MINI – CAS ON MECHANICAL ENGINEERING

CHALLENGES IN ADDITIVE MANUFACTURING (of metals)

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Additive Layer Manufacturing (ALM) is a production process based on a processing idea called “Material Incremental Manufacturing” (MIM) in which a component is created, starting from a 3D model, by deposition material layer by layer.
## Classification

<table>
<thead>
<tr>
<th>CATEGORIES</th>
<th>TECHNOLOGIES</th>
<th>PRINTED “INK”</th>
<th>POWER SOURCE</th>
<th>STRENGTHS / DOWNSIDES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material Extrusion</td>
<td>Fused Deposition Modeling (FDM)</td>
<td>Thermoplastics, Ceramic slurries,</td>
<td>Thermal Energy</td>
<td>• Inexpensive extrusion machine</td>
</tr>
<tr>
<td></td>
<td>Contour Crafting</td>
<td>Metal pastes</td>
<td></td>
<td>• Multi-material printing</td>
</tr>
<tr>
<td>Powder Bed Fusion</td>
<td>Selective Laser Sintering (SLS)</td>
<td>Polyamides /Polymer</td>
<td>High-powered Laser Beam</td>
<td>• High Accuracy and Details</td>
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<tr>
<td></td>
<td>Direct Metal Laser Sintering (DMLS)</td>
<td>Atomized metal powder (17-4 PH</td>
<td></td>
<td>• Fully dense parts</td>
</tr>
<tr>
<td></td>
<td>Selective Laser Melting (SLM)</td>
<td>stainless steel, cobalt chromium,</td>
<td></td>
<td>• High specific strength &amp; stiffness</td>
</tr>
<tr>
<td></td>
<td>Electron Beam Melting (EBM)</td>
<td>titanium Ti6Al-4V, ceramic powder</td>
<td></td>
<td>• Powder handling &amp; recycling</td>
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<tr>
<td>Vat Photopolymerization</td>
<td>Stereolithography (SLA)</td>
<td>Photopolymer, Ceramics (alumina,</td>
<td>Ultraviolet Laser</td>
<td>• Support and anchor structure</td>
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<td></td>
<td></td>
<td>zirconia, PZT)</td>
<td></td>
<td>• Fully dense parts</td>
</tr>
<tr>
<td>Material Jetting</td>
<td>Polyjet / Inkjet Printing</td>
<td>Photopolymer, Wax</td>
<td>Thermal Energy / Photocuring</td>
<td>• High specific strength and stiffness</td>
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<tr>
<td>Binder Jetting</td>
<td>Indirect Inkjet Printing (Binder 3DP)</td>
<td>Polymer Powder (Plaster, Resin),</td>
<td>Thermal Energy</td>
<td>• Multi-material printing</td>
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<td>Ceramic powder, Metal powder</td>
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<td>• High surface finish</td>
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<tr>
<td>Sheet Lamination</td>
<td>Laminated Object Manufacturing (LOM)</td>
<td>Plastic Film, Metallic Sheet,</td>
<td>Laser Beam</td>
<td>• Low-strength material</td>
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<td>Ceramic Tape</td>
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<td>Directed Energy</td>
<td>Laser Engineered Net Shaping (LENS)</td>
<td>Molten metal powder</td>
<td>Laser Beam</td>
<td>• Full-color objects printing</td>
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<tr>
<td>Deposition</td>
<td>Electronic Beam Welding (EBW)</td>
<td></td>
<td></td>
<td>• Require infiltration during post-processing</td>
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<tr>
<td></td>
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<td></td>
<td>• Wide material selection</td>
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<td>• High porosities on finished parts</td>
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<td></td>
<td>• High surface finish</td>
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<td>• Low material, machine, process cost</td>
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<td>• Decubing issues</td>
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<td>• Repair of damaged / worn parts</td>
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<td>• Functionally graded material printing</td>
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<td></td>
<td></td>
<td>• Require post-processing machine</td>
</tr>
</tbody>
</table>
Parte I: Generalità sul processo di produzione additiva

