

Chris Wiseman

TWI

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Joining and Surfacing Technologies for Lightweight Materials

Chris Wiseman - TWI  
EUROPEAN LIGHT RAIL CONGRESS – MARCH 2024



Materials Joining and Engineering Technologies

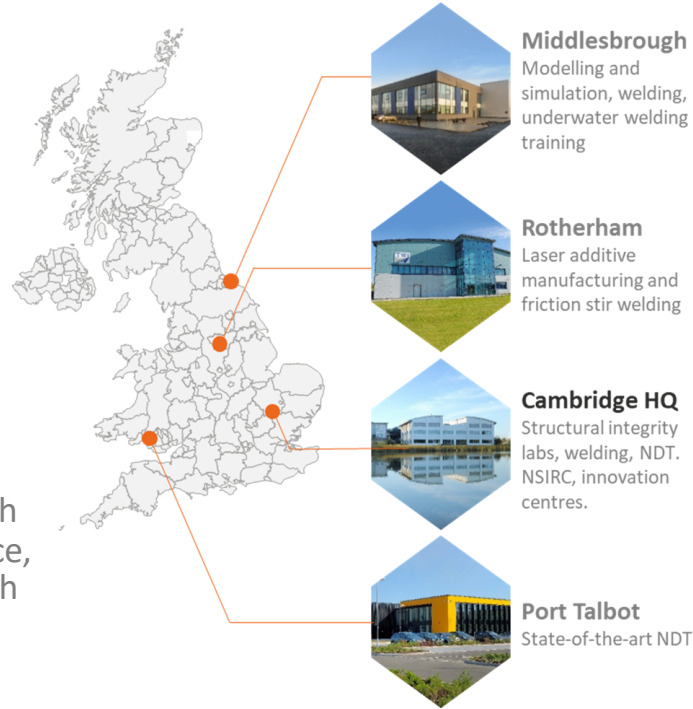
# TWI Ltd – Snapshot

## Non-profit distributing, membership driven RTO with:

- 600+ Industrial Members
- 600+ staff globally
- 2000+ professional members
- 4 main UK R&D centres
- 18 international offices

### Our mission:

To provide our Industrial Members with authoritative and impartial expert advice, knowhow and safety assurance through engineering, materials and joining technologies.



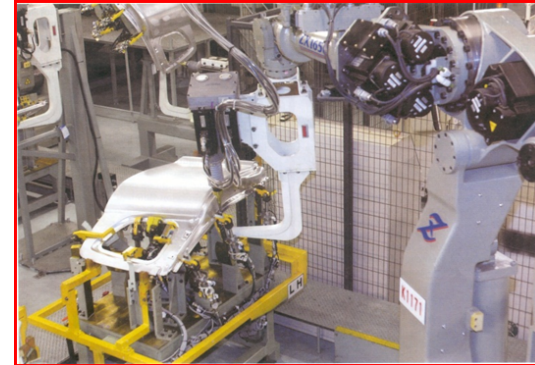
# International Presence



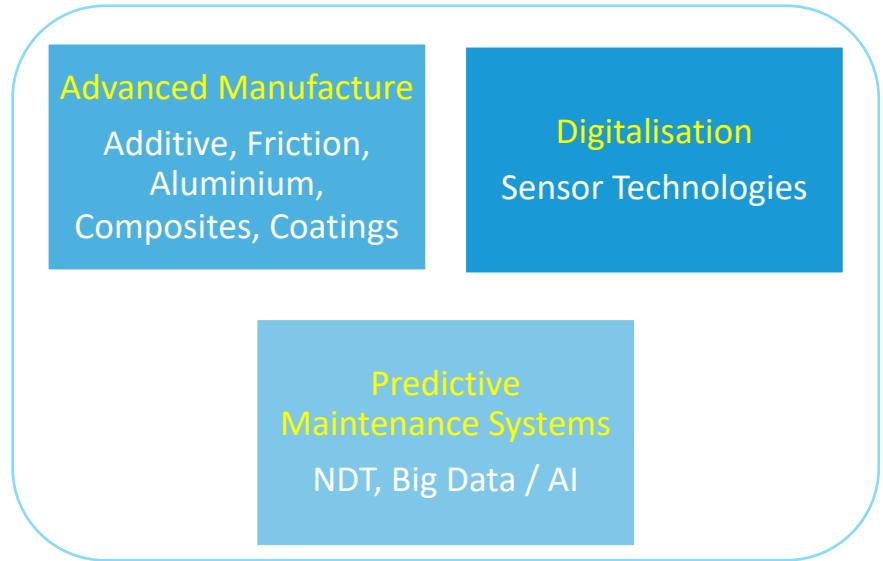
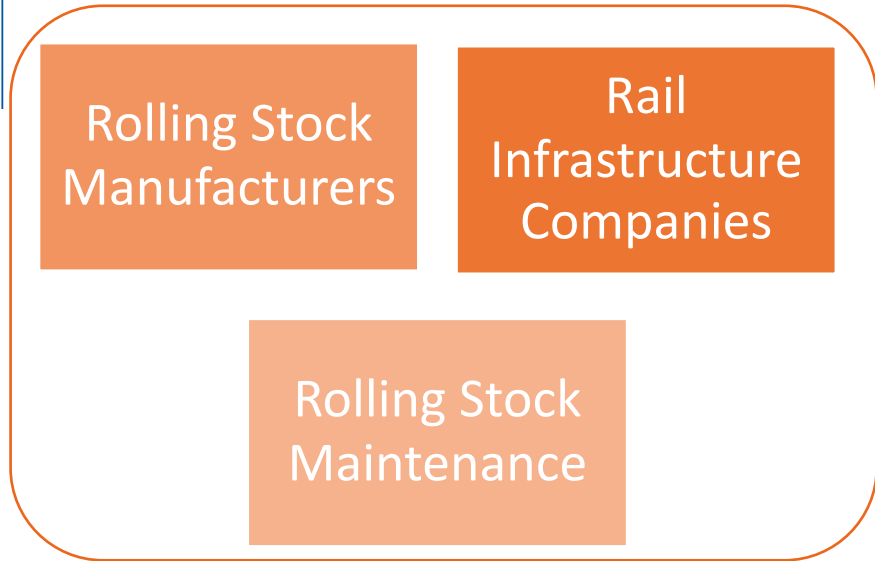


