5/8	800	50
	Impact 5/11	1100	50
Inovati	PCS-1373	1100	9

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Portable Cold Spray Systems

CGT Kinetiks 2000

CenterLine SSM-PP3300

Benefits vs Limitations

Benefits

- Low heat input
- Particles not oxidised or thermally modified
- Nano-phase, intermetallic, amorphous – retain microstructure
- Thick layers >20mm
- Incoming particles impart compressive stresses
- Dense, hard, cold-worked
- Reduced surface prep.
- High feed rates, DEs
- Uses inert gases

Limitations

- Ceramics only possible with metal binder
- Substrates must be resilient
- Low ductility substrates ⇨ low bond strength
- Line of sight limitations
- Some coatings have limited ductility
- Few technology standards (MIL-Std-3021)

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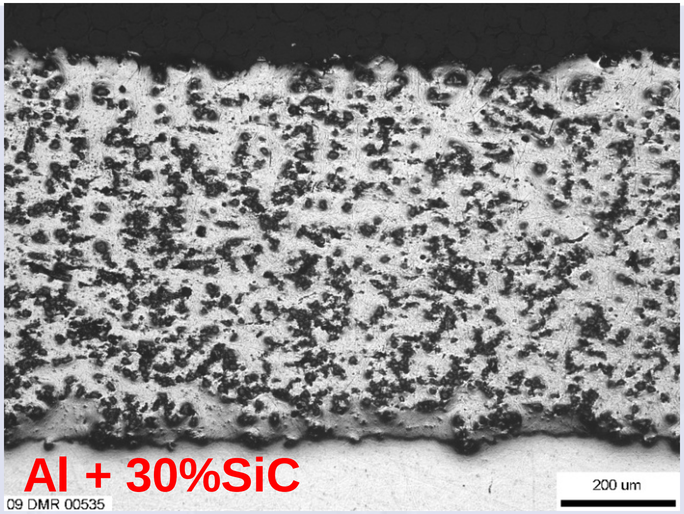
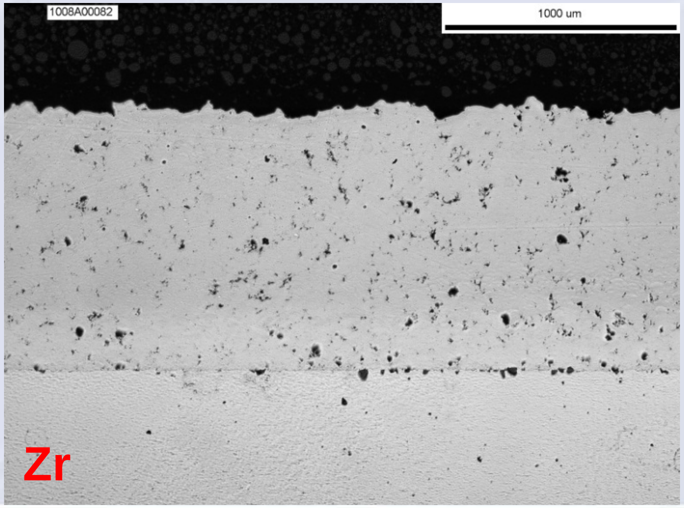
Cold Spray Summary

- **Oxide-free metallic coatings deposited by high velocity powder spraying process:**
  - **Non-combustion / non-arc.**
  - **Powder / inert gas heaters.**

- **Capital & operating costs similar to HVOF or plasma spraying**

- **Materials deposited by cold spray:**
  - **Al, Cu, Ti, Ni, Zr, Ta**
  - **CoNiCrAlY, Ni alloys 625, 718**
  - **Al+Al_2O_3, Al+SiC, Cu-W**
  - **Polymers**





Laser Surface Engineering

Dave Harvey

Consultant, Surface Engineering

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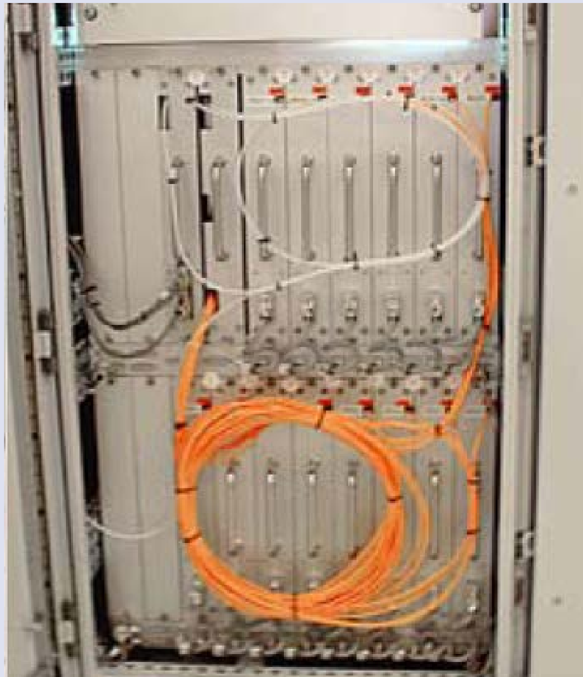
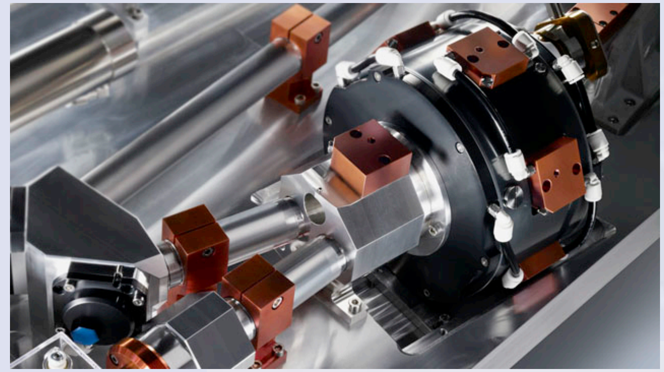
Content

- Lasers for materials processing
- Introduction of laser surfacing
- Advantages of laser surfacing
- Applications of laser surfacing
- Summary

Lasers for Materials Processing



Images from www.ipgphotonics.com



Images from www.trumpf.com

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Advantages of Laser Surfacing

- A chemically clean light source
- Precisely controlled and localised modification.
- Robot manipulation and easily automated
- Low heat input
- High processing speeds
- Near net shape processing with tailored properties.

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Laser Surfacing Techniques

Pyrolytic - involving direct heating of material

heating	melting	vapourisation
↓	↓	↓
Scabling	Cladding	Texturing
Transformation hardening	Re-melting	Marking
Forming		
Marking		
Shock-peening		

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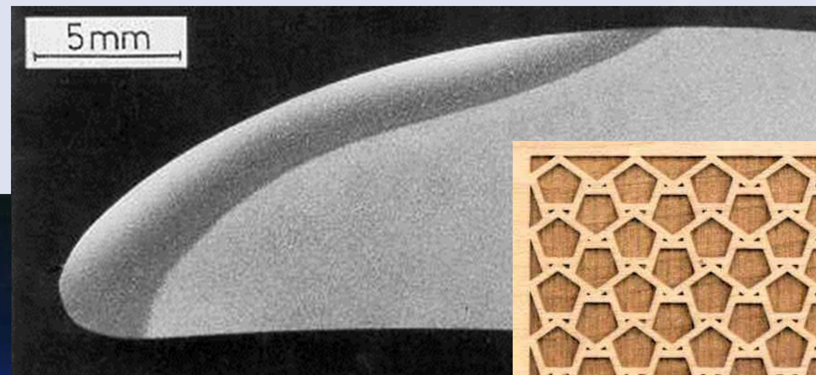
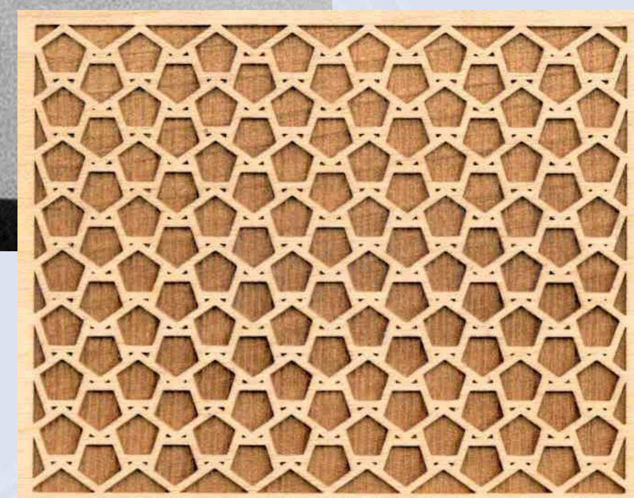
Laser Surfacing Technologies





