- Research & Technology Organisation
  - Welding and joining
  - Materials performance
  - Corrosion
  - NDT
- Established in 1946
- Independent
  - Not government funded
  - No shareholders; any profit is used to build/maintain capability
- Nuclear pedigree
TWI Headquarters at Granta Park, Cambridge
TWI Headquarters at Granta Park, Cambridge

- £80m turnover p.a.
  - 700 Single Client Projects
  - 50 Joint Industry Projects (JIPs)
  - 70 Core Research Projects
  - 65 Collaborative Projects
- 900 staff (≈550 engineers)
- 700 Industrial Members
  - 4,500 locations in 80 countries
  - Over 15,000 visitors per annum
- TWI influences over 120 International Codes and Standards
The Thermal and Cold Spray Section
Ten different thermal & cold spray systems (all commercially available)
Four spray booths, two of which can combine to form one large booth (7.5m long x 6m deep x 4m high)
Impact Innovations 5/11 – 6/10
Cold Spray System
Large mechanised grit blasting room
The Cold Spray Process
Helium or nitrogen gas at up to 1100°C and 50-60 bar

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 build up a coating.
Localised, transient adiabatic shear instabilities at the interface:

- Kinetic energy converted to deformation and thermal energy
- Rapid, highly localised, transient temperature increase at interface → drop in yield strength at interface (YS=f(T))
- Brief and highly localised plastic flow of particle and substrate leads to bonding
Critical Velocity: A key concept in cold spraying

Deposition Efficiency

Erosion

Particle velocity

$V_{crit}$

Spray particle - deformed on impact

Material jet

Copyright © TWI Ltd 2016
Powder particle velocity (ms\(^{-1}\))
He vs N\(_2\) (CGT Kinetiks® 4000/47)

\(<v_p(\text{He})> = 570\text{ m.s}^{-1}\)

\(<v_p(\text{N}_2)> = 380\text{ m.s}^{-1}\)
- Cu coating
- Oxygen level, wt%
  - Powder 0.05
  - Coating 0.05

There is usually minimal oxidation of the powder in cold spraying

- Al coating
- Oxygen level, wt%
  - Powder 0.20
  - Coating 0.20
Spray-Formed Ti

< O.D. 48mm >
Spray-Formed Ti

- Spray time: ~12 min
- Deposit thickness: ~12 mm
- Machined mass: ~300g
- As-deposited cohesive strength: 230MPa
## Oxygen pickup during deposition

<table>
<thead>
<tr>
<th>System</th>
<th>Powder</th>
<th>P</th>
<th>Temp.</th>
<th>Thickness (avg.)</th>
<th>Porosity (avg.)</th>
<th>$O_2$</th>
<th>Bond strength</th>
<th>Tensile cohesive strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetiks® 4000/47</td>
<td>TWI</td>
<td>40 bar</td>
<td>800°C</td>
<td>≈ 150 µm</td>
<td>3.6-4.0%</td>
<td>0.03% (300 ppm)</td>
<td>28 MPa</td>
<td>n.d.</td>
</tr>
<tr>
<td>Kinetiks® 8000/52</td>
<td>SM</td>
<td>40 bar</td>
<td>1000°C</td>
<td>≈ 130-145 µm</td>
<td>2.0%</td>
<td>0.05% (500 ppm)</td>
<td>&gt;70 MPa</td>
<td>n.d.</td>
</tr>
<tr>
<td>PCS-1000</td>
<td>PG (N₂ gas)</td>
<td>50 bar</td>
<td>1000°C</td>
<td>≈ 715 µm</td>
<td>1.8%</td>
<td>0.08-0.09% (800-900 ppm)</td>
<td>Disbonded</td>
<td>n.d.</td>
</tr>
<tr>
<td>Impact 5/11</td>
<td>TWI</td>
<td>46 bar</td>
<td>1000°C</td>
<td>≈ 700-740 µm</td>
<td>0.3-0.9%</td>
<td></td>
<td>34 MPa</td>
<td>289 MPa</td>
</tr>
<tr>
<td></td>
<td>IMP</td>
<td>46 bar</td>
<td>1000°C</td>
<td>≈ 585-610 µm</td>
<td>0.6-0.8%</td>
<td></td>
<td>&gt;72 MPa</td>
<td>266 MPa</td>
</tr>
</tbody>
</table>

Powders were 300 ppm. There is up to 600 ppm oxygen pickup during coating deposition with 1000°C N₂
### Oxygen pickup during deposition