# TWI Competence

- Design & Structural Integrity
- All Joining and Welding processes
- Additive Manufacturing
- Surfacing and coatings
- Metals, Composites and Polymers
- Testing
- NDE & Inspection
- Corrosion
- Quality, Safety and Standards
- Industry “4.0”
- Software
- Training and Certification



# Rail Sector in a renewed cycle of investment and innovation



- Smart City / Metropolitan railways (Especially Asia, EU & Middle East >\$1 trillion to 2029)
- Sustainability Environmental & Alternative Propulsion (H2, Electrification, High-Speed Rail (large NEW investments in UK, India, USA, Middle East and Europe)
- Safety (such as FSW for passenger protection)

# Some Technology Themes for Rail and Light Rail

- **Advanced Materials:**
  - Lightweight Metals
  - High-Strength Steel
  - Composite / Thermoplastic Materials
  
- **Joining Technologies:**
  - Friction Welding (FSW and LFW)
  - Laser Welding
  - Electron Beam Welding (EBW)
  - Adhesives
  
- **Enablers:**
  - Coatings through Coldspray, Thermal Spray etc.
  - Dissimilar joining
  - Modelling
  - Additive manufacture including EHLA
  - Electrification and Hydrogen
  
- **Inspection Technologies:**
  - Non-Destructive Testing (NDT)
  - Infrared Thermography
  - Digital Inspection Solutions
  - Full Structural Health Monitoring



# Examples of Lightweight Materials

- **Magnesium** - Typical mass reduction vs steel 30%-70%
- **Carbon Fibre Composites** - 50%-70%
- **Aluminium Alloys** – 30%-60%
- **Titanium** – 40%-55%
- **Glass Fibre Composites** – 25%-35%
- **High Strength Steels** – 10%-28%
- **Combinations Thereof** – or just less material.

The margins may not be as game-changing as envisaged when other factors considered?

# Joining Processes used

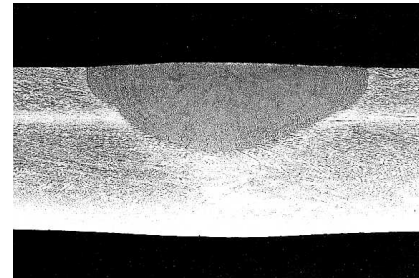
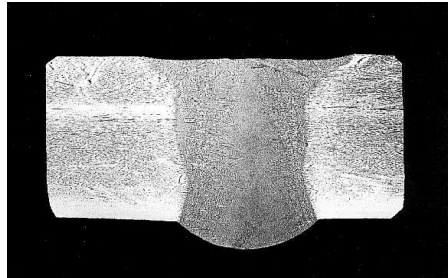
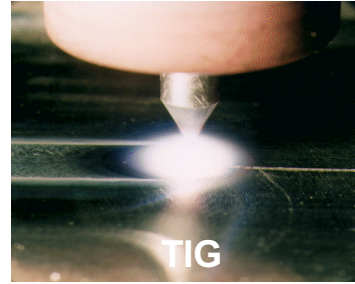
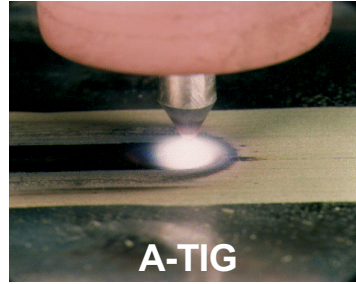
Material	Fusion processes			Non-fusion processes		
	Resistance Welding	Arc	Laser & EB	Friction	Mechanical fastening	Adhesive
Steels	Y	Y	Y	Y	Y	Y
Al alloys	Y	Y	Y	Y	Y	Y
Mg alloys	Y	Y	Y	Y	Y	Y
Ti alloys	Y	Y	Y	Y	Y	Y
Polymers	N	N	Y	Y	Y	Y
Composites	N	N	N	Y	Y	Y

**Y** – Technically feasible, but not generally applied

## Arc Welding -

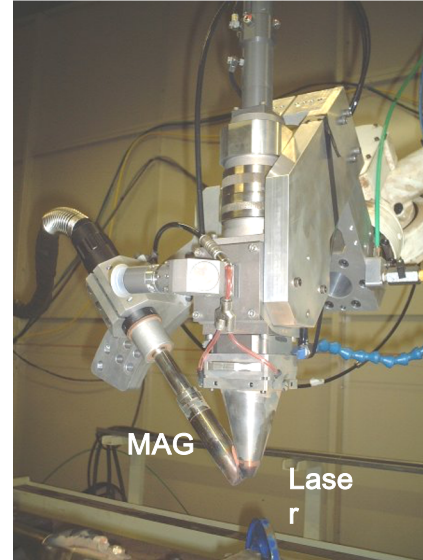
- **Widely established, tested – and available**
- **Skillsets are fine tuned and standardised globally**
- **Can be automated** – including adaptive control
- **Innovations** aimed at productivity and quality (e.g. CMT, A-Tig, K-Tig)
- **Innovations in equipment and consumables** (Hybrid welding / cored wires)