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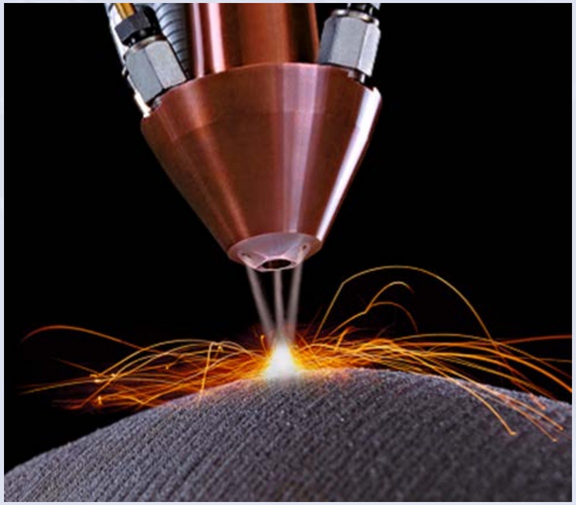
Uses for Laser Cladding

- **Hard Facing**
- **Repair**
- **Mainly used for Corrosion Resistance and to improve wear resistance**
- **3D free form shapes**



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Comparison for Coatings

	Coating thickness (mm)	Deposition rate (kg/h)	Porosity	Dilution with substrate (%)
SAW (Submerged Arc Welding)	2.5-5	5-20	Low	25-35
MIG (Metal Inert Gas)	2-4	5-12	Low	20-30
TIG (Tungsten Inert Gas)	1-2.5	2-4	Low	10-20
Laser Metal Deposition (Powder)	0.2-3	0.1 -6	Very Low	< 5
Laser Metal Deposition (Wire)	3-5	6-10	Very Low	< 5
Thermal Spray	0.02-3	1-45	High	Near 0
Plasma transfer arc (PTA)	1-4	1-13	Low	5-7

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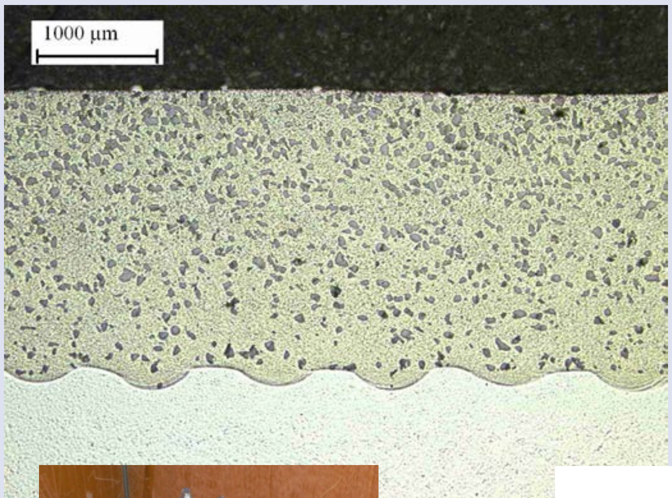
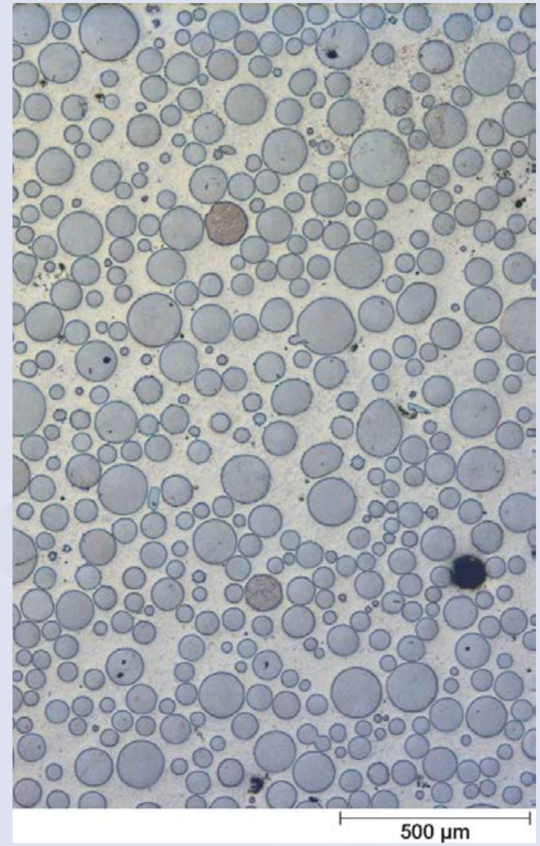
Uses of Laser Cladding

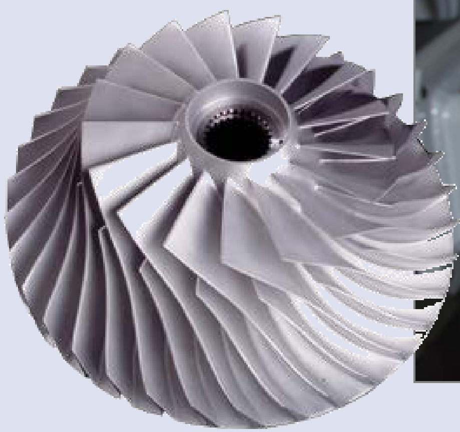
Tungsten Carbide Tipping of Drill Bits



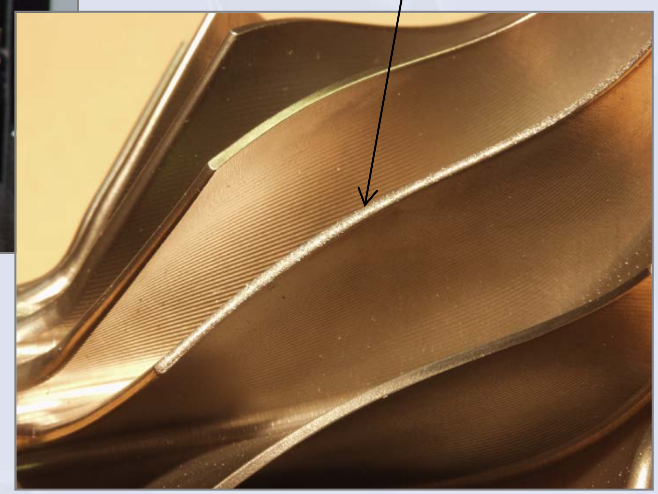


Oil and Gas Component Repair

Component repair and reconditioning – eg pump impeller and casing to bring back within geometric tolerance



