SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

Co-funded by the Erasmus+ Programme of the European Union

Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

# CU 01: DED-ARC

## Session 5.6 – Stress & distortion management

**Prepared by: David Wimpenny**

FOR SAM PILOT ATTENDEES AND TRAINERS ONLY

MM17,21

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# Contents

- Thermal stress
- Deposition strategy to reduce stress
- Impact of part geometry
- Doubled sided deposition
- Rolling
- Peening
- Other stress relieving methods

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# Thermal stress

All fusion based AM processes suffer from thermal stresses

Successive layers of metal are deposited, solidify and cool leading to tensile stresses accumulating

In PBF-LB the general strategy is to build onto very thick build plates (>50mm thick) but even these can distort and in some cases the supports can fail allowing the part bend upwards

https://www.canadianmetalworking.com/canadianmetalworking/article/metalworking/multi-laser-additive-manufacturing

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# Thermal stress in DED

- Can be much higher than PBF-LB
- Even bolting parts to welding table can lead to the table bending
- The stress can be sufficient to  detach the parts from the base plate

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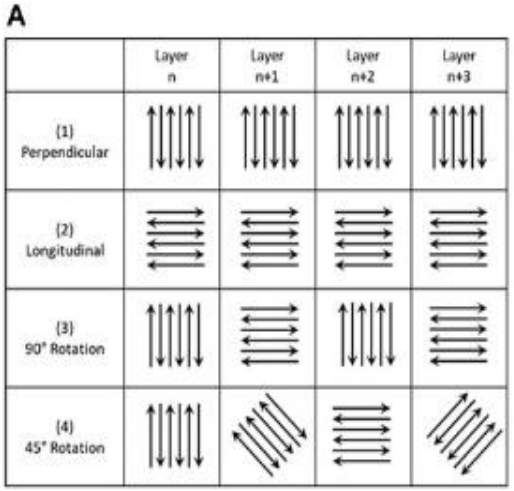
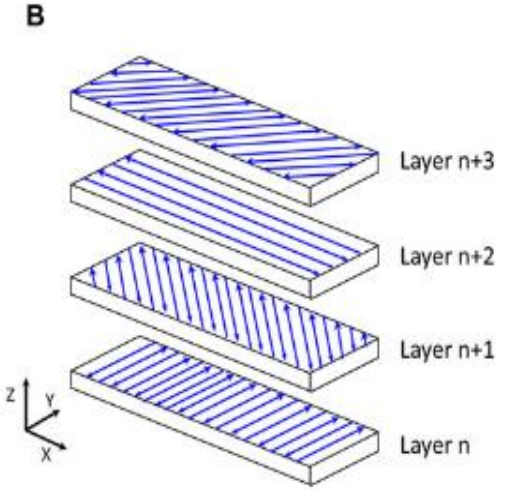
# Deposition strategies

- Stress tends to be highest in the deposition (along the bead) direction.
- Depositing at different orientations is a common approach in PBF-LB and is also used in DED




**An Efficient Track-Scale Model for Laser Powder Bed Fusion Additive Manufacturing: Part 2—Mechanical Model**

*Reza Tangestani[1], Trevor Sabiston[1], Apratim Chakraborty[1], Lang Yuan[2], Nicholas Krutz[3] and Étienne Martin[4]**

*[1]Department of Mechatronic and Mechanical Engineering, University of Waterloo, Waterloo, ON, Canada, [2]Department of Mechanical Engineering, University of South Carolina, Columbia, SC, United States, [3]GE Additive, 8556 Trade Center Dr, West Chester, OH, United States, [4]Department of Mechanical Engineering, Polytechnique, Montréal, QC, Canada*

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# DED deposition strategies to reduce stress