# Activated Flux TIG (Paton, EWI, TWI, Commercial) constricted arc - increased penetration



# Hybrid Laser-Arc Welding

- Improved fit-up tolerance
- Improved weld quality and profile
- Filler metal addition
  - control of weld microstructure
  - control of hot cracking





# Some Advantages of Laser Welding

- Low heat input
- High speed
- Low distortion
- Single pass
- Narrow weld beads/flanges
- Single-sided access
- Can be performed
  - in air (BiW)
  - inert shielding (higher quality)
- Non-contact process



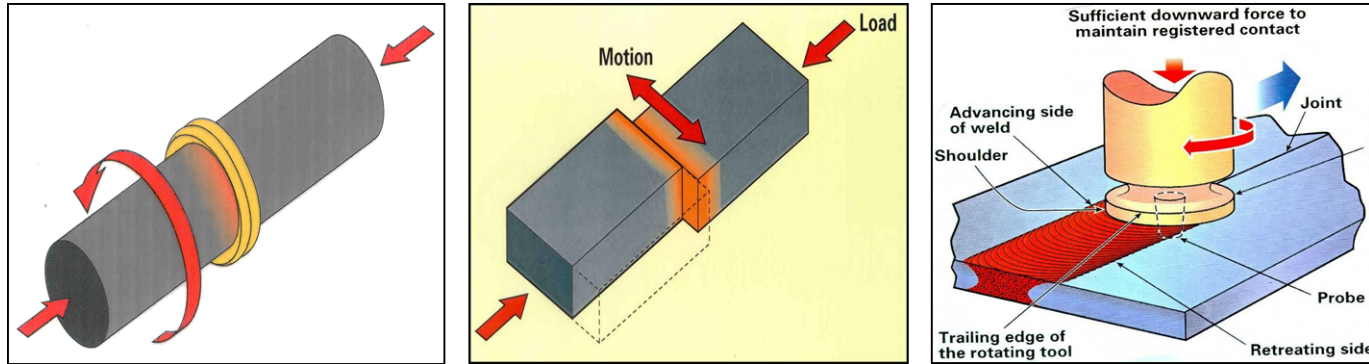
- Remote Laser allows greater freedom in lightweight designs

# Friction and Forge Processing

Rotary, Linear and Friction Stir Welding

Increasing use in Aerospace, Automotive, Marine

TWI FSW Global Patent ended in 2016



# FFP Technology – FSW

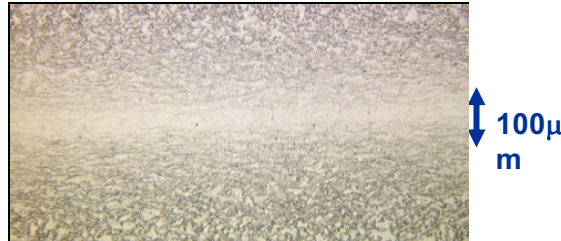
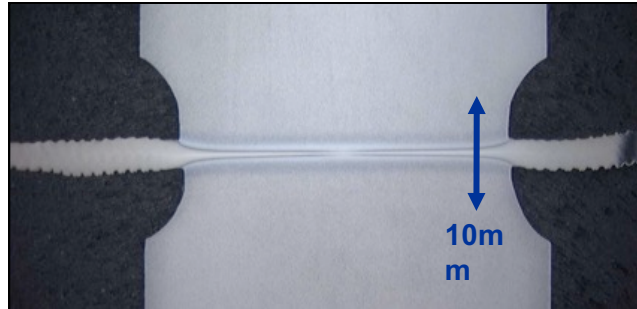


# Friction welded materials

- Weldable materials
  - Aluminium alloys
  - Titanium
  - Polymers
  - **Steels**
  - **High strength steels**
  - Dissimilar combinations
    - e.g. Aluminium to steel
    - e.g. Al to Mg



# LFW Weld Quality in Ti-6Al-4V (Near Net Shape)

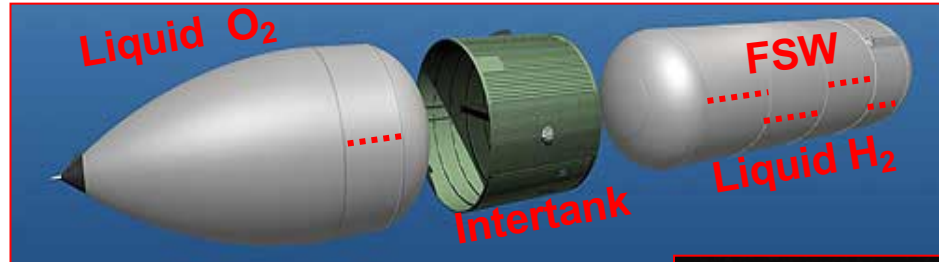


Fine grained hot  
forged weld  
microstructure

Recrystallised to  
fine grained  
equiaxed at  
weld centre

Near parent  
tensile and  
fatigue  
properties can  
be achieved

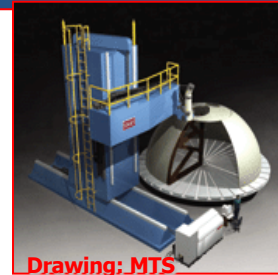
# Lightweight Tank by Lockheed Martin Space Systems for NASA (Superior properties enable thinner lighter design)



External Tank: 154' long, 27.6' dia

The only non-reusable major component of  
the Space Shuttle

Structural backbone of the shuttle,  
absorbing most of the six million pounds of  
thrust