Impeller blades built up using laser deposition



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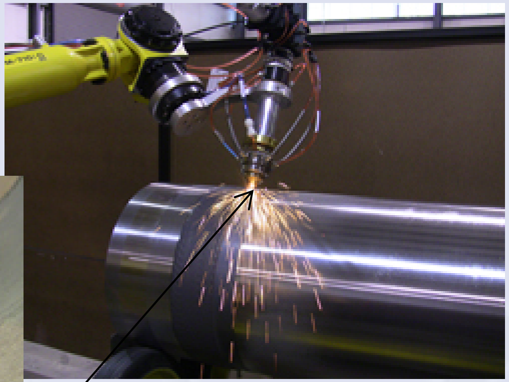
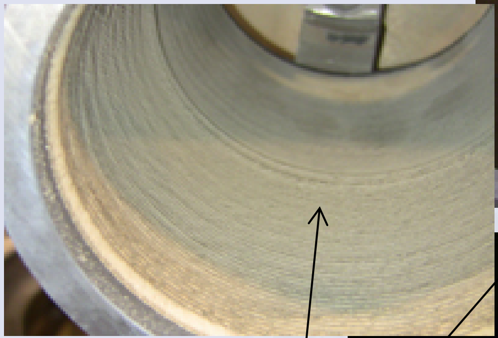
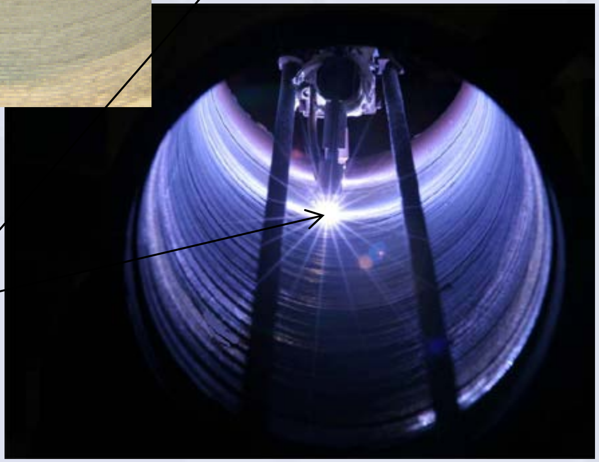
Pipe Cladding using LMD

- Pipe cladding (internal and external) for oil and gas applications using LMD.
- Typically alloy steel pipe material using cladding material of In625.
- Low dilution due to lower heat input than conventional processes allows lower deposit thickness.
- Consumable applied as both wire (single and twin feed) and powder.
- Wire can also be preheated to increase deposition rate.

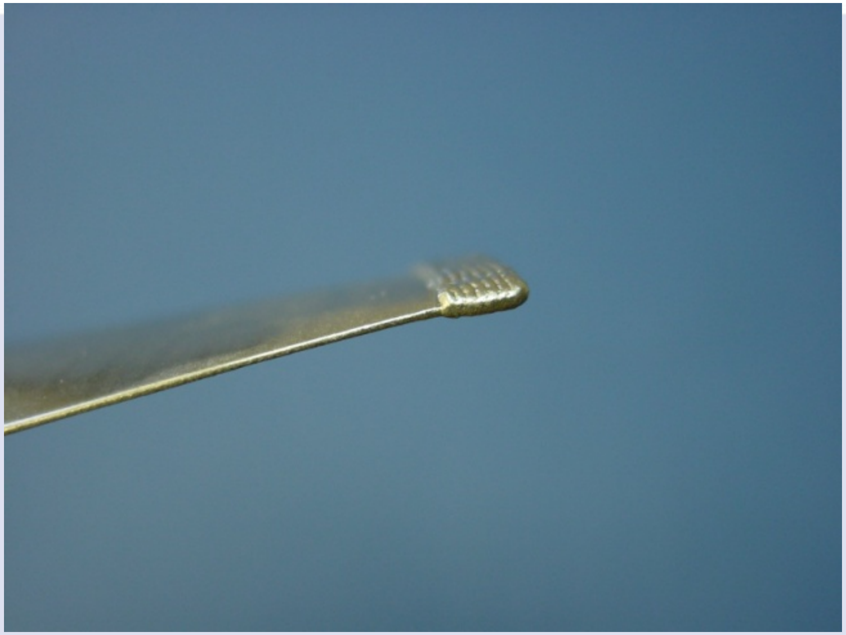






In 625 LMD deposit internally and externally applied

Repair of Aero Engine Parts



LMD repair of base fins and blade tips before final machining

ALM – Laser Deposition of Seal Segment

(Courtesy of Rolls-Royce plc)

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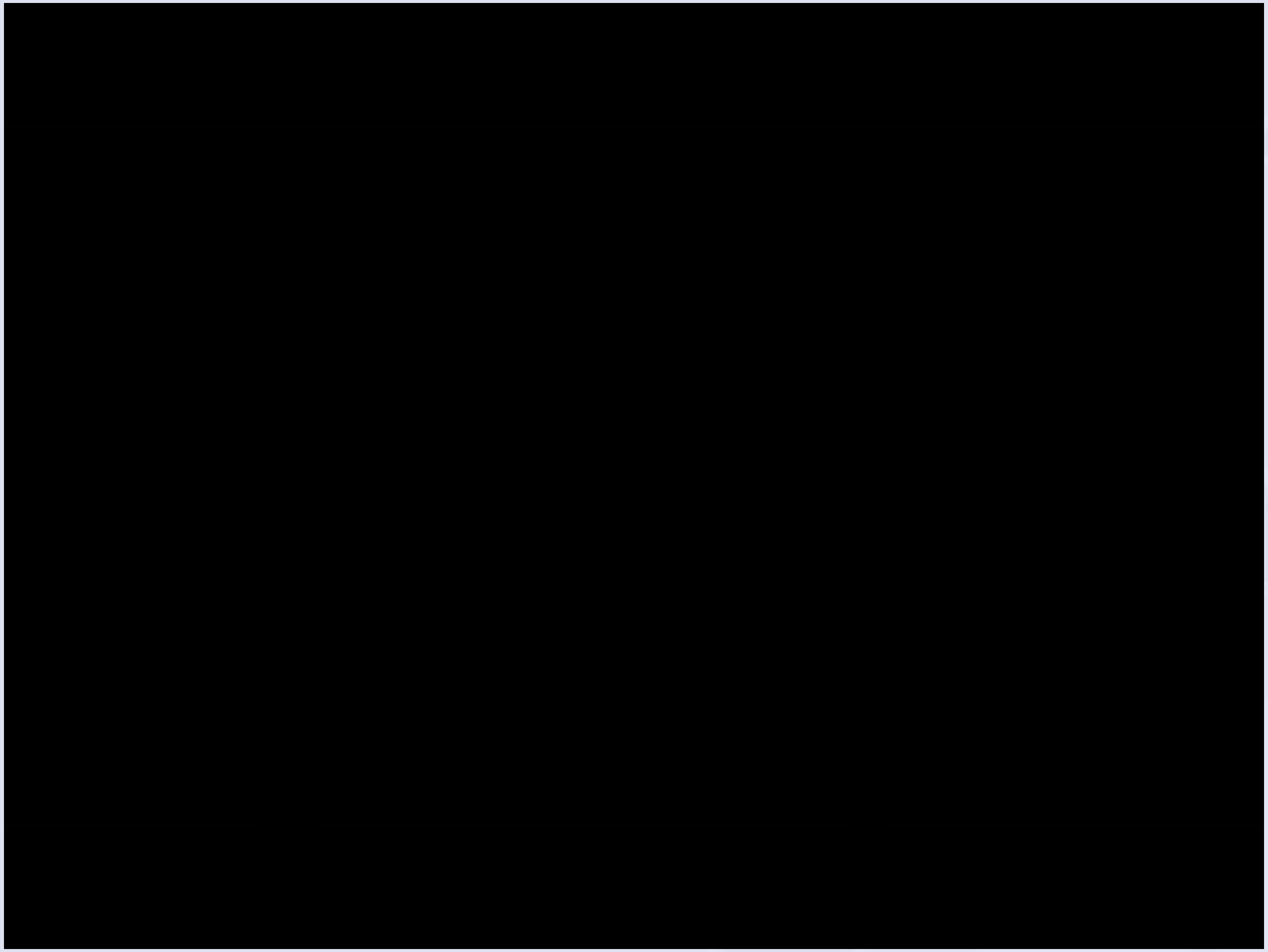
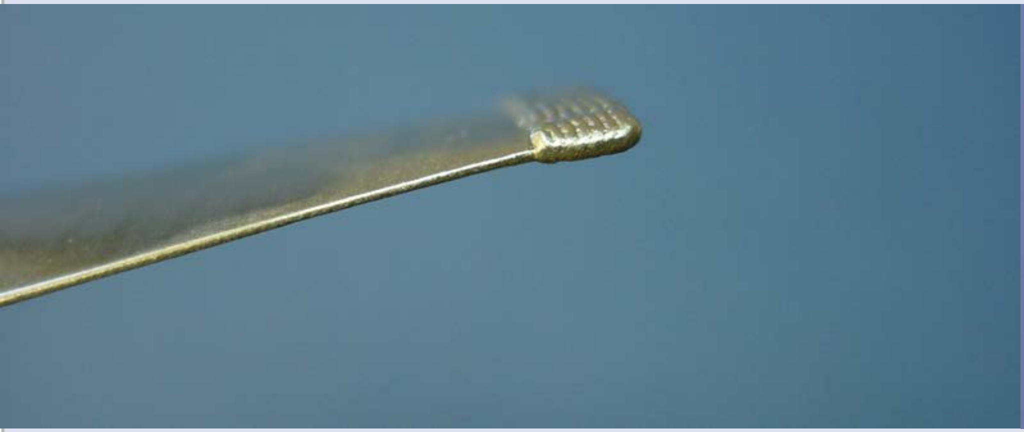
Component Repair/Hybrid Manufacture

