Additive Manufacturing – A European Perspective

Dr Robert Scudamore

Associate Director, Group Manager Joining Technologies and Additive Manufacturing, TWI Ltd. Additive Manufacturing Platform Committee
1. European Funding of AM

2. Strategic Research Agenda (SRA)

3. Research Focus Areas

4. Capabilities
EC Funding of AM

226Mn Euro EC funding
335Mn Euro Budget
AM projects in EC Frameworks

Number of EC funded projects

- FP3: 4
- FP4: 8
- FP5: 3
- FP6: 12
- FP7: 60
- H2020: ?
Typical Project

- Range from 100k Euro to 10Mn Euro Grant

- 5Mn Euro Grant
- Three Large Companies
- Four Research Entities
- Four SME’s
- Material supply, design, processing, NDT, validation etc....
<table>
<thead>
<tr>
<th>EC AM Projects</th>
<th>EC AM Projects</th>
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<tr>
<td>VITAMIN</td>
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<td>RAPIDOS</td>
<td>IC2</td>
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<td>BIO-SCAFFOLDS</td>
<td>MICROFLUID</td>
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<td>RAMA3DP</td>
<td>M&amp;MS</td>
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<td>RC2</td>
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<td>PERFORMANCE</td>
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<tr>
<td></td>
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<td>ARTIVASC 3D</td>
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</tbody>
</table>
Background

- Dr Emma Ashcroft - TWI
- Pentti Eklund - VTT
- Frits Feenstra - TNO
- Magi Galindo I Anguera - Leitat
- Martin Baumers - Nottingham University
- Anna Hoiss - DSM
- Olivier Jay - Teknologisk Institut
- Dr.-ING Eric Klemp – DMRC
- Jörg Lenz - EOS
- Prof. Gideon Levy - TTA
- Dr Phil Reeves - Econolyst Ltd
- Martin Schaefer - Siemens AG
- Jan Sehrt - University of Duisburg
- Dipl.-Wirt.-Ing. Marina Wall - Heinz Nixdorf Institute, University of Paderborn
- Dr Robert Scudamore - TWI
- Dr Tom Craeghs – Materialise
- Prof. D Wimpenny - MTC

Over fifty reference documents from the AM community and beyond
EU focus and more country specific
Benefits

- Design freedom
- Cost – Material utilisation, energy, lead time, tooling
- Customisation – Process flexibility
- Increased part performance
- Light weighting
- New products
- Localised manufacturing – EU job creation and retention and Economic Growth
Main Industrial Sectors

- Medical and Dental
- Aerospace
- Automotive
- Consumer
- Electronics
- Niche areas
- New markets
Technology Readiness Level

**Phase 1: Technology Assessment and Proving**
- **Level 1:** Process concept proposed with scientific foundation
- **Level 2:** Applicability and validity of concept described and vetted, or demonstrated
- **Level 3:** Experimental proof of concept completed

**Phase 2: Pre-production**
- **Level 4:** Process validated in laboratory using representative development equipment
- **Level 5:** Basic capability demonstrated using production equipment
- **Level 6:** Process optimised for capability and rate using production equipment

**Phase 3: Production Implementation**
- **Level 7:** Capability and rate confirmed via economic run lengths on production parts
- **Level 8:** Fully production capable process qualified on full range of parts over significant run lengths
- **Level 9:** Fully production capable process qualified on full range of parts over extended period (all business case metrics achieved)
### Recommendations

<table>
<thead>
<tr>
<th><strong>Productivity</strong></th>
<th><strong>Process Stability</strong></th>
</tr>
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<tbody>
<tr>
<td>Increase build-speed, possibly through new approaches to scanning or sources of</td>
<td>Decrease the time to create each layer, the overall time between layers, and start-up and shut-down time.</td>
</tr>
<tr>
<td>energy.</td>
<td>Develop methodologies for measurement of AM products.</td>
</tr>
<tr>
<td>Support higher volume production, possibly through enabling batch consistency</td>
<td>Develop methodologies for 'Right first time' processing.</td>
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<td>and methodologies for consistent materials supply.</td>
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<td>The development of new/advanced AM machines e.g. machines with multiple lasers.</td>
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<td>Improve geometrical stability.</td>
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<td>Analyse energy consumption and development of methodologies for its reduction.</td>
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<td></td>
<td>Increase software utilisation.</td>
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<td>Develop multi-material manufacturing for AM technologies.</td>
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**Process Stability**