Drawings: <http://www.lockheedmartin.com/michoud/et/description.htm> and  
<http://www.memagazine.org/contents/current/features/coolweld/coolweld.html>

swk

# Electrical Resistance Welding (Very established & cost effective)

- Can be fast
- Lends to large-scale manufacturing
- **Often a preferred choice for joining thin parts**
- Some electric resistance processes are automatic
- No consumable materials used
- Usually very cost effective process over time
- **Can weld dissimilar metals**
- **Can weld through adhesives**

**These requirements may arise when light-weighting**

# Battery Busbar Welding

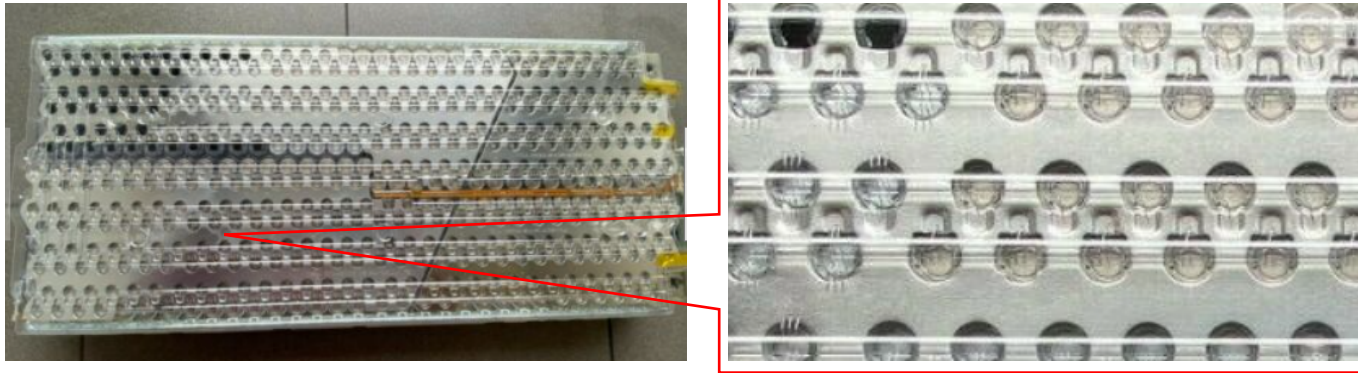


# EV cell types



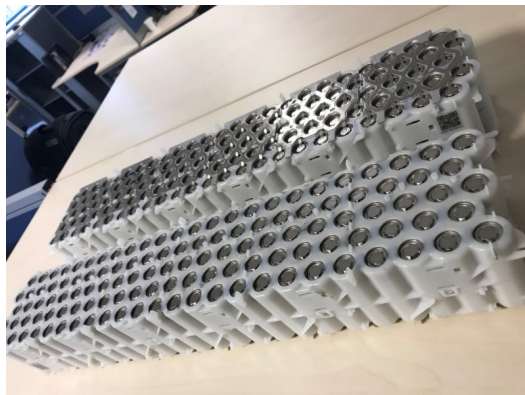
Cylindrical, pouch and prism cells

## Tesla – cylindrical cells - wire bonding

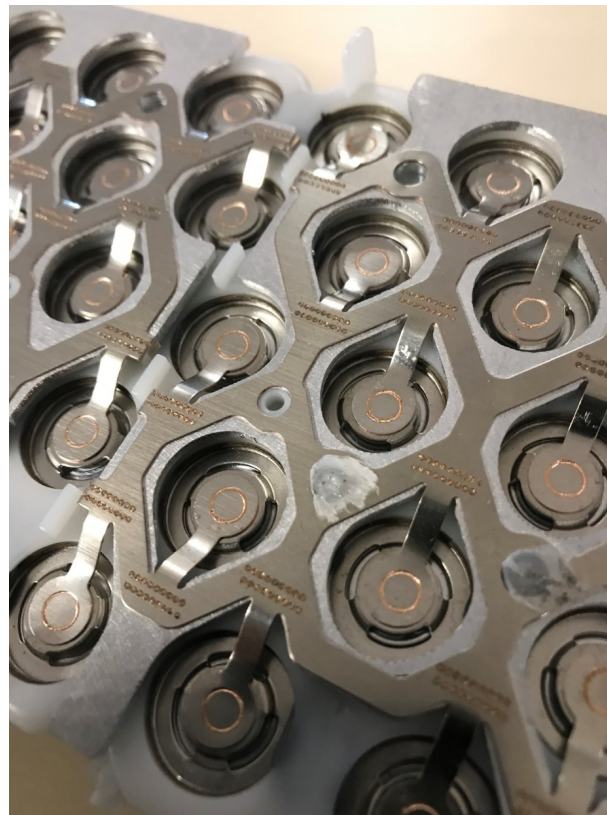


- The battery is about 40-50% of the cost of an EV
- A Tesla has 3000 battery cells, at least 12,000 welds
- **Bond integrity is critical to the EV performance**
- For example, Tesla produced 500,000 EVs in 2020, using 1.5 billion cells