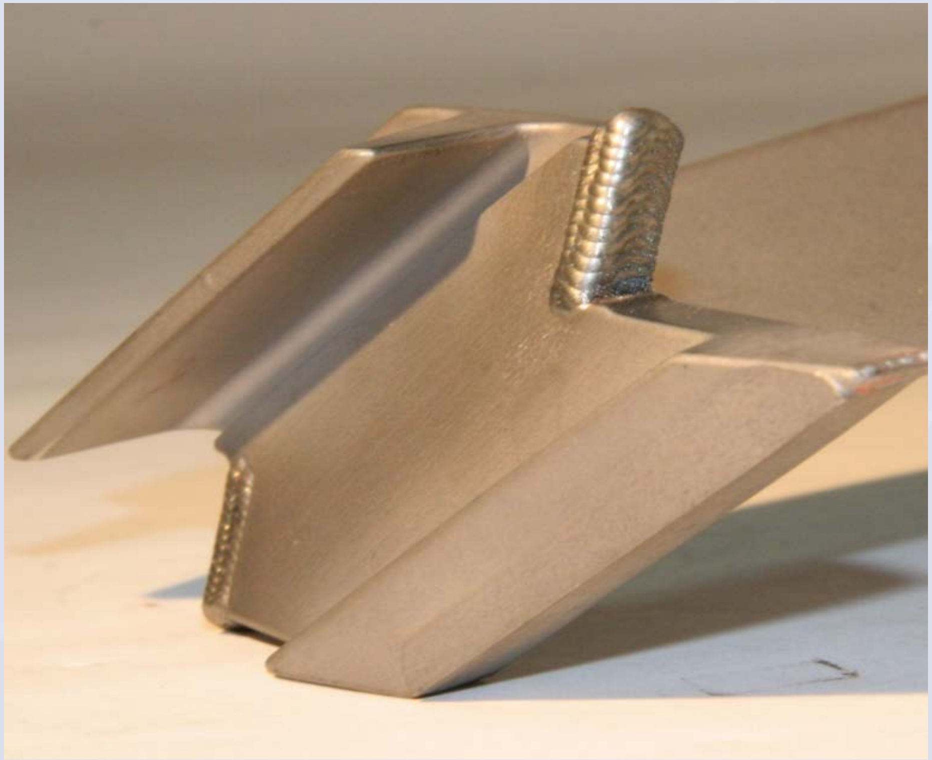


Compressor Blade Tipping



Net Shape comparison

Blade Tip and Z-Notch OEM and Repair



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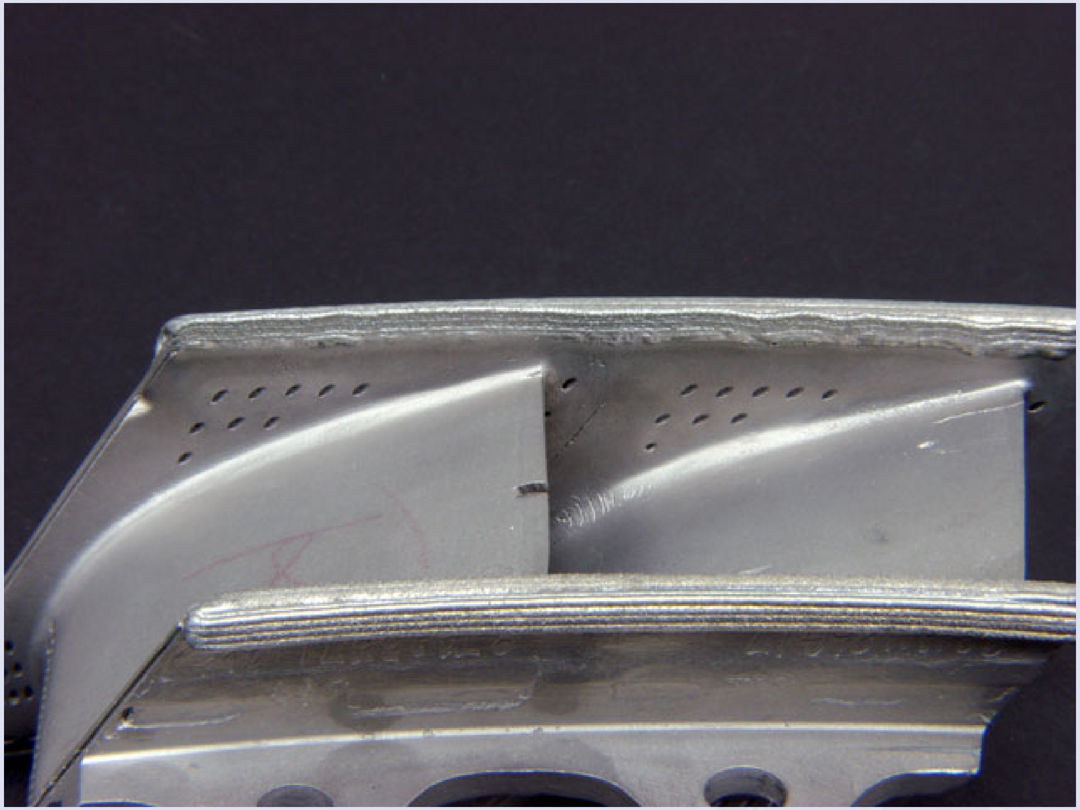
Nozzle Flange and Edge



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Deposited Blisk

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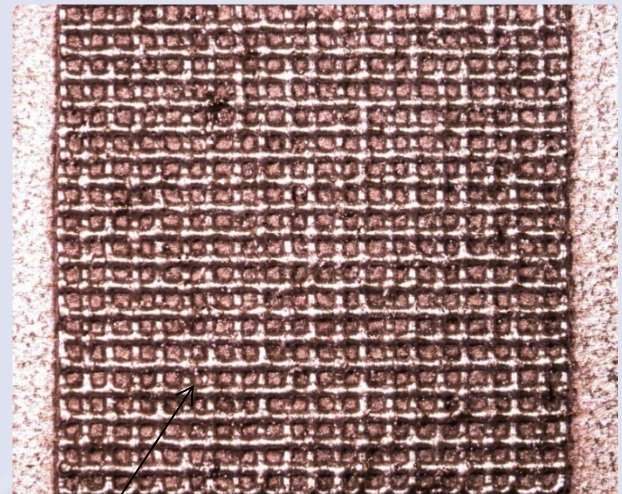
Medical Applications

To promote integration of a titanium implant into a patient, it is necessary to have a specific surface texture that encourages the patient's bone to grow onto it. The implant will then become much more stable and secure than one that is merely cemented.

LMD, which is both precise, accurate and reproducible, can be successfully used to produce the required geometry and surface finish.