- Increase material processability, quality and performance.
- Increase control of process tolerances.
- Improve surface finish of processed parts.
- Improve process control and monitoring.
- Further develop lasers with improved efficiency and control.
- Reduce residual stresses.
- Analyse stability of the AM process in order to make improvements to AM systems that will allow production components to be produced with required properties.
## Recommendations

<table>
<thead>
<tr>
<th>Other</th>
<th></th>
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<tbody>
<tr>
<td>Global collaboration in the area of AM would be beneficial particularly between EU and USA.</td>
<td>Identification of applications and work with end-users to understand the business case for using AM over other manufacturing routes.</td>
</tr>
<tr>
<td>Mechanisms for taking a product into production e.g. taking proven concepts at TRL4 and moving them to TRL 7 to 9.</td>
<td>Supply chain development, from material supply, reliable AM systems to post-processing.</td>
</tr>
<tr>
<td>Functionally graded structures in terms of design or material.</td>
<td>More consideration to the value proposition for AM e.g. digital data.</td>
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<tr>
<td>The creation of assemblies using AM.</td>
<td>Establishment of bio-tissue engineering using AM.</td>
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Standardisation Roadmap

Roadmap for Standardisation
Additive Manufacturing

**Goals**
- Certification for quality of life enhancing applications
- Certification for energy saving applications
- General mechanical applications

**Materials**
- Ti grade 1
- CoCr
- Al
- Tool steel
- Ti6Al4
- Inconel 635 & 718
- Stainless steel
- PA12
- ABS
- PA11
- Rubber like
- PA flame retarded
- Med 610
- PEEK
- Ceramics Alumina
- Gold & bronze

**Process stability / Product quality**
- Geometrical tolerance (shape and position)
- Fatigue testing
- Flexural strength
- Impact strength
- Crack extension
- Compressive properties
- Hardness
- Creep
- Shear resistance
- Surface texture
- Ageing
- Appearance

**Productivity /other**
- Post-processing
- Process monitoring
- Lattice structures
- Databases with material properties (IMS)

**SASAM Prio number**
- 2014: 4,5
- 2015: 4
- 2016: 3,5
- 2017: 3
Focus Areas

- Design freedom
- Topology optimisation
- Customisation
- Raw material quality
- Equipment design
- Process capability
- Process stability
- Process flexibility
- Process modelling
Focus Areas

- Material properties
- Residual stress
- Non-destructive testing
- Surface finish
- Dimensional tolerances
- Standardisation
- Supply chain initiatives
- Access for SME’s
Topology Optimisation

(courtesy of GE)
Selective Laser Melting - Topology

Structural efficiency can be improved by enabling optimised topology that could not normally be achieved by machining or casting.

A collaboration between the following organisations: TWI Ltd, University of Exeter, EADS UK, Bombardier Aerospace plc, TISICS Ltd and Materialise UK. The Project was managed by TWI Ltd and partly funded by the TSB under the Technology Programme ref: “AB183A”. TP No: TP11/HVM/6/I/AB183A

Added Value by Laser Assisted Additive Manufacture

Images Courtesy of AVLAM
Equipment Capability - FastEBM
Process Modelling - FastEBM
NDT - CT Scanning
Material and Cost Reduction
Aims
• Deposition procedures for combustion chamber parts.
• Material IN718.
• Reduce time to manufacture (2-3 months -> 6 hours).