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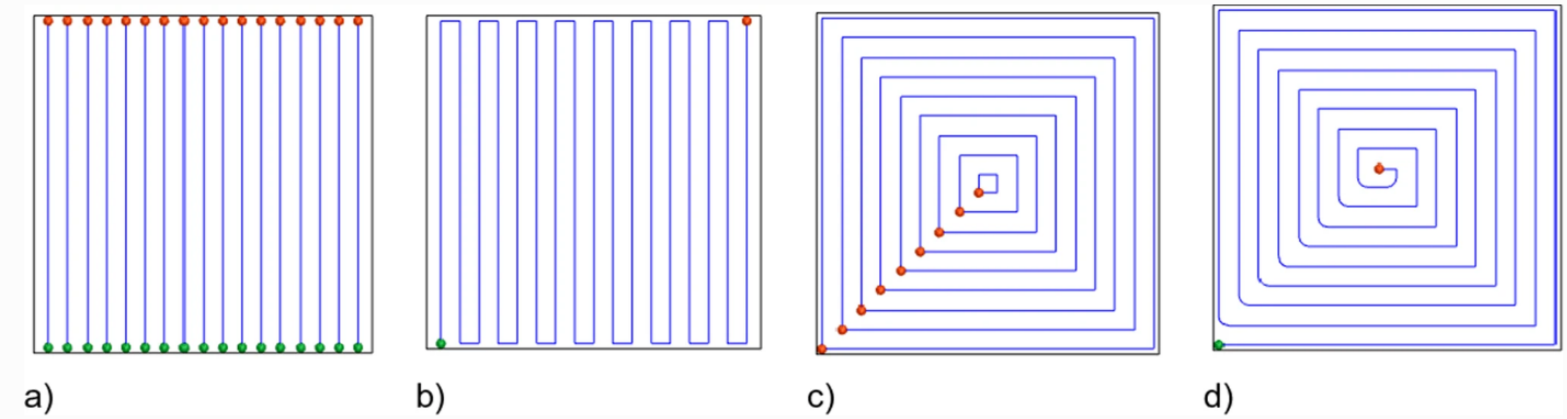
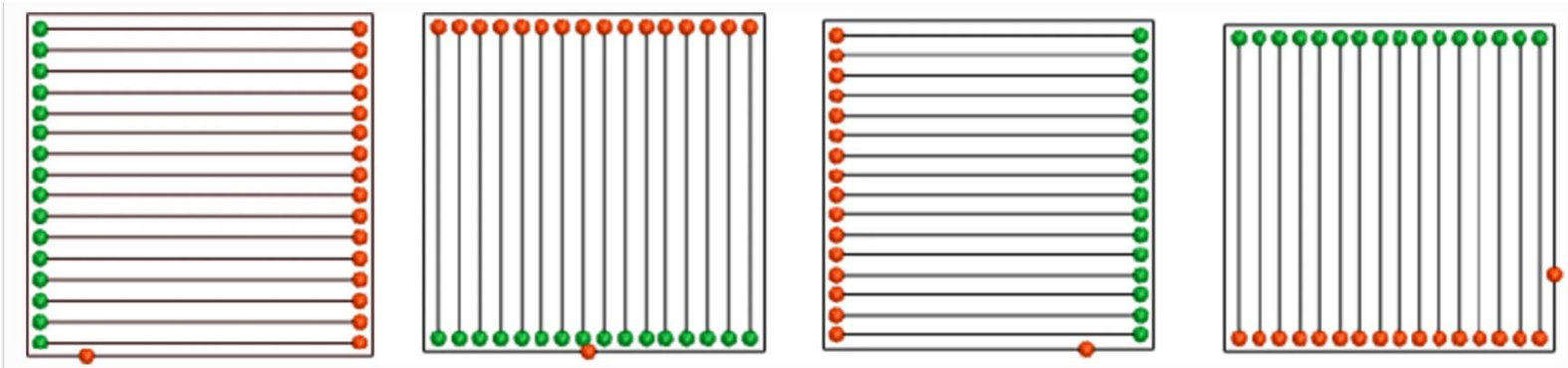