# Laser Tab welding

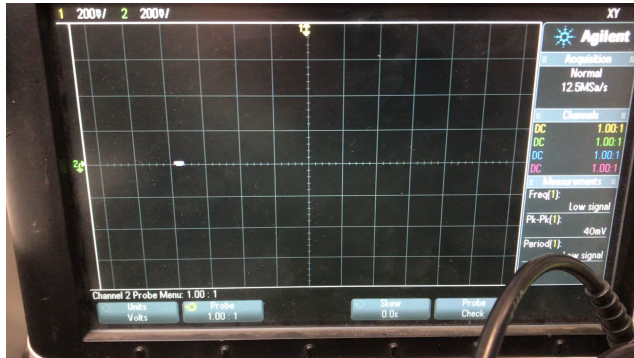


- For 3000 cells, ~57minutes
- Higher integrity & reproducibility



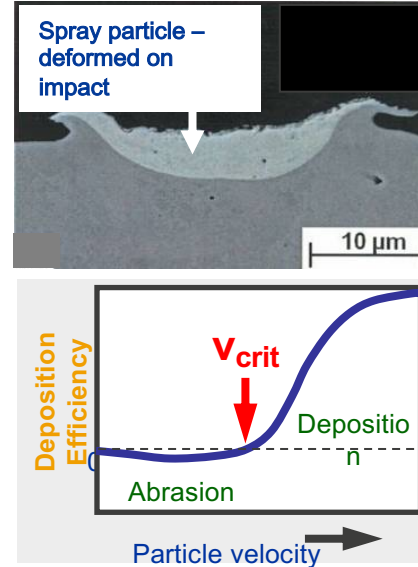
# Electron Beam Spot Welding

- No reflectivity from copper or aluminium – **consistent penetration**
- **Ultra-fast beam deflection** – up to 10,000m/sec, no moving parts
- Effective joining rates of 1000mm/sec (**10x faster than laser**)



# Cold Spray for repair (Circular Economy)

- If solid particles strike a target fast enough, they bond to the substrate (and each other).
- Particle velocity,  $v > 600\text{m}\cdot\text{s}^{-1}$  typically.
- Particle velocity achieved with high pressure, high flow gas