Additive manufacturing technologies

- Vat photopolymerization
  - Cured by laser
  - Cured by LED and oxygen
- Direct material melting
  - Extrusion
  - Drop deposition
- Sheet lamination
- Direct energy deposition
  - Fused by laser
  - Fused by electron beam
- Binder jetting
  - Powder joined by bonding agent
  - Cured by UV light
  - Cured by heat
- Material jetting (inkjet)
  - Milled to form
- Powder bed fusion
  - Fused by agent and energy
  - Fused by laser
  - Fused by electron beam

SLA
  - Stereolithography
DLP
  - Digital Light Processing
CDLP
  - Continuous Digital Light Processing
FDM
  - Fused Deposition Modeling
APF
  - Arburg Plastic Forming
LOM
  - Laminated Object Manufacturing
LENS
  - Laser Engineering Net Shape
EBAM
  - Electron Beam Additive Manufacturing
BJ
  - Binder Jetting
MJM / PJ
  - MultiJet Modeling / Poly Jetting
NPJ
  - Nano-Particle Jetting
DOD
  - Drop On Demand
MJF
  - Multi Jet Fusion
SLS
  - Selective Laser Sintering
DMLS / SLM
  - Selective Laser Melting
EBM
  - Electron Beam Melting
ADDITIVE MANUFACTURING OF METALS

CLASSIFICATION BASED ON FEEDSTOCK MATERIAL

- WIRE
- POWDER
WIRE ARC ADDITIVE MANUFACTURING
DIRECT METAL DEPOSITION

CO₂ laser beam
Nozzle shielding gas
Feedback sensor 1
Feedback sensor 2
Workholding fixture
Solid free from shape by direct deposition
Subtract or die preform
Final focus optics
To powder feeder

(b)

Nozzle
Feeder stream
Melt pool
V_y

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Cold Spray Deposition Additive Manufacturing

The Cold Spray Process

Gas Control Module  Electric Heater
N₂ or He gas

Particle Stream

Powder Feeder  Supersonic Nozzle

Substrate

Deposit

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POWDER BED FUSION ADDITIVE MANUFACTURING
2. What You See Is What You Build
3. Weight Reduction
TRADITIONAL DESIGN

Source: SAVING project

- A conventional steel buckle weights 155 g\(^1\)
- Weight should be reduced on a like-for-like basis within the SAVING project
- Project partners are Plunkett Associates, Crucible Industrial Design, EOS, 3T PRD, Simpleware, Delcam, University of Exeter

AM OPTIMIZED DESIGN

Source: SAVING project

- Titanium buckle designed with AM weighs 70 g – reduction of 55%
- For an Airbus 380 with all economy seating (853 seats), this would mean a reduction of 72.5 kg
- Over the airplane’s lifetime, 3.3 million liters of fuel or approx. EUR 2 m could be saved, assuming a saving of 45,000 liters per kg and airplane lifetime
5. Customization
6. DLD: repairing
Additive Manufacturing (AM), Digital Fabrication
1 CAD
2 STL convert
3 File transfer to machine
4 Machine setup
5 Build
6 Remove
7 Post-process
8 Application
Sandblasting

Sandpapering

Polishing

Vapor smooth

Before Polishing

After Polishing

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CNC MACHINING

Chemical Polishing
8. Application
POWDER BED FUSION ADDITIVE MANUFACTURING
SOME FUNDAMENTAL ASPECTS

MATERIALS
• DEVELOP THE PROCESS FOR MORE MATERIALS
  • HANDLING
  • RE-USE
  • CHOICE (SIZE, SHAPE, DISTRIBUTION, FABRICATION)
  • MIX (TO TAILOR THE PROPERTIES OF THE COMPONENT)