<table>
<thead>
<tr>
<th>System</th>
<th>Powder</th>
<th>P</th>
<th>Temp.</th>
<th>Thickness (avg.)</th>
<th>Porosity (avg.)</th>
<th>O₂</th>
<th>Bond strength</th>
<th>Tensile cohesive strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kinetiks® 4000/47</td>
<td>TWI</td>
<td>40 bar</td>
<td>800°C</td>
<td>≈ 150 µm</td>
<td>3.6-4.0%</td>
<td>0.03% (300 ppm)</td>
<td>28 MPa</td>
<td>n.d.</td>
</tr>
<tr>
<td>Kinetiks® 8000/52</td>
<td>SM</td>
<td>40 bar</td>
<td>1000°C</td>
<td>≈ 130-145 µm</td>
<td>2.0%</td>
<td>0.05% (500 ppm)</td>
<td>&gt;70 MPa</td>
<td>n.d.</td>
</tr>
<tr>
<td>PCS-1000</td>
<td>PG (N₂ gas)</td>
<td>50 bar</td>
<td>1000°C</td>
<td>≈ 715 µm</td>
<td>1.8%</td>
<td>0.08-0.09% (800-900 ppm)</td>
<td>Disbonded</td>
<td>n.d.</td>
</tr>
<tr>
<td>Impact 5/11</td>
<td>TWI</td>
<td>46 bar</td>
<td>1000°C</td>
<td>≈ 700-740 µm</td>
<td>0.3-0.9%</td>
<td></td>
<td>34 MPa</td>
<td>289 MPa</td>
</tr>
<tr>
<td>Impact 5/11</td>
<td>IMP</td>
<td>46 bar</td>
<td>1000°C</td>
<td>≈ 585-610 µm</td>
<td>0.6-0.8%</td>
<td></td>
<td>&gt;72 MPa</td>
<td>266 MPa</td>
</tr>
</tbody>
</table>


*Powders were 300 ppm. There is up to 600 ppm oxygen pickup during coating deposition with 1000°C N₂*
Al-B$_4$C composite
NucleoStore™ coating

20 vol% B$_4$C in an aluminium matrix
Al-B₄C composite
NucleoStore™ coating

Almost unlimited thickness
### Al-B₄C composite NucleoStore™ coating

<table>
<thead>
<tr>
<th>Property</th>
<th>BORAL® Composite</th>
<th>BORTEC® MMC</th>
<th>TWI NucleoStore™</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description</strong></td>
<td>Flat shapes fabricated from 1100 Series Al alloy plates, separated by a core of Al + B₄C powder</td>
<td>Flat, rolled plates of metal-matrix composite consisting of Al alloys (or Al) containing B₄C particles</td>
<td>An MMC coating that can be deposited onto a wide variety of fabricated metal shapes</td>
</tr>
<tr>
<td><strong>Minimum thickness</strong></td>
<td>1.905 mm</td>
<td>1.905 mm</td>
<td>≈ 200 µm</td>
</tr>
<tr>
<td><strong>Maximum thickness</strong></td>
<td>6.858 mm or more</td>
<td>9.525 mm or more</td>
<td>Potentially no limit.</td>
</tr>
<tr>
<td><strong>Max %B₄C by mass</strong></td>
<td>≈ 61% in the core</td>
<td>≈ 32%</td>
<td>Currently ≈ 18%</td>
</tr>
<tr>
<td><strong>Max %B₄C by volume</strong></td>
<td>≈ 65% in the core</td>
<td>≈ 34%</td>
<td>Currently ≈ 20%</td>
</tr>
<tr>
<td><strong>Relative density</strong></td>
<td>N/A</td>
<td>&gt;98%</td>
<td>&gt; 98%</td>
</tr>
<tr>
<td><strong>Tensile strength approx.</strong></td>
<td>≈ 10 ksi (≈69 MPa)</td>
<td>21-31 ksi (145-215 MPa)</td>
<td>&gt; 16 ksi (&gt; 110 MPa) Parallel to substrate</td>
</tr>
<tr>
<td><strong>Adhesion strength of NucleoStore™ coating to AISI 316 S/S substrate:</strong></td>
<td></td>
<td></td>
<td>≈ 23 MPa</td>
</tr>
<tr>
<td><strong>Adhesion strength of NucleoStore™ coating to duplex steel substrate:</strong></td>
<td></td>
<td></td>
<td>≈ 18 MPa</td>
</tr>
</tbody>
</table>
Summary

- Nuclear engineering experience
- Large scale, state-of-the-art cold spray facility
  - Can handle large parts (craneage)
  - Offline programming of coating toolpaths
  - Full process: Grit blasting, machining, coating, NDT
  - HIP consolidation
  - Laser assisted cold spray
  - Laser surface consolidation
- Full suite of coating evaluation and characterisation capabilities
  - Corrosion
  - Wear
- Highly experienced engineers and technicians
Heidi Lovelock CEng FIMMM
Section Manager: Surface Engineering

Tel: +44 (0)1223 899 000

E-mail: heidi.lovelock@twi.co.uk

Web: www.twi-global.com