Surface texture produced by LMD

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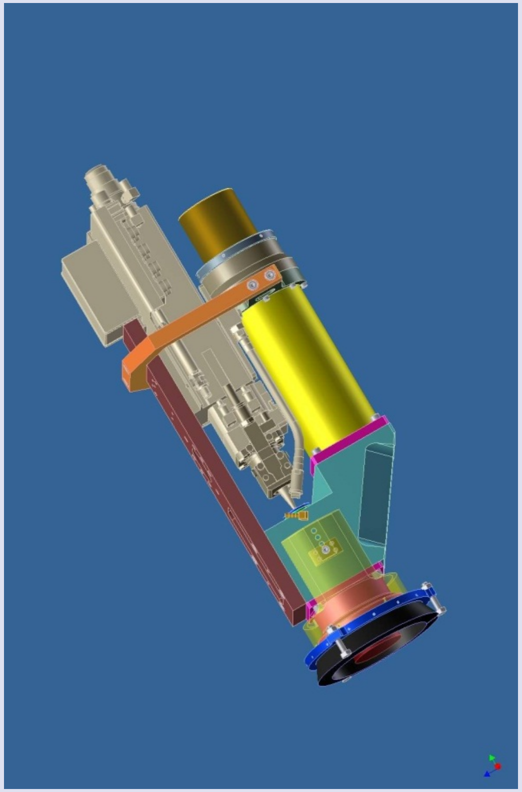
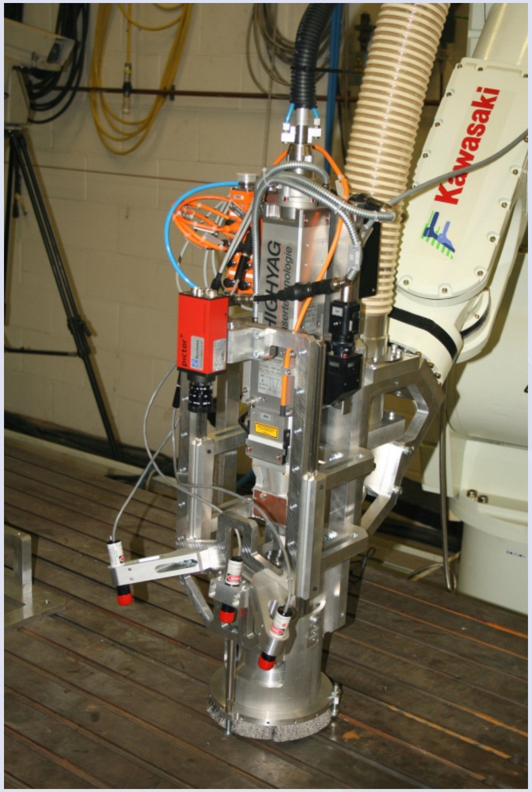
Nuclear Decommissioning - Scabbling

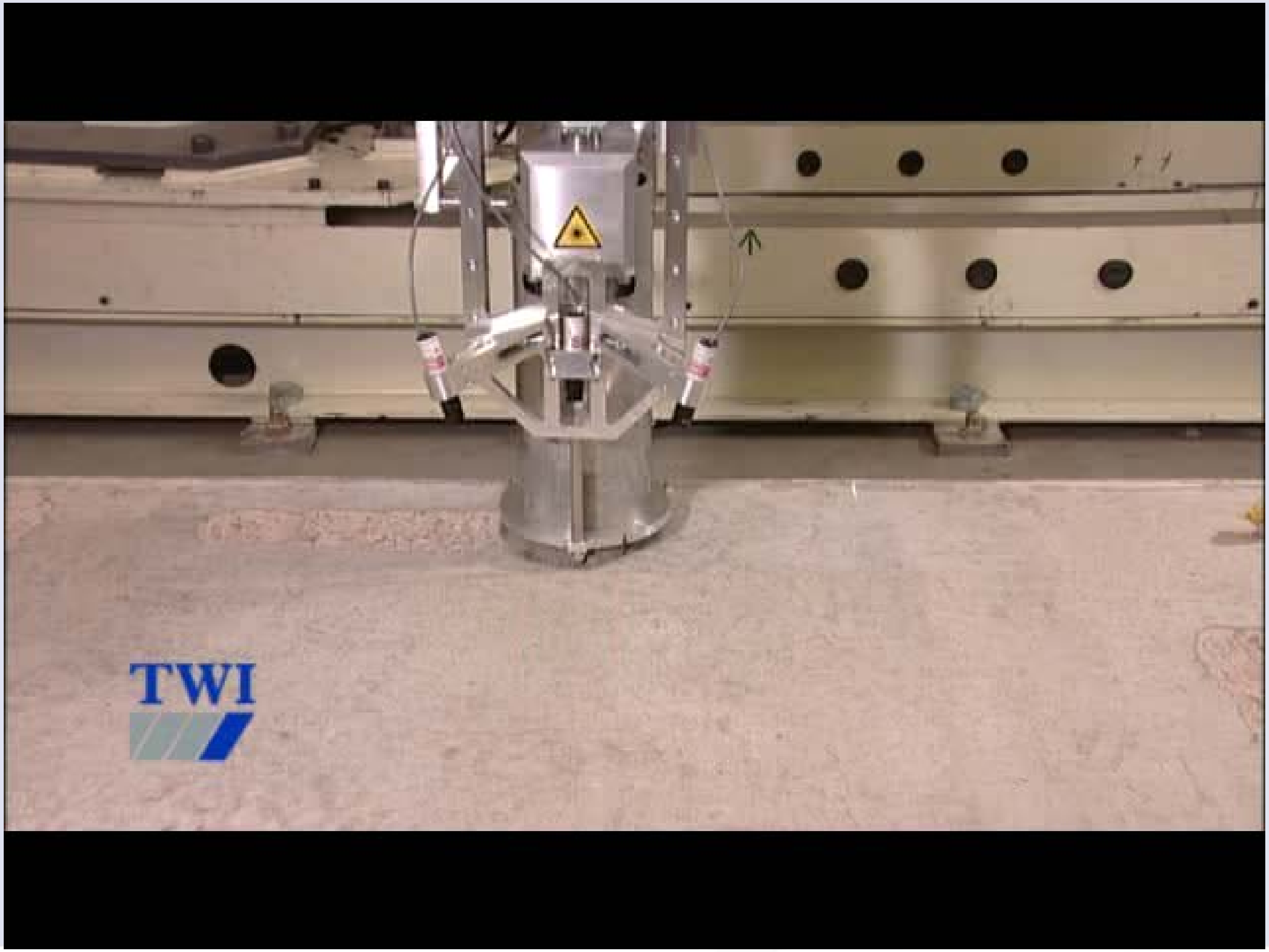
TWI designed head for concrete scabbling

- 5kW Yb-fibre laser





Nuclear Decommissioning - Scabbling



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Surfi-Sculpt®

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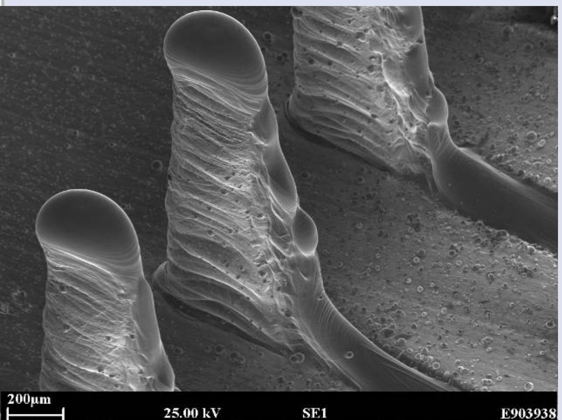
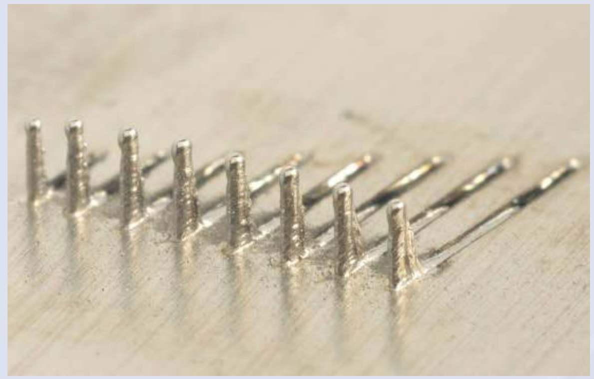
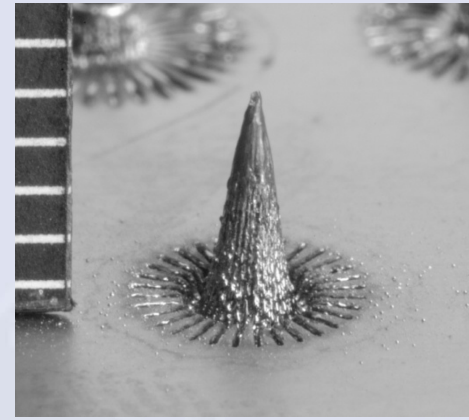
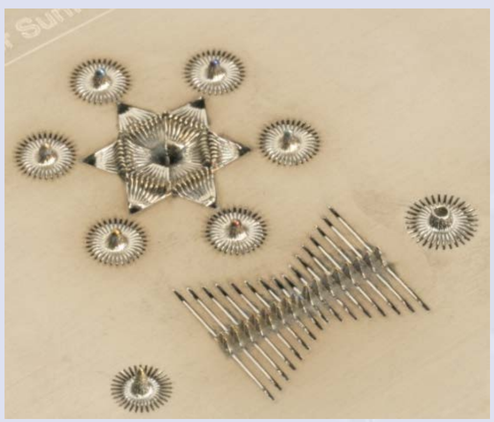
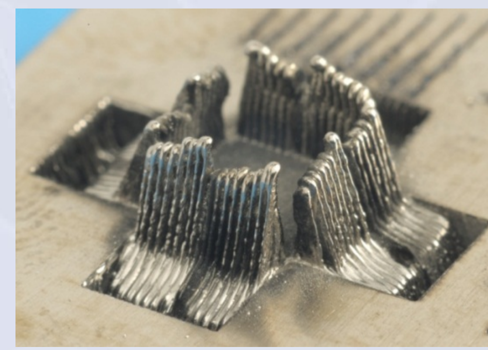
Surface Modification – Surfi-Sculpt®