POWDERS

PROCESS
• PARAMETERS (POWER, SCAN SPEED, LAYER THICKNESS, GAS)
• REPETEABILITY (DIRECTION OF GROWTH, POSITION WITHIN THE BUILDING CHAMBER, ANISOTROPY)
• MAXIMUM DIMENSIONS
• DEFECTS (POROSITIES, RESIDUAL STRESSES, SURFACE ROUGHNESS)

POST TREATMENTS
• HOT ISOSTATIC PRESSING (REDUCE POROSITIES)
• HEAT TREATMENT (TAILOR MICROSTRUCTURE AND STRESS RELIEF)
• SURFACE TREATMENTS (IMPROVE SURFACE FINISHING)
TOPICS COVERED IN THIS PRESENTATION

POWDERS

• CHOICE
• MIX
• HANDLING
• RE-USE

PROCESS

• PARAMETERS CHOICE FOR NEW MATERIALS
• SOLID JOINING OF ADDITIVELY MANUFACTURED PARTS

TREATMENTS

• CHEMICAL TREATMENTS
• HEAT TREATMENTS
• FLUIDIZED BED TREATMENTS
POWDERS

CHOICE: FABRICATION METHOD AND SHAPE

MECHANICAL PRODUCED POWDERS

GAS ATOMIZED POWDERS
POWDERS

CHOICE: FABRICATION METHOD AND SHAPE
POWDERS

CHOICE: FABRICATION METHOD AND SHAPE

• CONTROL THE GAS ATOMIZATION PROCESS
• CHECK THE POWDERS THAT YOU USE
POWDERS

CHOICE: HANDLING AND RE-USE
POWDERs
CHOICE: HANDLING AND RE-USE
POWDERS

CHOICE: HANDLING AND RE-USE

Jobs 1 to 8

Residual powder recovering and sieving

Build platform replacement

Sieved powder loading

DMLS parts fabrication

Virgin powder loading

Density test
Tensile test
High Cycle Fatigue Test
Metallographic analysis
Fracture surfaces analysis

Job 0

Moisture content
Chemical composition
Particle Size Distribution
Particle shape
Tap density
Apparent density
Flow rate

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POWDERS

CHOICE: HANDLING AND RE-USE
POWDERS

CHOICE: HANDLING AND RE-USE

![Graph 1: UTS (MPa) vs. Reuse times]

![Graph 2: Rp0.2% (MPa) vs. Reuse times]
POWDERS

CHOICE: HANDLING AND RE-USE

![Graphs showing fatigue life and stress range for powder reuse](image)

- **a)** Virgin material showing cycles to failure vs. stress range.
- **b)** Material reused 3 times showing similar graph.
- **c)** Material reused 8 times showing a slight increase in cycles to failure compared to previous reuse.
POWDER MIX: TAILOR THE PROPERTIES OF THE MATERIAL

INCONEL 718

PURE COPPER
POWDERS
MIX: TAILOR THE PROPERTIES OF THE MATERIAL

1% CU
LEAF SHAPE
POWDERS
MIX: TAILOR THE PROPERTIES OF THE MATERIAL

5% CU
LEAF SHAPE
POWDER MIX: TAILOR THE PROPERTIES OF THE MATERIAL

1% CU

LEAF SHAPE
PODWERS
MIX: TAILOR THE PROPERTIES OF THE MATERIAL

5% CU
LEAF SHAPE
POWDERS
MIX: TAILOR THE PROPERTIES OF THE MATERIAL

5% CU
SPHERE SHAPE
POWDERS MIX: TAILOR THE PROPERTIES OF THE MATERIAL

20% CU SPHERE SHAPE
POWDERS MIX: TAILOR THE PROPERTIES OF THE MATERIAL

5% CU SPHERE SHAPE
POWDERS MIX: TAILOR THE PROPERTIES OF THE MATERIAL

20% Cu
SPHERE SHAPE

Spectrum1

Full Scale 4669 cts Cursor: 0.000
keV
POWDER HANDLING: POWDER BED DEPOSITION
Additive manufacturing: how does it work?
Additive manufacturing: Issues

- Repeatability
- Variation of mechanical properties in the chamber
- Defects (keyhole, lack of fusion, porosity etc.)