Schematic of different build-up patterns: a raster, b zigzag, c contour, and d spiral



Fabrication strategy of the solid block; layers 1–4 from left to right with welding start (green) and stop points (red)

Note: don't have to be orthogonal (90° to each other) then can be at 45°

Springer Link

Home › Welding in the World › Article

Research Paper (invited) | Open Access | Published: 03 February 2023

WAAM of structural components—building strategies for varying wall thicknesses

Johanna Müller & Jonas Hensel

*Welding in the World* (2023) | Cite this article

153 Accesses | Metrics

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# Destortion depends on the part geometry

- Although all DED parts suffer from stress not all suffer from distortion
- Cylindrical parts tend to be more stable

(although based plates will bend slightly)

Long parts with ribs (eg wing spar) will suffer the worst


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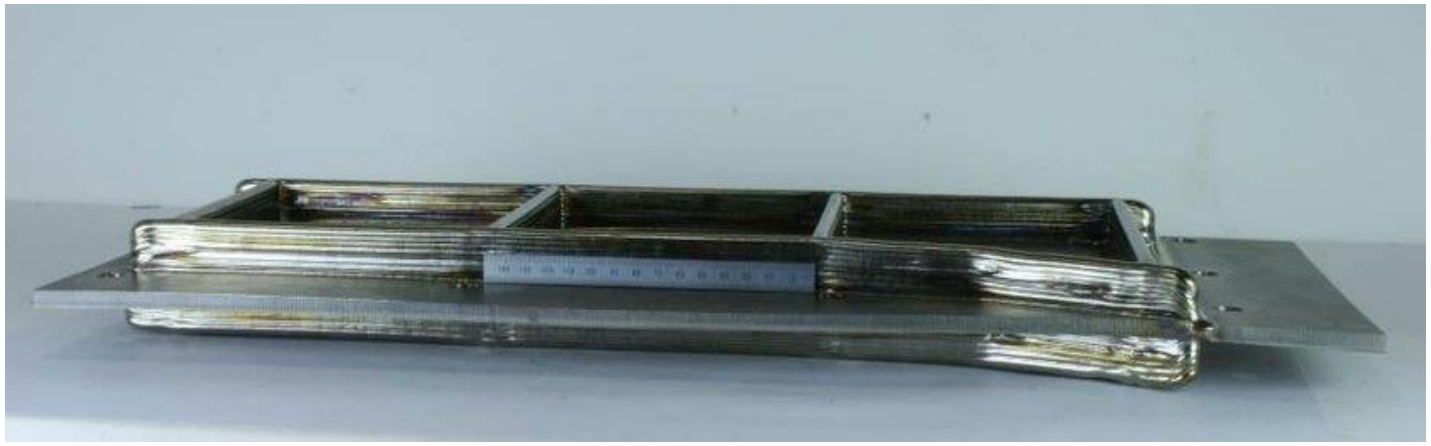
# Doubled sided deposition

- One approach to overcome distortion is to undertake doubled sided deposition
- This can be either two of the same part (one on either side of the build plate)