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Summary

- Laser surfacing can offer unique advantages over other surfacing techniques
- Laser surfacing has been widely used for surface modification and repair of high value components
- More applications are being considered for additive manufacturing and rapid prototyping

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Thank you for your attention!

Any questions?

Protecting Steel Structures from Corrosion using Thermal Spray Aluminium (TSA)

Dave Harvey
Consultant, Surface Engineering

Project Leader: Shiladitya Paul

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Why / How Paints Fail…

- Poor preparation…
- Poor application…
- Poor specification…
- Poor design…

Weld / field joint coating failure

Crevice corrosion

Edges and corners

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Why / How Paints Fail…

Galvanic corrosion

Corrosion under insulation

Mechanical damage

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Sable Joint Venture Coating Failure

- Premature failure of Amercoat 132 / PSX 700 system, including failure to corrode (& protect steel).
- Amercoat 132 primer <85% by weight Zn specified.
- Structural integrity of the $1.4 bn facility compromised by corrosion damage.
- Damage estimates range from $135 - $440 million.

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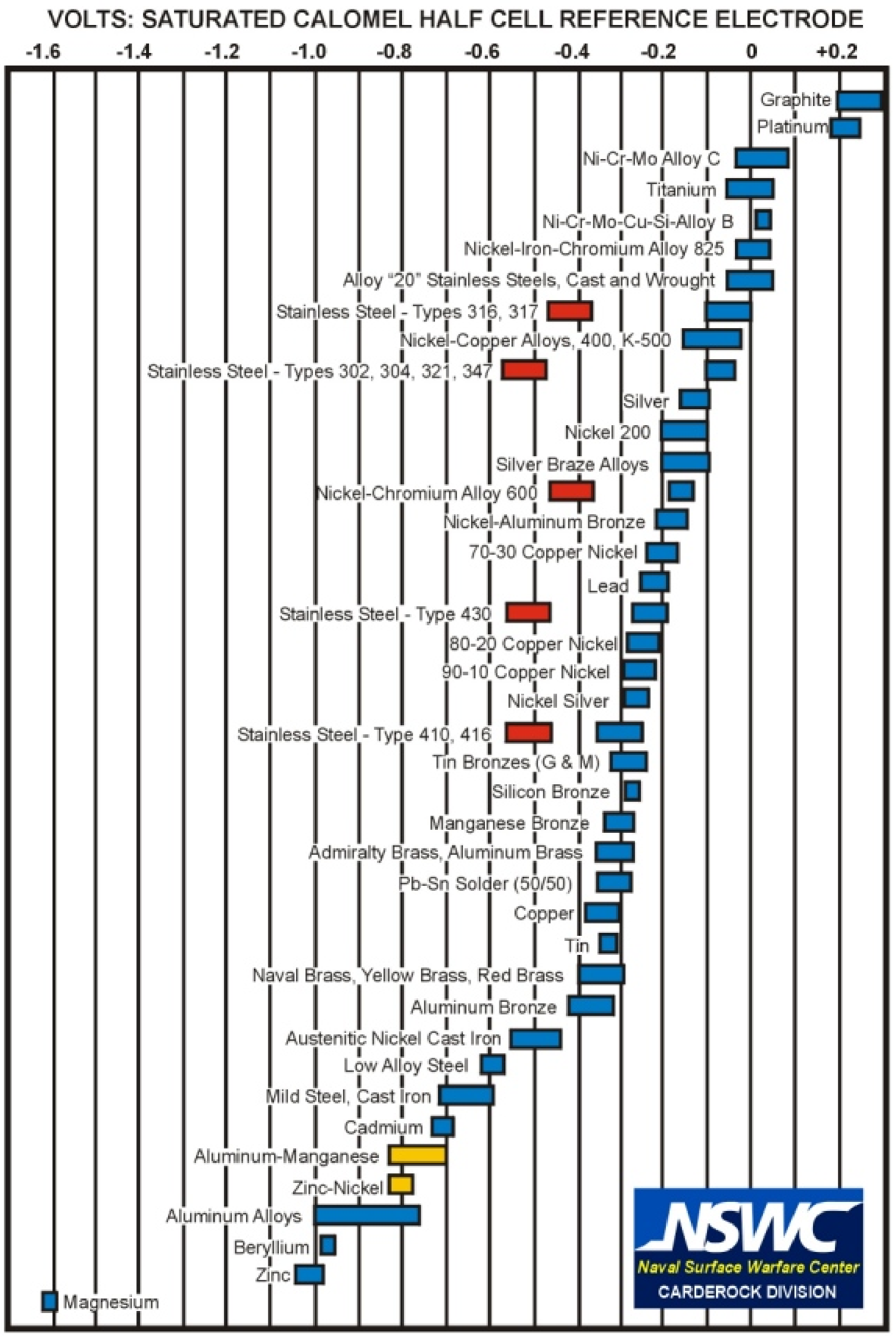
High Cost of Coating Failures

- Wind turbine coating failures…
- Horns Rev "too expensive to fix"
- Arklow $1m per tower

Galvanic Series…

- ‘Anodic’ materials such as Al, Zn and their alloys protect steels
- Mg is too reactive (too electronegative) for a conventional anode material
- Corrosion resistant alloys (CRAs) such as stainless steel, Ni and Ti alloys are cathodic with respect to steels



What is TSA?