Powder bed deposition

Laser melting

Cooling and solidification
Focus: the powder bed

- Speed of the recoating device.
- Layer thickness.
- Shape of the recoating device.
- Powder bed solid volume fraction.
- Effective layer thickness.
- Material/shape segregation.
A ratio between the layer thickness and the particles’ diameter close to 1 can hinder the spreading process leading to the formation of voids and jamming phenomena.
Literature

Speed of the recoating device [4,2]

A lower spreading speed gives better results in term of void fraction and roughness of powder bed. However this impact is strongly related to the shape of the recoating device and to the characteristics of the powder bed.
An incorrect modeling of the cohesion effects can compromise the results and lead to anti-
physical bheaviour.
Most of the works are still focused on developing a reliable strategy to obtain the powder bed characteristics at the loose state. Usually focused on one characteristic.
| Literature |

**Numerical**
- Not calibrated
- Does not faithfully reproduce the process (i.e. geometry, only considers one part of the process etc.)
- Mostly not validated

**Experimental**
- General scarcity of data
- No reliable strategy to acquire the characteristics of the powder bed

---

Interaction with geometrical features

Experimental analysis of the loose powder bed

Open questions

Mix of heterogeneous powders

Parameter optimization

Interaction with the previous layer
| Discrete element method |

Contact detection and particle overlap

Overlap $\delta$

Apply Newton’s second law to calculate the resultant motion of the particle

Update position and velocity

Force-displacement law:

$$ F = \left( k_n \delta n_{ij} - y_n v n_{ij} \right) + \left( k_t \delta t_{ij} - y_t v t_{ij} \right) $$

Nonlinear Hertz-Mindlin

$$ k_n = \frac{4}{3} E' \sqrt{R' \delta_n} $$

Additional cohesive force simplified

Johnson-Kendall-Roberts

$$ F = k_A $$
| Powder Spreading simulation |

- Material segregation
- Particle size
- Velocity profile

- Local packing factor and density
- Local variation of the PSD
- Effective layer thickness
**Experimental device**

Removable blade

Micrometric screws to adjust the layer thickness and powder feedstock

Control panel with 6 different blade’s speeds and selectable temperature for the plate

Set of portable microscopes with different levels of magnification

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Experimental device

Extract samples of the powder bed to measure the local density.

Analysis of Sem images to study variations in the PSD and characteristics of the powders.

Acquire images on situ at different levels of zoom with a portable microscope to perform analysis of the powder bed.

Extract samples of the powder bed to measure the local density.
POWDER HANDLING: POWDER BED DEPOSITION

Case 1

Case 2

Case 3

69.7%

70.2%

67.3%
A force chain can occur during the fabrication process. The resultant forces can damage the fabricated part.
POWDER HANDLING: POWDER BED DEPOSITION

INFLUENCE OF LAYER THICKNESS ON PACKING DENSITY

![Graph showing relative packing density vs. layer thickness]
POWDERS

POWDER HANDLING: POWDER BED DEPOSITION

INFLUENCE OF POWDERS FLOWABILITY
**POWDER HANDLING: POWDER BED DEPOSITION**

**Ar** = ASPECT RATIO OF THE PARTICLES

**V** = SPREADING VELOCITY OF THE POWDERS

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POWDER HANDLING: POWDER BED DEPOSITION

SPREADER GEOMETRY
TAKE CARE OF THE POWDERS!!!
THEY RULE THE PROCESS!!!
Interaction between Laser Beam and Powders

Blown Powder Energy Transfer
- Laser/powder interaction
- scattering, absorption, sputtering, melting and

Conduction
- Heat Affected Zone (HAZ) volume/depth
- high heat flux transport
- sensible heating/thermal cycling
- substrate interaction (heat sinking effects)