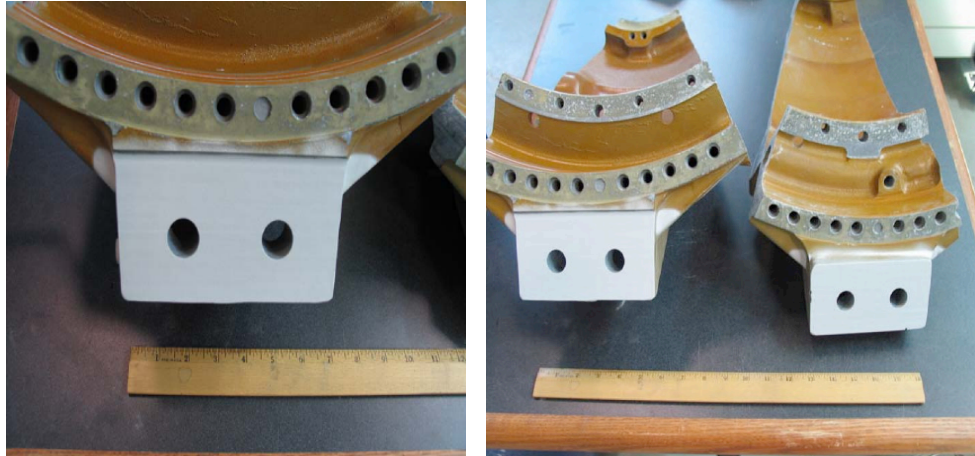


# Cold Spray Process



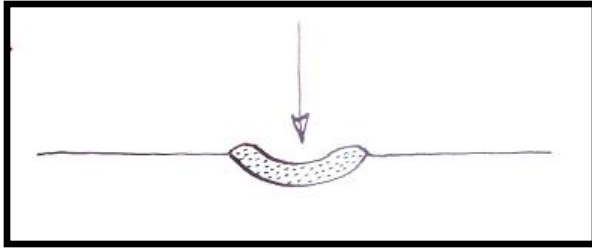


# Lightweight Mg Alloy gearbox housing repaired with cold sprayed Al

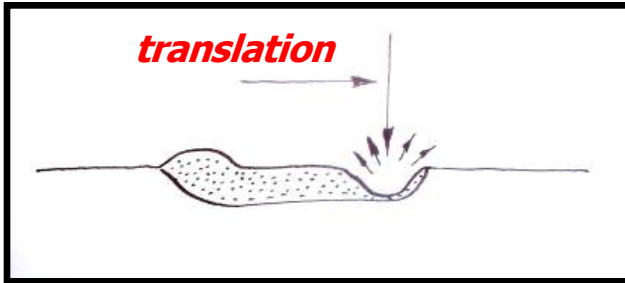


**Cold Spray is being developed at a rapid pace** including as an additive process - e.g for thin walled hydrogen tanks.

# *Electron Beam Texturing and Surfi-Sculpt®*



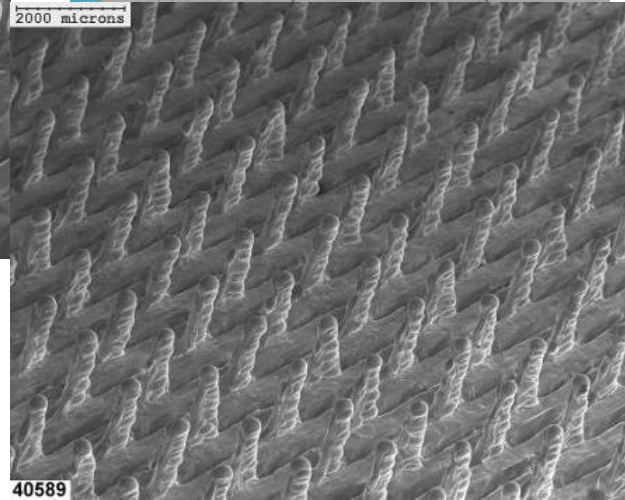
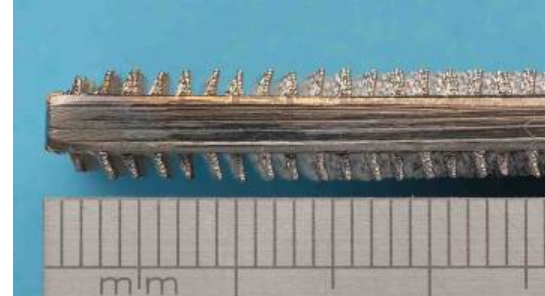
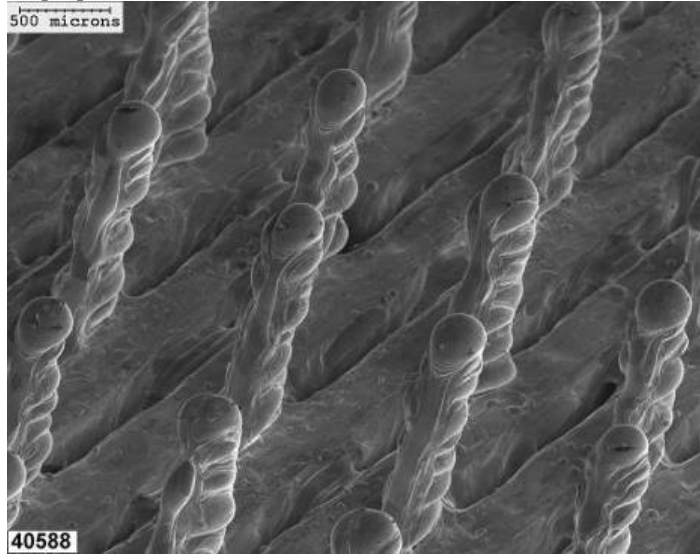
*an intense electron beam  
can displace material via  
vapour pressure; against  
surface tension*





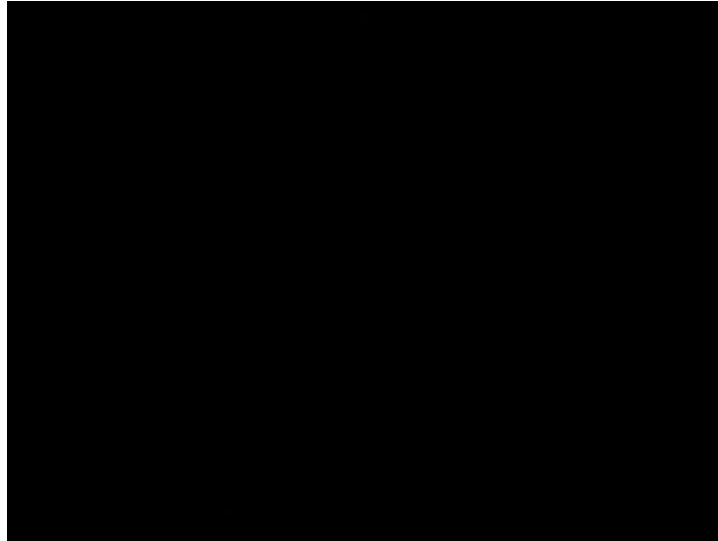
# *Electron Beam Texturing and Surfi-Sculpt®*

Applications - Comeld™



*Stainless Steel 316*

## *Electron Beam Texturing and Surfi-Sculpt<sup>®</sup>*

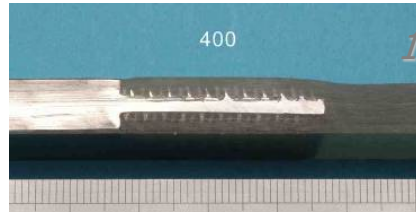


- *rotating parts may be processed*

# *Electron Beam Texturing and Surfi-Sculpt®*

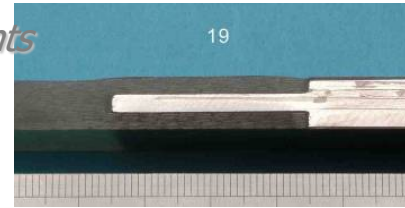
Applications – Comeld (Metal / Composite Joining)

