Topics

- Brief summary of Wire + Arc Additive Manufacture process in relation to other AM processes
- WAAM business drivers
- WAAM Systems
- Future plans
Wire + Arc Additive Manufacture (WAAM) Process

Deposition time 24 hours

0.5 m
Benefits and limitations

Note – our assessment
Key WAAM process features

- Build rates 0.5 - 4 kg/hour – **typical 1kg/hr titanium**
- Unlimited build volume
- **Buy to fly ratio** – typical 1.5 but always <2
- Fully dense materials with excellent mechanical properties
- Minimum feature size 2 mm
- **No commercial systems available** – yet
Aluminium stiffened frame

After machining
WAAM - Business Drivers

- WAAM business drivers are
  - Cost and material saving compared to current manufacturing methods
  - Greatly reduced lead times
  - Application to large engineering structures

<table>
<thead>
<tr>
<th>Design option (MRR = 65 kg/h)</th>
<th>BTF</th>
<th>Cost (£k)</th>
<th>Cost red.</th>
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<tbody>
<tr>
<td>Machined from solid</td>
<td>69</td>
<td>4.9</td>
<td>-</td>
</tr>
<tr>
<td>WAAM + machining</td>
<td>8</td>
<td>2.4</td>
<td>&gt;50%</td>
</tr>
</tbody>
</table>

Titanium wing frame
WAAM business driver – cost saving case studies - Bombardier rib

<table>
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<tr>
<th>Design option</th>
<th>Mass (kg)</th>
<th>BTF</th>
<th>Cost (£k)</th>
<th>Cost red.</th>
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<tbody>
<tr>
<td>Original machined</td>
<td>20</td>
<td>12</td>
<td>16.2</td>
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<tr>
<td>WAAM + machining</td>
<td>20</td>
<td>2.3</td>
<td>5</td>
<td>69%</td>
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</table>

<table>
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<tr>
<th>Design option</th>
<th>Mass (kg)</th>
<th>BTF</th>
<th>Cost (£k)</th>
<th>Cost red.</th>
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</thead>
<tbody>
<tr>
<td>Original, machined</td>
<td>36</td>
<td>12</td>
<td>1.6</td>
<td>-</td>
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<tr>
<td>WAAM + machining</td>
<td>36</td>
<td>2.3</td>
<td>0.7</td>
<td>55%</td>
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</table>
**WAAM business driver – cost saving case studies**

**CAD:**

- Green deposited material

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<th>Cost (£k)</th>
<th>Cost red.</th>
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</thead>
<tbody>
<tr>
<td>Machined from solid (MRR = 332 kg/h)</td>
<td>45</td>
<td>4.4</td>
<td>-</td>
</tr>
<tr>
<td>WAAM + machining</td>
<td>12.3</td>
<td>1.9</td>
<td>56%</td>
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</table>

15 kg aluminium wing rib (DR = 1kg/h)
What we’ve deposited so far

- Ti-6Al-4V
  - Grade 5
  - Grade 23
- Aluminium
  - 2024
  - 2319
  - 4043
  - 5087
- Refractories
  - Tungsten
  - Molybdenum
  - Tantalum
- Steels
  - ER60
  - ER80
  - ER90
  - ER120
  - Maraging grade 250
  - Maraging grade 350
  - Stainless (17-4 PH, 316L)
- Inconel
  - 625
  - 718
- Bronze
- Copper
Unique features - cold work

Rolled @ 50 kN
139 μm

Rolled @ 75 kN
66 μm

Control – no rolling

[images showing different materials and structures]
Ti64 // Static properties (average)

- Reduction in prior β grain size
- Reduction in α lamellae thickness
- Possibly some work-hardening effects still left in the structure
Aluminium properties (2024 – 2319 – 5087 (average))

Graphs showing the relationship between proof strength (MPa) and ultimate tensile strength (MPa) for different aluminium alloys (2024, 2319, 5087). The graphs include data for different processing conditions and test loads.
There is no porosity in the rolled + heat treated sample.

As deposited

ST+AA

Rolled + ST + AA
The systems

Tent + part rotator option

Open architecture systems
Rolling Assisted WAAM

Wire Feeder and Spool

Tool Holder

Roller

Torch

Argon Shield
Local shielding and 2 D rolling
WAAM system developments – multi robot systems for parallel processing

Parallel processing
• 2 x deposition
• Deposition + NDT + layer removal (machining)
• Deposition + metrology
• Deposition + cold work
• Combinations of the above

10 m maximum part size and/or multiple parts
WAAM system developments first long linear part
Where we are aiming - HELP!

Aluminium:
• 14 months for forging
• 4 months for machining
• 90% waste

Titanium:
• 10 times worse problems
This summer/autumn

World’s largest metal AM parts:
- 6 m aluminium bulkhead
- 7 m steel cantilever beam (1500 kg)
WAAM system developments – multi robot systems for parallel processing
Future Developments

- Completion of software development - including parallel processing
- Process control systems
- On-line NDT
- Development of multi – robot and process systems
- Materials development
  - Higher strength aluminium > 500 MPa UTS
  - Refractory metal parts
  - Graded and mixed materials
  - MMCs
- Qualification for aerospace and oil & gas
- Commercial system development
WAAMMat programme aim is to reach TRL6 by 2019
It is a rolling technology programme incorporating over 65 projects – total value approximately £3M (Industry, collaborative, PhDs/Masters, internal projects)
Team of 26 at Cranfield to deliver the technology (academics, researchers, technicians and students)
14 academic partner institutions
19 industrial programme members (both end users + exploitation partners)
Much more information on our website
waammat.com

THANK YOU FOR YOUR ATTENTION ☺

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