Part Heat Loss
- convection to inert gas
- radiation to surroundings
  - emission, absorption

Interaction between Laser Beam and Powders

\[ q''_{\text{laser}} = \frac{2\alpha_m P}{\pi R^2} \exp \left( -\frac{2r^2}{r_{b,i}^2} \right) \]

\[ q''_{\text{loss}} \equiv h_x(T(x) - T_{\infty}) + \varepsilon\sigma(T^4(x) - T_{\infty}^4) + \rho_l \left| \frac{\Delta x}{\Delta t} \right|_{e}\ h_{LV} \]

\[ \bar{T}(x^*, z^*) = e^{-x^*} K_0 \left( \sqrt{x^*^2 + z^*^2} \right) \]

\[ \left| V_{\text{iso}} \right| = \left| V_{\text{beam}} \right| \cdot \cos \theta \]

\[ \frac{\Delta x}{\Delta t}_e = c_s \exp[-\tilde{h}_{LV}/T(x)] \]


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PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX
EXPERIMENTAL PLAN

PROCESS PARAMETERS
COPPER CONTENT (0%; 1%; 5%; 20%)
COPPER PARTICLES SHAPE (SPHERICAL, COMPLEX SHAPE)
LAYER THICKNESS (30 MICRONS; 45 MICRONS)
SCAN SPEED (20 DIFFERENT VALUES)
LASER POWER (20 DIFFERENT VALUES)
SCAN STRATEGY KEPT CONSTANT

MEASURED OUTPUT
MICROSTRUCTURE
MICROHARDNESS
DENSITY
THERMAL CONDUCTIVITY
POROSITY ANALYSIS

Island size = 5 mm
PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX

MICROSTRUCTURE

1 mm

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PROCESS STUDY FOR INCONEL 718/COPPER MIX

MICROSTRUCTURE

Upskin –
IN1;
P=170 W;
Vs = 530
mm/s;

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PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX
MICROSTRUCTURE

Upskin – IN10; P= 210 W; Vs = 655 mm/s;
PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX
MICROSTRUCTURE

Upskin – IN20; P= 220 W; Vs = 820 mm/s;
PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX

MICROSTRUCTURE

Upskin – 
IN20; P= 220 W; Vs = 820 mm/s;
PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX

MICROSTRUCTURE

Core – N1;
P = 350 W;
Vs = 1700 mm/s;

1 mm
PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX

MICROSTRUCTURE

Upskin–N1; P=350 W; Vs=1700 mm/s;

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PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX

MICROSTRUCTURE

Core – N10;
P=372 W;
Vs=930 mm/s;
PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX

MICROSTRUCTURE

Upskin – N10; P=372 W; Vs=930 mm/s;
PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX

MICROSTRUCTURE

N1;
P=350
W;
Vs=1700
mm/s;

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PROCESS
PROCESS STUDY FOR INCONEL 718/COPPER MIX

MICROSTRUCTURE

N10;
P=372 W;
Vs=930 mm/s

% CU
PROCESS
SOLID STATE JOINING OF AM PARTS

ADDITIVE MANUFACTURING: MULTILEVEL MICROSTRUCTURE
PROCESS
SOLID STATE JOINING OF AM PARTS
ADDITIVE MANUFACTURING: MULTILEVEL MICROSTRUCTURE
PROCESS
SOLID STATE JOINING OF AM PARTS
PROCESS
SOLID STATE JOINING OF AM PARTS

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LINEAR FRICTION WELDING OF Ti6Al4V PARTS MADE THROUGH ELECTRON BEAM MELTING
PROCESS
SOLID STATE JOINING: LINEAR FRICTION WELDING

Oscillation frequency [Hz]