- **Thermally sprayed aluminium (aluminum)**
- **Thermal spray aluminium (aluminum)**
- **Metal spraying (also includes Zn)**
- **Metallizing (also includes Zn)**

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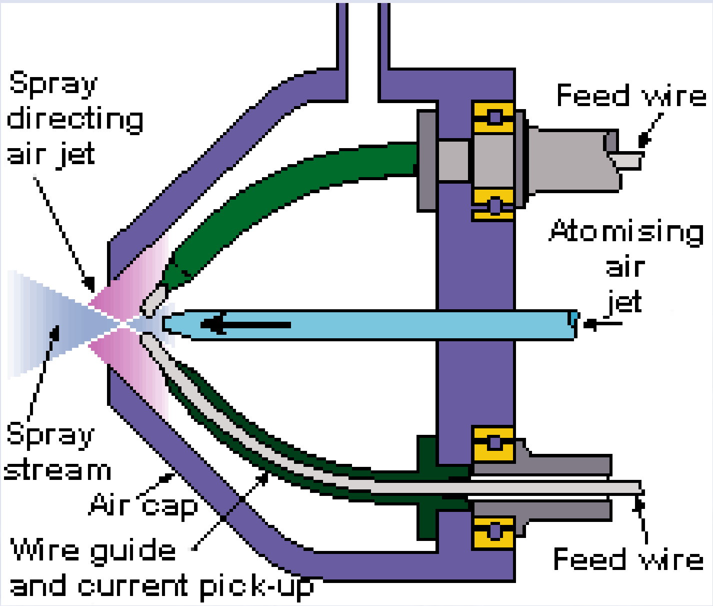
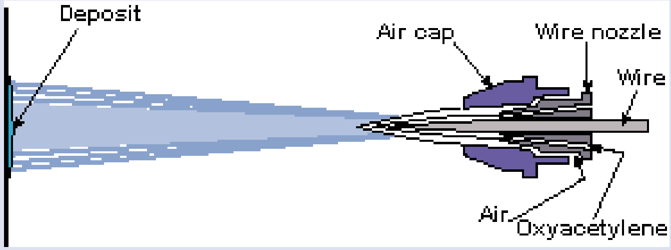
Twin Wire Arc Spraying (TWAS)

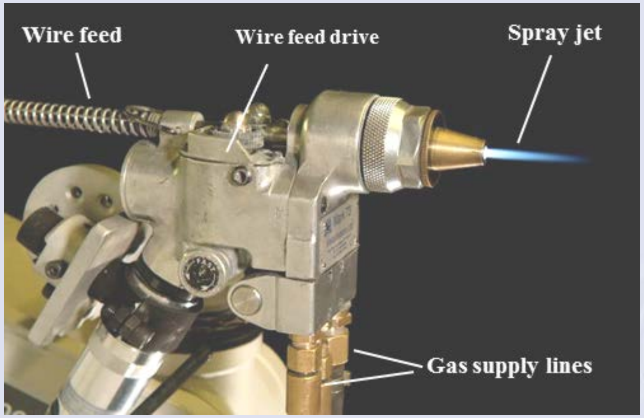
Wire Flame Spraying (WFS)

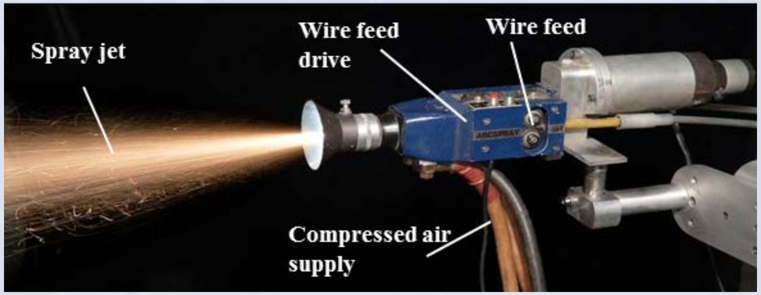
TSA – Flame or Arc?

- **Both processes used…**
  - Wire *flame* spraying (WFS)
  - Twin wire *arc* spraying (TWAS) or just ‘*arc* spraying”









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Surface Preparation

- Steel surface 3°C above dew point and RH < 90%.
- Surface cleanliness to Sa 3 (visual examination = white metal finish).
- Contamination: Cl^- < 5μg/cm^2 (salt contamination meter or test kit).
- Anchor profile typically 75-125 μm Rz (surface profile tool).
- Blast abrasive:
  - Preferably Al_2O_3 (alumina, aluminium oxide) eg F60
  - Possibly chilled iron or steel

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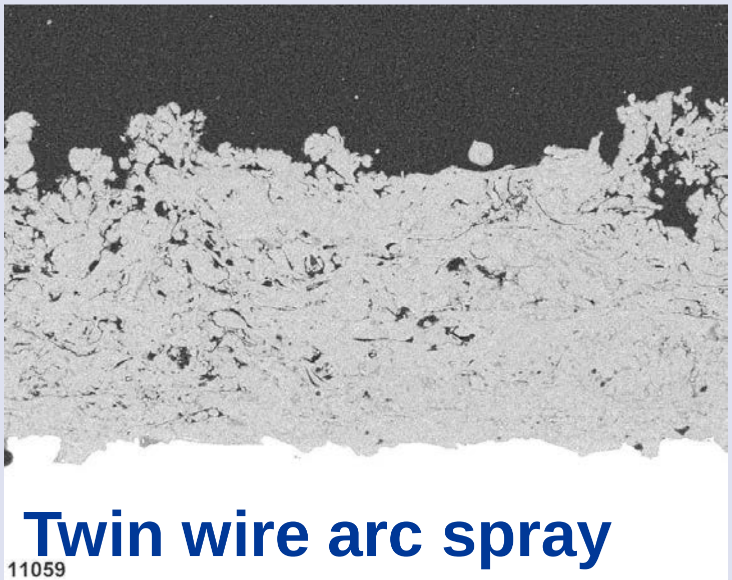
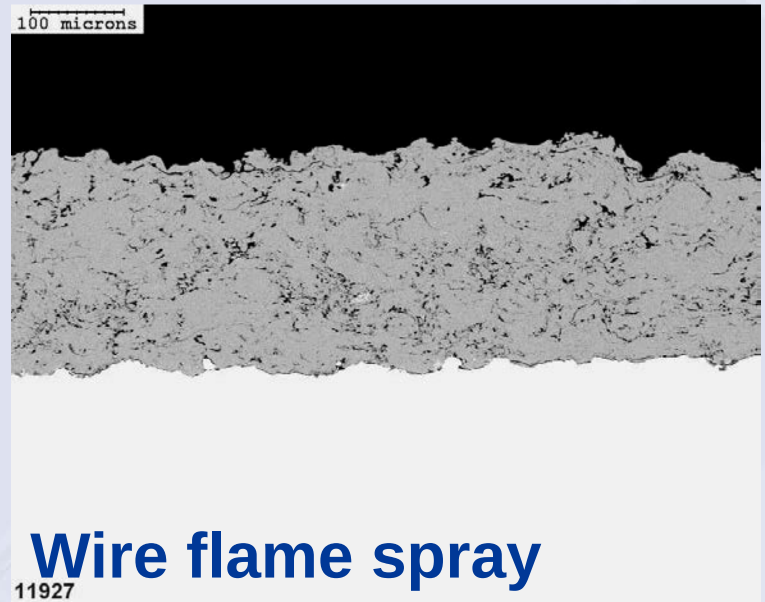
TSA Application - Summary

- Clean substrate
- Mask off areas not coated
- Grit blast substrate
- Apply by flame or arc wire spraying process
- Typically 200-350μm thick
- No curing time
- Seal if required

TSA Coating Cross Section



Twin wire arc spray



Wire flame spray

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Who Uses TSA?

- Oil & gas sector:
  - ~40 years use on offshore platforms & jacket structures
  - Subsea pipelines
  - Heat exchangers
  - Insulated process plant.
  - Substrate materials include CS, SS, DSS, SDSS
- Highways agencies:
  - Steel bridges
  - Other highways furniture
  - Steel reinforced concrete bridges
- Navies:
  - Ships
  - Dockyard assets







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Offshore Environments

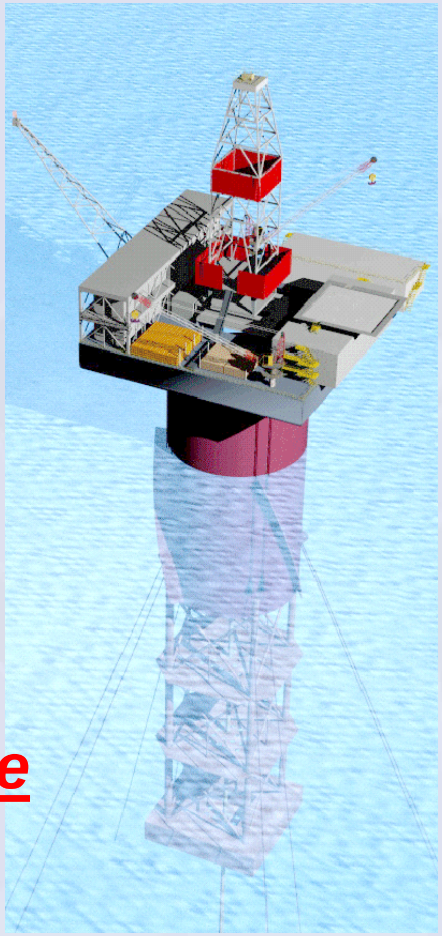
TSA is used in many locations…

Atmosphere
Air
UV exposure
Seawater

Splash zone
Air
UV exposure
Seawater

Subsea
Seawater

Subsea/Subsurface
Seawater
Mud



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Corrosion Mitigation - Offshore

- Issues with ‘conventional’ corrosion mitigation:
  - Anodes add significant weight
  - CP level varies over structure
  - Paints degrade following mechanical damage
  - Different paints (and multiple layers) required for topside, splash zone, subsea…
- Thermally sprayed aluminium (TSA):
  - Typically 30-40% weight of anodes for same coverage
  - CP level consistent over entire structure
  - Performs well following mechanical damage
  - One composition for all zones!