Challenges
• Complex shape – overhanging features and fillet radii.
• Thin wall (0.8mm) and Ra (15-25 microns).
• Large aspect ratios i.e. thin wall (0.8mm) vs. overall build height (~100mm)
Cost effective manufacturing of existing parts/designs

- Reduction of raw materials cost
- Replacement of milling/casting

R&D steps for realisation

- Part quality
- Material characterisation/validation
- Process qualification
## Laser impact generation

<table>
<thead>
<tr>
<th>a) Thermoelectric regime</th>
<th>b) Ablation regime</th>
</tr>
</thead>
</table>

## Laser ultrasonics principle

- Laser source
- Photodetector
- Acoustic source
- Solid surface

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by D. Royer Paris, at WCU’95 Berlin
Laser Ultrasonic Testing
EC Projects: AMCOR

- Automotive FGM gears
- Cladding of large hydraulic cylinder piston rods – to replace PTA process
- Repair of broach machine tools
- Cladding of valves used to introduce steam into power station turbines
- Hybrid manufacture of cutting rollers used for cutting rocks

Images Courtesy of SKM and BCT

Integrated geometric scanning for repair and inspection

Multi-axis non-planar tool path generation

Images Courtesy of AMCOR

Failed HVOF coating

FGM Automotive gear

Failed PTA coating

Rock cutting roller after use
OXIGEN Project

• Oxide Dispersion Strengthened (ODS) alloys for high temperature power generation component manufacture.

• Development and manufacture of specialist powder alloys (Mechanical Alloying) and demonstrator manufacture using laser AM technologies.

• Prospect of higher efficiency power generation turbine systems.
MANufacturing decision and supply chain management SYStem for additive manufacturing

www.mansys.info
TWI activities in AM

Understand the processing parameters of LMD and SLM and new materials.

Challenges being addressed
- Process and Material Capability and Stability
- Productivity
- Design and Implementation
- Business models

Re-engineering/Design for AM

Involved in the development of AM standards through ASTM
Strategy Case Study: MTU (Aero)

Phase 3: New AM Design
Manufacturing of functional structures to reduce weight and cost (bionic design)

Phase 2: Substitution
Cost effective manufacturing of raw parts
Substitution of castings

Phase 1: Tooling, Rig and Development
Manufacturing of tooling, Rig- and development hardware
TWI Laser Additive Manufacturing

1 – Nozzle powder delivery (Laser Metal Deposition)

2- Powder bed deposition (Selective Laser Melting)
## Technology Comparison

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>LMD</th>
<th>SLM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Materials (procedures development)</td>
<td>Large Materials Diversity (Ni, Ti, Al, CoCr alloys....)</td>
<td>Large Materials Diversity</td>
</tr>
<tr>
<td>Multi-Material Capability</td>
<td>Yes (metal matrix, FGM)</td>
<td>No</td>
</tr>
<tr>
<td>Part Dimensions</td>
<td>Limited by manipulation system (e.g. 1000x500x2000mm)</td>
<td>Limited by the process chamber (e.g. 600x400x400mm).</td>
</tr>
<tr>
<td>Part Complexity</td>
<td>Self supporting (Limited)</td>
<td>Nearly Unlimited</td>
</tr>
<tr>
<td>Dimensional Accuracy</td>
<td>&gt;200 µm</td>
<td>&gt;100µm</td>
</tr>
<tr>
<td>Roughness (Ra)</td>
<td>40 -100µm</td>
<td>&gt;5µm</td>
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<tr>
<td>Substrates</td>
<td>OEM part (conformal) surfaces</td>
<td>Flat build plate</td>
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<tr>
<td>Layer Thickness</td>
<td>200µm – 3mm</td>
<td>&gt;20µm – 200µm</td>
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<tr>
<td>Powder Particle size</td>
<td>45 - 100µm</td>
<td>15-45µm</td>
</tr>
<tr>
<td>Applications</td>
<td>3D parts, surface cladding, OEM repair</td>
<td>Complex 3D parts</td>
</tr>
</tbody>
</table>
TRUMPF DMD505 system (LMD 1)

- 2m x 1.1m x 0.75m build chamber allows large and complex parts to be processed.
- 1.8kW HQ (High Quality) CO$_2$ laser.
- 0.25mm (minimum) spot size at focus position.
- Variable laser spot size capability.
- 5-axis beam manipulation for maximum flexibility.
- 2-axis fully integrated rotary/tilt manipulator allows high tolerance cladding of cylindrical components.
- Sulzer Metco Twin-10-C double hopper powder feeder (FGM LMD)
Robotic LMD Capability - Manipulation