<table>
<thead>
<tr>
<th>Pressure [MPa]</th>
<th>40</th>
<th>45</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>0.70 W/mm²</td>
<td>0.79 W/mm²</td>
<td>0.87 W/mm²</td>
</tr>
<tr>
<td>75</td>
<td>0.95 W/mm²</td>
<td>1.10 W/mm²</td>
<td>1.19 W/mm²</td>
</tr>
</tbody>
</table>
PROCESS
SOLID STATE JOINING: LINEAR FRICTION WELDING

![Deformed α layer](image1.png)

![α layer](image2.png)

![Deformed α layer](image3.png)

![α layer](image4.png)
PROCESS
SOLID STATE JOINING: LINEAR FRICTION WELDING

![Graph showing microhardness and lath thickness variations in different zones of the weld.](image)

**Microhardness (HV)**
- WCZ
- TMAZ
- BM

**Lath thickness (μm)**
- 0
- 1
- 2
- 3

**Frequency**
- 40 Hz
- 45 Hz
- 50 Hz
- 55 Hz
- 75 Hz

**Distance from the weld centre (mm)**
- 0.0
- 0.5
- 1.0
- 1.5
- 2.0
- 2.5
- 3.0

**55 MPa**
- WCZ
- TMAZ
- BM

**75 MPa**
- WCZ
- TMAZ
- BM

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PROCESS
SOLID STATE JOINING: LINEAR FRICTION WELDING

Distance from the weld centre [mm]
Microhardness [HV]

55 MPa

Distance from the weld centre [mm]
Microhardness [HV]

75 MPa

Process parameters:
- 40 Hz
- 45 Hz
- 50 Hz

Microhardness values:
- 280
- 300
- 320
- 340
- 360
- 380
- 400

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PROCESS
SOLID STATE JOINING: FRICTION STIR WELDING

FRICTION STIR WELDING OF ALSI10 PLATES MADE THROUGH SELECTIVE LASER MELTING
PROCESS
SOLID STATE JOINING: FRICTION STIR WELDING
PROCESS
SOLID STATE JOINING: FRICTION STIR WELDING

800 µm

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PROCESS
SOLID STATE JOINING: FRICTION STIR WELDING
PROCESS
SOLID STATE JOINING: FRICTION STIR WELDING

![Graph showing hardness variation with distance from weld centre.
- BM (Base Metal)
- TMAZ (Thermomechanically Affected Zone)
- Nugget
- TMAZ
- BM

Distance from weld centre [mm]

Hardness [HV]
TREATMENTS
RECAP

Surface finishing treatments

- Laser re-melting
- Hybrid AM-CNC machining
- Shot peening
- Chemical polishing
- Electrochemical polishing
- Abrasive Jet Machining
TREATMENTS

FLUIDIZED BED SURFACE FINISHING
TREATMENTS
FLUIDIZED BED SURFACE FINISHING

Substrate
Adjacent Ridges
Rolling
Bouncing Back Abrasive
Impinging Abrasive
Sliding
Prow Ahead Machining Track
Bouncing Back Abrasive

Impinging Abrasive
TREATMENTS
FLUIDIZED BED SURFACE FINISHING

Internal pipe finishing
(Tagliaferri et al., 2006)

Finishing di Thermally-Sprayed Coatings
(Barletta et al., 2008)

Finishing additively manufactured plates
(Barletta et al., 2016)
TREATMENTS
FLUIDIZED BED SURFACE FINISHING