*Comeld™ joints*



*1 step joints*

*Control joints*

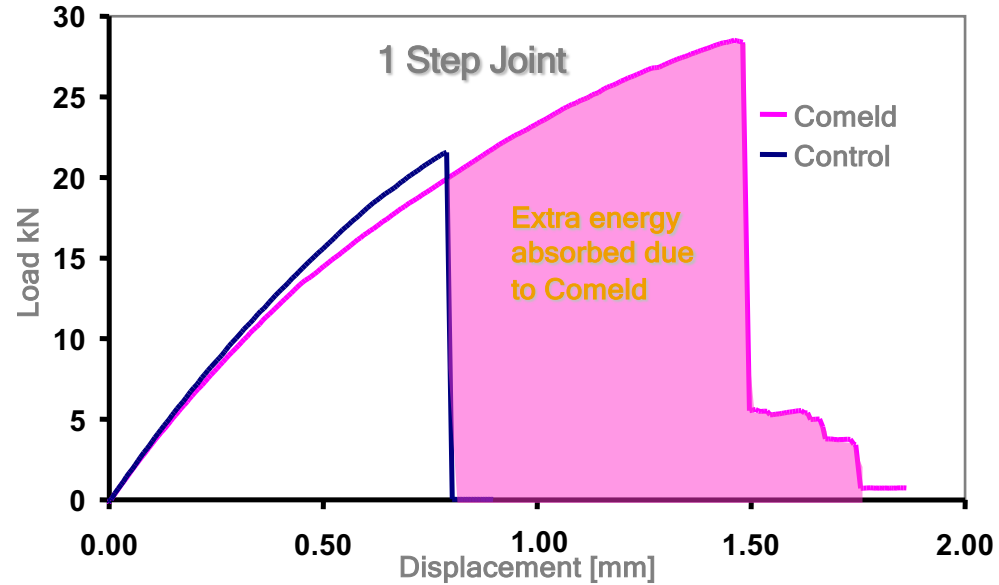


*2 step joints*

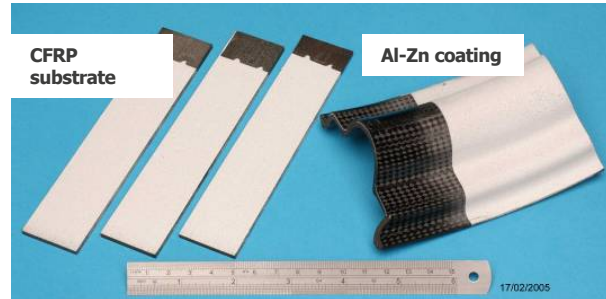
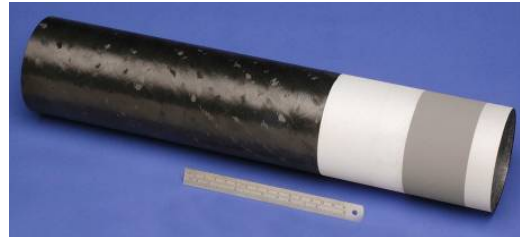
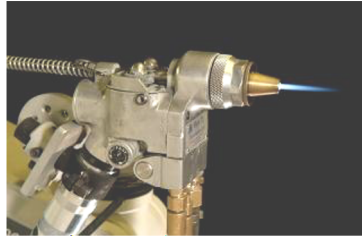


*SS/GFRP joint made by vacuum infusion*

# Comeld™



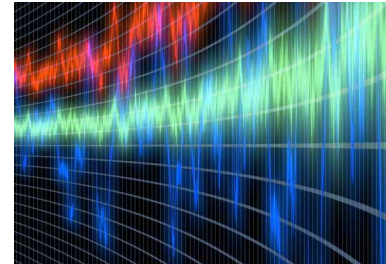
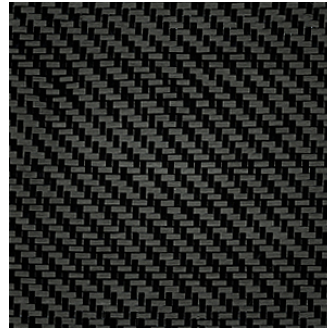
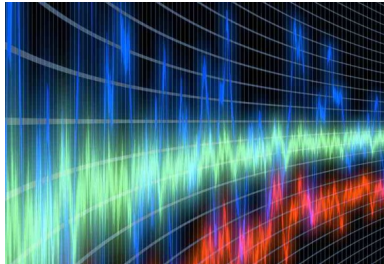
# Thermal spraying of Composites – Thermal Barrier, Lightning Strike, Wear Resistance (Enabling use of composites in difficult environments)



# Smart composites

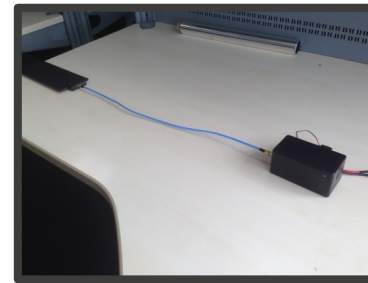
Radio wave transmission using surface waves.

Experiments indicate the potential for transmission of data in structural composite materials.



# Passing data through composites without using wires and fibre optics

- Connections can be made and positioned anywhere along its length, just add more branches, nodes or extensions.
- Can transfer data at 3 Gbps per channel
- Signals can re-route around any damage
- **3x faster than a typical Cat6 ethernet cable**



## Likely global trends in welding in the next 10 years.

**Arc Welding** – constant

**Lasers & Electron Beam**– considerable increase

**Spot Welding** – considerable decrease

**Friction Welding** – constant **(Why?) – see last slide**

**Adhesives** – considerable increase – how do we easily dismantle, segregate & recycle?

**Diffusion Bonding** – considerable increase – especially in Space and Defence

**Robotics** – considerable increase.



# Track

Technical support on...

- Rail welding and joining
- Non destructive testing
- Application of industry best practice
- Innovative solutions

Individual competency-

- Institute of Rail Welding



# Institute of Rail Welding

Managed by TWI

- Supports competency of all personnel involved in rail welding and inspection
- Training, qualification and promoting teamwork within the industry are key features
- Corporate membership of rail sector organisations

# Rail Vehicles & Equipment

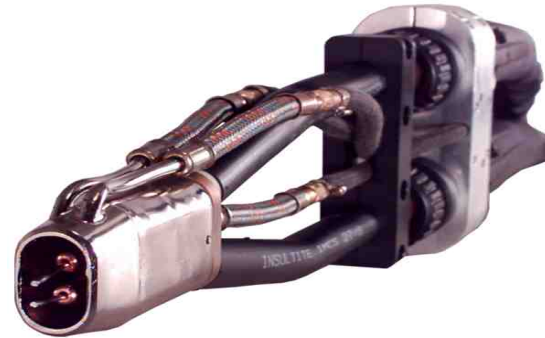
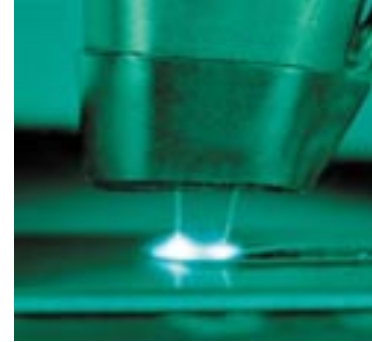
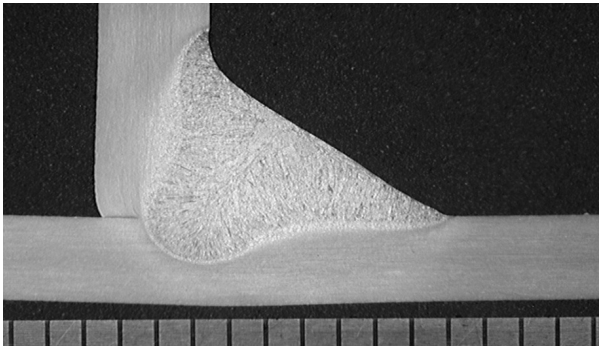
- High deposition rate arc welding
- Laser welding
- Low distortion fabrication
- Crashworthiness
- Detailed design and FEA modelling for structural integrity: fatigue & fracture
- Distortion control modelling techniques
- Friction Stir Welding (FSW)
- Metal / Composite joining
- Electrification & Hydrogen