KUKA KR30 (HA) Robot Cell
- 30kg payload, ± 0.05mm repeatability
- Radial reach of 2033mm
- High accuracy (HA) robot model for best ‘path following’ accuracy
- Sulzer Metco Twin-10-C single hopper powder feeder delivers consistent powder flow

New TRUMPF Disk Laser
- Feeds both robotic cells
- LMD

REIS RV60-40 Robot Cell
- 40kg payload, ± 0.1mm repeatability
- Radial reach of 2500mm
- Integrated rotary/tilt manipulator (8-axis in total)
- 2.5m long cylindrical components can be cladded
- Sulzer Metco Twin-10-C double hopper powder feeder (FGM LMD)
The Business end:

**Geometric Complexity**
- **Coaxial**
  - Powder Spot ≥ 0.3 mm
  - Laser Power ≤ 2KW
  - Oxygen Contamination ≤ 20ppm

- **Multi-Jet**
  - Powder Spot ≥ 1.5 mm
  - Laser Power ≤ 6KW
  - Oxygen Contamination ≤ 50 ppm

- **Off-Axis**
  - Geometries with limited access
  - Surface cladding

Images Courtesy of Fraunhofer ILT
Robotic LMD Capability – Laser System

- Adjustable spot size technology
- Combine with variable power and speed to create a powerful tool for any aerofoil type application, especially ‘full chord’ replacement

Image Courtesy of TRUMPF

Different laser spot sizes

Typical aerofoil re-build
Powder Bed Processing - SLM

**Ability to manufacture parts of virtually any complexity of geometry entirely without the need for tooling.**

Process parameters:

1. Layer thickness
2. Exposure time
3. Point distance
4. Laser power
5. Focus position
6. Scan strategy
7. Boundary conditions
8. Hatch conditions

Process criteria:

1. Density
2. Surface finish
3. Mechanical properties
4. Dimensional accuracy

Image Courtesy of TWI
Selective Laser Melting Capability

Realizer SLM100
- Build volume: 125 (dia.) * 180 (z) mm
- 200W fibre laser
- 20-50µm layer height
- Cp Ti, Titanium 6-4, Nickel alloys, CoCr and SS, Al

Renishaw AM250
- Build volume: 250 * 250 * 280 (z) mm
- 200W fibre laser
- 50-75µm layer height
- Titanium 6-4, Nickel alloys, CoCr, AlSi10Mg and SS

Rapid Part System 1kW
- Build volume: 250 * 250 * 280 (z) mm
- 1000W fibre laser
- 75-200µm layer height
- Titanium 6-4, Nickel alloys, Al alloys and SS
### Design Optimisation for Additive Manufacture

<table>
<thead>
<tr>
<th>Used to create designs that <em>exploit</em> AM processes</th>
<th>Introduce complex geometries (sub-structures and lattices)</th>
<th>Multiple-part assemblies combined into single builds</th>
</tr>
</thead>
</table>

![Image](image_url1)

![Image](image_url2)

![Image](image_url3)
Design Optimisation at TWI for Additive Manufacture

Design-for-Function

- Structural performance
- Fatigue performance
- Surface finish and tolerances
- Geometric constraints

Design-for-Manufacture

- Support structures
- Orientation and platform design
- Machine tolerances
- Minimum feature sizes

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AlSi10Mg Mechanical properties

<table>
<thead>
<tr>
<th>Sample Id</th>
<th>0.2% PS (MPa)</th>
<th>UTS (MPa)</th>
<th>4D Elong. (%)</th>
<th>5D Elong. (%)</th>
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Improved UTS and comparable Elongation
Lead Time Reduction
1. 226Mn Euro EC funding, 335Mn Euro Budget
2. 12 FP6, 60 FP7 Projects 88 in total
3. Strategic Research Agenda
4. Drivers, Focus areas, Risk, Timescales...
5. Targeted Development Examples
6. TWI Capabilities
7. LMD and SLM
Thank You

Rob Scudamore

PhD, SenMWeldI, FCMI, CMgr, CEng, MBA
Group Manager – Additive Manufacturing and Joining Technologies
Associate Director
TWI Ltd.

E-mail: robert.scudamore@twi.co.uk
Web: www.twi-global.com

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