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TREATMENTS
FLUIDIZED BED SURFACE FINISHING: AL-SI10 AM PART

UNTREATED

ANGLE 0°

ANGLE 90°

ANGLE 150°
TREATMENTS
FLUIDIZED BED SURFACE FINISHING: AL-SI10 AM PART

UNTREATED

ANGLE 0°

ANGLE 90°

ANGLE 15°
TREATMENTS

FLUIDIZED BED SURFACE FINISHING: AL-Si10 AM PART
TREATMENTS
CHEMICAL FINISHING OF ALSi10 PARTS

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# TREATMENTS

## CHEMICAL FINISHING OF ALSI10 PARTS

<table>
<thead>
<tr>
<th>CHEMICAL MACHINING:</th>
<th>CHEMICAL BRIGHTENING:</th>
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<tbody>
<tr>
<td>20 ml $HF$</td>
<td>150 ml $H_2PO_4$</td>
</tr>
<tr>
<td>50 ml $HNO_3$</td>
<td>34 ml $H_2SO_4$</td>
</tr>
<tr>
<td>930 ml $H_2O$</td>
<td>12 ml $HF$</td>
</tr>
<tr>
<td>12 ml $HF$</td>
<td>12 ml $H_2NO_3$</td>
</tr>
<tr>
<td>12 ml $H_2NO_3$</td>
<td>0.106 g Cu $SO_4$</td>
</tr>
</tbody>
</table>

1) $2Al + 6HNO_3 \rightarrow Al_2O_3 + 6NO_2 + 3H_2O$

3) $Si + 4HNO_3 \rightarrow SiO_2 + 4NO_2 + 2H_2O$

2) $Al_2O_3 + 6HF \rightarrow 2AlF_3 + 3H_2O$

4) $SiO_2 + 4HF \rightarrow SiF_4 + 2H_2O$
TREATMENTS
CHEMICAL FINISHING OF ALSI10 PARTS

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TREATMENTS
CHEMICAL FINISHING OF ALSi10 PARTS

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DCU, 06/09/2018
UNTREATED

TREATMENTS
CHEMICAL FINISHING OF ALSi10 PARTS

TREATED
TREATMENTS
HEAT TREATMENT OF IN 718/CU SAMPLES

Core – 500x

Core – 5000x
TREATMENTS

HEAT TREATMENT OF IN 718/CU SAMPLES

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TREATMENTS
HEAT TREATMENT OF IN 718/CU SAMPLES

Core – 500x
Core – 5000x

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Assessment of the Mechanical Properties of AlSi10Mg Parts Produced through Selective Laser Melting Under Different Conditions

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Abstract

Additive manufacturing technologies of metals are gaining increasing interest due to several advantages, among those processes the Selective Laser Melting (SLM) is of particular interest for industrial applications. Despite the clear advantages related to this technique, there are some issues that still hamper a mainstream industrial application of SLM, one of the replicability of the process. It is well known that varying, for instance, the building directions or the position in the building chamber the components obtained show different microstructures and mechanical properties, several authors are trying to develop processing routes aiming to increase the replicability of the process. Another issue is the fact that different SLM equipment, produced by different manufacturers, even if the process parameters adopted are the same will lead to the production of components with slightly different properties. These differences are due to small differences among the different equipments, for instance the gap used to the chamber or the way the laser is delivered. The scope of this work is to investigate the mechanical properties of AlSi10Mg components produced with different SLM machines: EOS M400, SLM 280 and REINREHAW AM60400. Aiming to assess which are the differences and try to find a range of properties that can be assumed for SLM-based parts. Tensile specimens, designed according to ASTM standard, were printed with the above-mentioned equipment and tensile tests were carried out. The results obtained showed that slight differences can be suffered among the different samples and a range of tensile properties has been also proposed.

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Keywords: Additive Manufacturing, Selective Laser Melting, Tensile Properties, Building order.

1. Introduction

Additive manufacturing (AM) of metals is gaining increasing interest due to several advantages and to its intriguing potentialities but, on the other hand, some more research is needed to fill some gaps of knowledge and widen the application field of these techniques [1, 2]. AM is the formalized term for what used to be called rapid prototyping and is what is popularly called 3D Printing. The basic principle of this technology is to build a model, initially generated using a three-dimensional Computer-Aided Design (3D CAD) system, can be fabricated directly without the need for process planning [3]. Among the additive techniques, powder-based ones are the most promising for metals, in particular the process that uses a laser as a source of energy to melt the powder, i.e. Selective Laser Melting (SLM), is of great interest for industrial applications. Nevertheless, despite the clear advantages related to this technique, there are some issues that still hamper a mainstream industrial application of SLM, one is the replicability of the process. Promising that the building...
Fig. 4. Ultimate Tensile Stress, Yield Strength and Young's Modules
Electron beam melting of Ti6Al4V: Role of the process parameters under the same energy density