# High Productivity Arc Welding

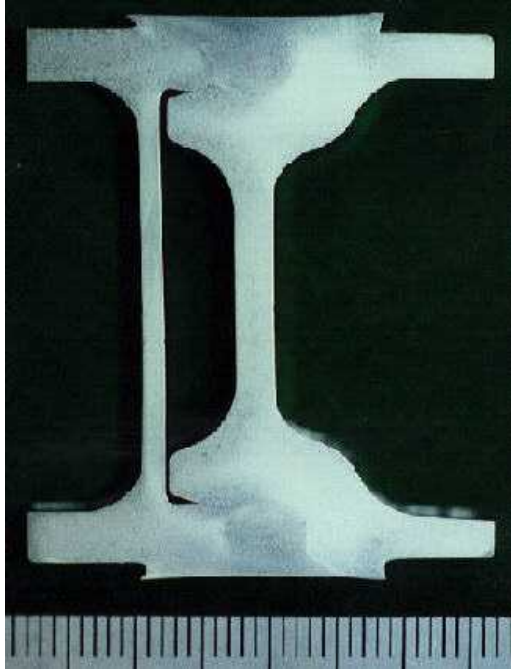
## Tandem Wire MIG Welding

- High deposition rate process
  - Up to 17kg/h
  - Reduced number of passes
- High welding speed
  - 5m/min on 2mm sheet steel



# FSW of Rail Carriages

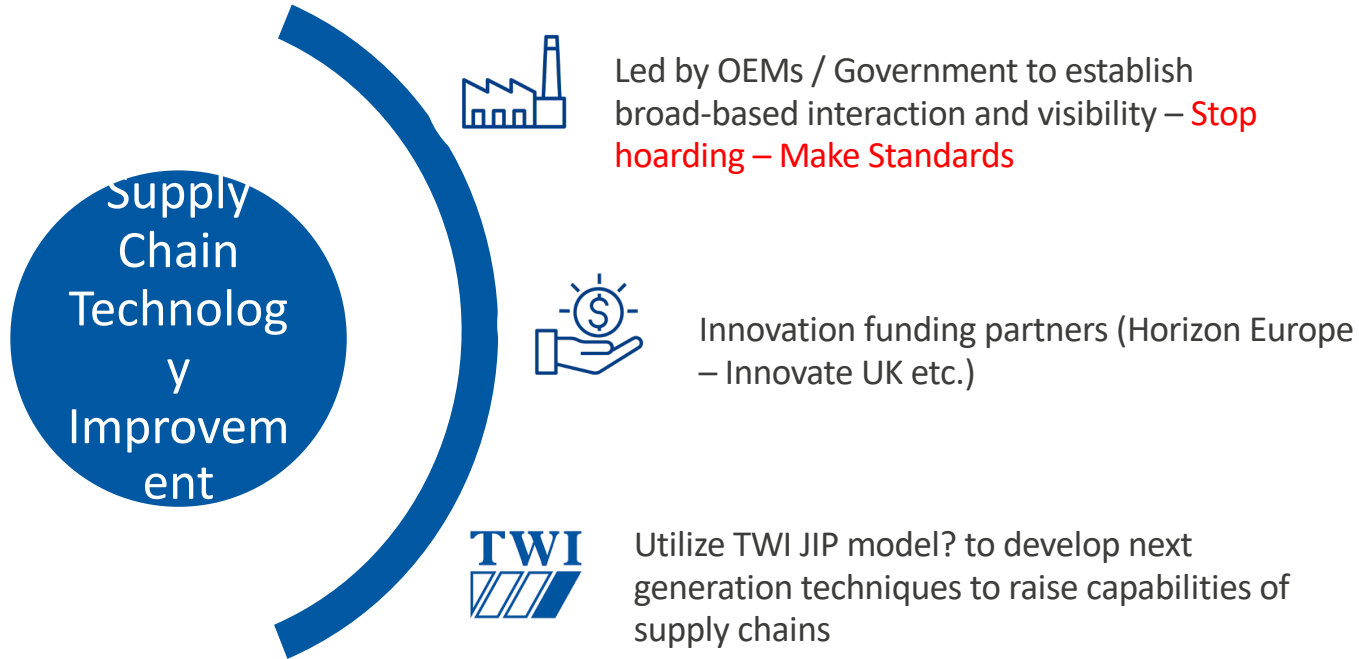
## FSW of Rail Carriages by Hitachi



# Rail Vehicle Maintenance

- Rail car bodies
  - Non routine non destructive testing
  - Whole structure health monitoring
  - Use of adhesives for repair
- Bogies and axles
  - Non routine non destructive testing
  - Development of improved non destructive techniques
  - Advice on fatigue mitigation and detailed design aspects
  - Risk based through-life management

# Supply chain improvement through collaborative programmes








Thank you!

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