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Offshore Use of Zn?

Coatings subjected to salt spray testing…

Typical marine paint

Rust!

Thermally sprayed aluminium (TSA)

Ca / Mg carbonates / hydroxides

Thermally sprayed zinc (TSZ)

Zinc oxide / hydroxide

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TSA Coating Process

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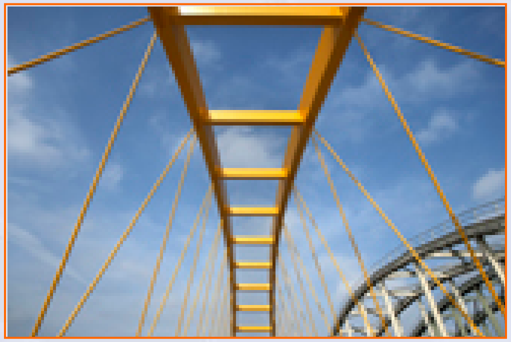
TSA – Bridge Application

- Total length : 170 m
- Total height : 25 m
- Total width : 26m
- Total weight : 3000 tons



TSA Coating:

- Total Surface : 11000 m^2
- Process spraying : Arc
- Material : 99,5 % Al
- Thickness : 250µm

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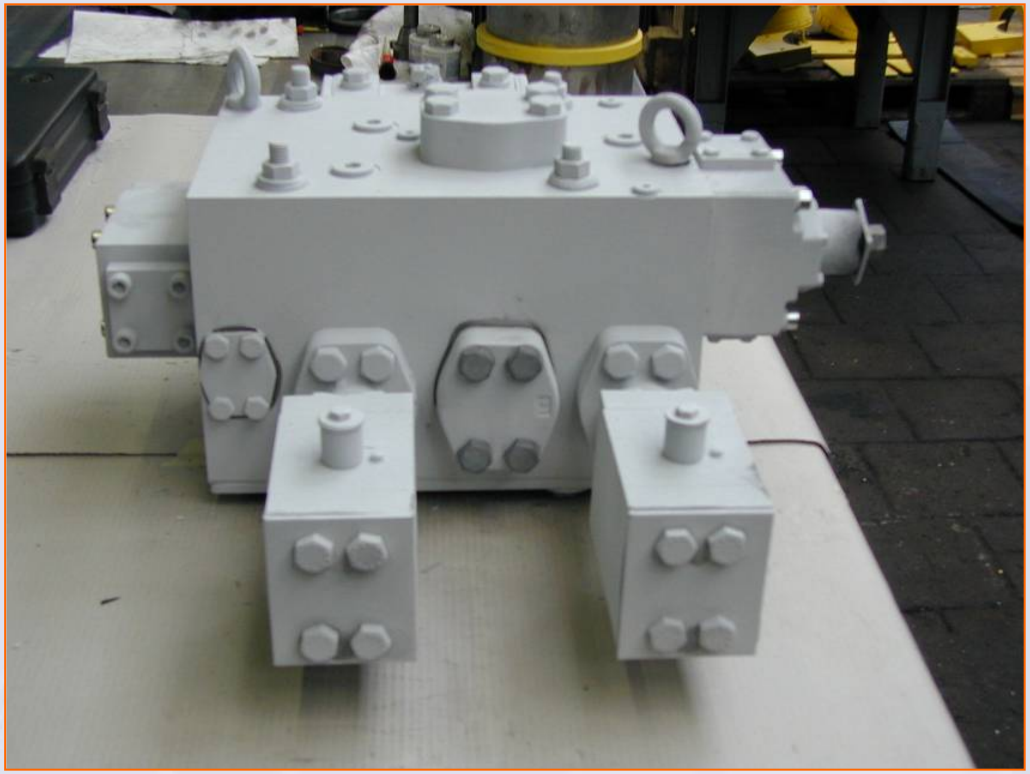
TSA – Reactor Vessel

- Chemical industry reactor barrel
- Coating: Al 99, 5 %
- Twin wire arc spraying
- Lifetime > 30 years

TSA – Water Gate Valve

- 700 x 500 x 500 mm
- Wire flame spray
- 99,5% Al coating
- Coating thickness:
  - 250-350 µm



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Quality / Inspection

- Daily record of temperature, humidity
- Roughness of grit blasted areas
- Coating thickness measurements
- Bond strength measurements

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Offshore Wind Turbine Corrosion

- Operators wish to increase design life from 20 to 40 years
- Corrosion major issue. Design codes call for at least 0.3mm per annum (x 40 = 12mm)
- Splash and tidal zone most rapid corrosion, most difficult to maintain (coffer dams)
- Conventional coatings last <20 years, typically primer or TSZ + 3 layer epoxy + PU
- Several notable wind farm coating failures

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Offshore Wind Turbine Coating Specification

- Topside (above transition section):
  - Thermal spray ZnAl.
  - 3-layer epoxy build-up.
  - Polyurethane topcoat (UV resistant).

- Transition section / splash and tidal zone / immersed (external):
  - Zn-primer.
  - 3-layer epoxy build-up.
  - Hi-viz PU topcoat (UV resistant).
  - Cathodic protection below water line.

- Internal – Zn primer + epoxy / PU

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Development of Coatings for a 40-year Offshore Design Life

- **TSA used by offshore oil & gas sector since 1984 for long-term corrosion mitigation**
- **Some use / specification of thermally sprayed Zn-Al for OWT topsides**
- **April 2010: TWI started Joint Industry Project (JIP) studying splash and tidal zone corrosion of TSA, TSA alloys and 40-year paint system**

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Summary

- TSA = thermally sprayed aluminium.
- Paints and organic coatings susceptible to mechanical damage, elevated temperature, UV.
- TSA is cost effective alternative to paints and organic coatings (short, medium and long-term).
- TSA has low corrosion rates (<5μm / year) when applied correctly.
- TSA provides cathodic protection when damaged.
- TSA is suitable for a wide range of environments:
  - Offshore (topside, splash zone, subsea), coastal
  - Onshore – coastal , industrial, rural
  - Under insulation, elevated temperature
  - C-steel, stainless, high strength duplex steels etc

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TSA vs Paint

Features	TSA	Conventional Paint
Required surface preparation	White/near white (Sa 2.5/3)	White/near white (Sa 2.5/3)
Application method(s)	Twin wire arc spay or flame spray	Spray, brush and roller
Application accessibility	Arc/spray head to within 30^{o} normal to surface	Brush/roll restricted access but life decreases
Application temperature limit	None, but surface must be dry	Ambient to about 60°C
Schedule impact	None - one coat application	24 hrs typically; multi coats required
Environmental impact	None	Must meet VOC & disposal regulations
Protection in thermal cyclic service	Yes	No effective paint system
Upper continuous operating temperature	480^{o}C	Increasingly susceptible to damage >120^{o}C
Durability	Resistant to mechanical abuse.	Susceptible to mechanical abuse.
Corrosion under insulation	Minor damage does not result in CUI 25 to 30 yrs	Any damage results in CUI 5 to10 yrs

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Recently Started New Projects

- **2012-2015 CRP: Automated surface preparation methods for thermal spray coating (grit blasting).**

- **UK Government: Automated surface preparation and thermal spray coating for OWT.**

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