Alessia Teresa Silvestri, Simona Foglia, Rosario Borrelli, Stefania Franchetti, Camille Pinzolit, Antonello Astarita

Abstract

The role of the process parameters under a fixed energy density in Electron Beam Melting of Ti6Al4V was investigated. The beam current, scan speed and line offset were varied in a wide energy keeping constant the energy density adopted, aiming to highlight the influence of such parameters on the properties of the printed part. The cross-section micrographs were analyzed and the results obtained showed that the amount of energy absorbed by the material depending on beam current and scan speed, thus due to the complex interaction between the electron beam and the state of the material. As a consequence, the samples showed different properties, even if the adopted energy density was the same; the influence of the process parameters on the as-processed microstructure remained constant.

Introduction

Additive manufacturing (AM) processes are finding an increasing, and apparently endless, interest in the last years. Referred to the functionalization of metallic parts, the most used processes are the direct energy deposition (DED) and the powder bed fusion (PBF), which includes the following commonly known technique: Selective laser melting (SLM) and electron beam melting (EBM) [1]. In these processes, a high-intensity heat source, a laser or an electron beam, interacts with the feedstock powders and produces a melt pool, where rapid melting and solidification take place [2]. Among these techniques, EBM is of high interest in aerospace, biomedical and energy industries because it involves some intriguing advantages concerning the laser based techniques [3]. EBM trials have been to a high vacuum chamber tolerance as the principles of producing metastable states, such as titanium alloys, that have a high affinity to nitrogen and oxygen. Another advantage is the deposition occurs in elevated temperatures, the build temperature is higher than 700 °C, reducing residual stresses in the final part [1]. Additionally, EBM genera a lower build rate, compared to SLM and DED, due to its superior energy input and laser scan rate [5]. As a drawback, the EBM process presents with a high roughness [6].

During the EBM process, the material undergoes a complex process, made of a succession of preheating, melting, rapid cooling (with solidification and phase transformation) and partial melting of each layer and powder [7], therefore a fundamental understanding of the mechanisms occurring during the process, as well as the link between processing conditions and properties of the component are required. According to previous studies, the processing variables for EBM can be divided into two main categories: input build and in-process. The former parameters are that can vary across multiple build (e.g., chamber, built plate thickness, powder morphology) whereas the latter parameters can vary within the same build (e.g., energy input, laser orientation). In that paper, the attention was put on the in-process parameters to assess their influence on the properties of the final part. In particular, it has been proved that the macrostructural evolution, as well as the formation of defects, depend on many factors, such as the electron beam current, scanning rate, powder particle size, layer thickness, hardenability and others [1-4].

The alloy under investigation in this paper is the Ti6Al4V which is a typical alpha plus beta dual phase alloy, where alpha phase normally precipitates in beta matrix with the typical R-phase relationship (α(001)∥γ(110), γ(011)∥α(111)) [1-4]. Concerning Aluminized, it is added to increase the strength of the alloy through solid solutions.
Fig. 20. Graded microstructure observed in the cross-section of the sample 20 mA, 1800 mm/s, 0.1 mm.
Experimental vs Johnson Cook model fitted curve for (a) EBM Ti-6Al-4V, (b) Conventional Ti-6Al-4V
<table>
<thead>
<tr>
<th>Processing condition</th>
<th>Material constants</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>A</td>
</tr>
<tr>
<td><strong>Massive Ti-6Al-4V</strong></td>
<td>930</td>
</tr>
<tr>
<td><strong>EBM Ti-6Al-4V</strong></td>
<td>949</td>
</tr>
</tbody>
</table>
Thanks!!!
Any question?

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