or

- Single parts with the build plate positioned at an axes of symmetry



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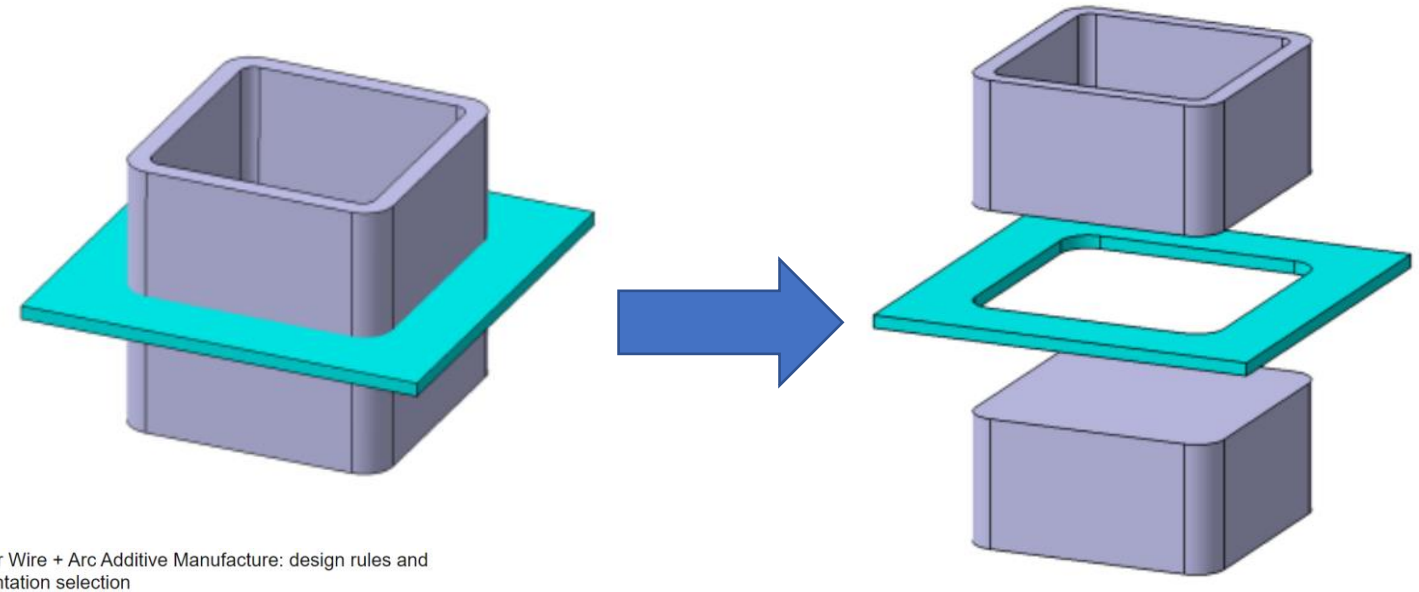
# Double sided strategy for two identical parts



Design for Wire + Arc Additive Manufacture: design rules and build orientation selection

August 2017 · Journal of Engineering Design 28(3):1-31
DOI:10.1080/09544828.2017.1365826
Project: WAAM research

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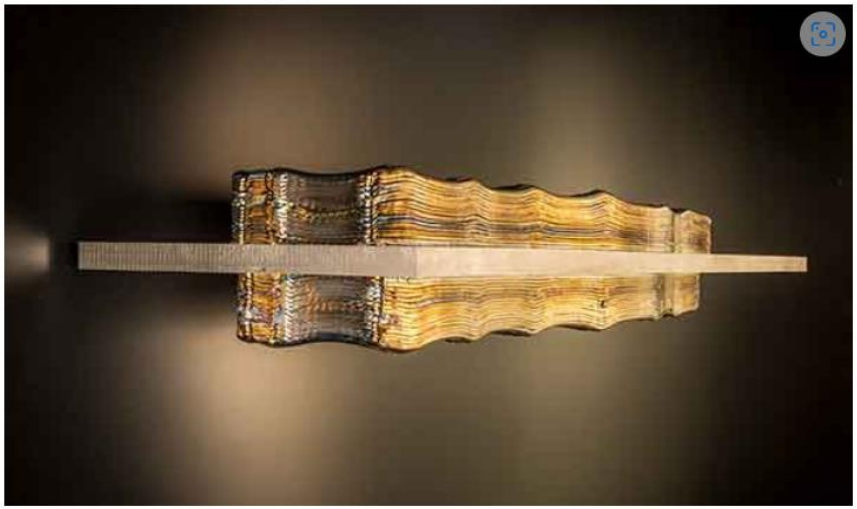
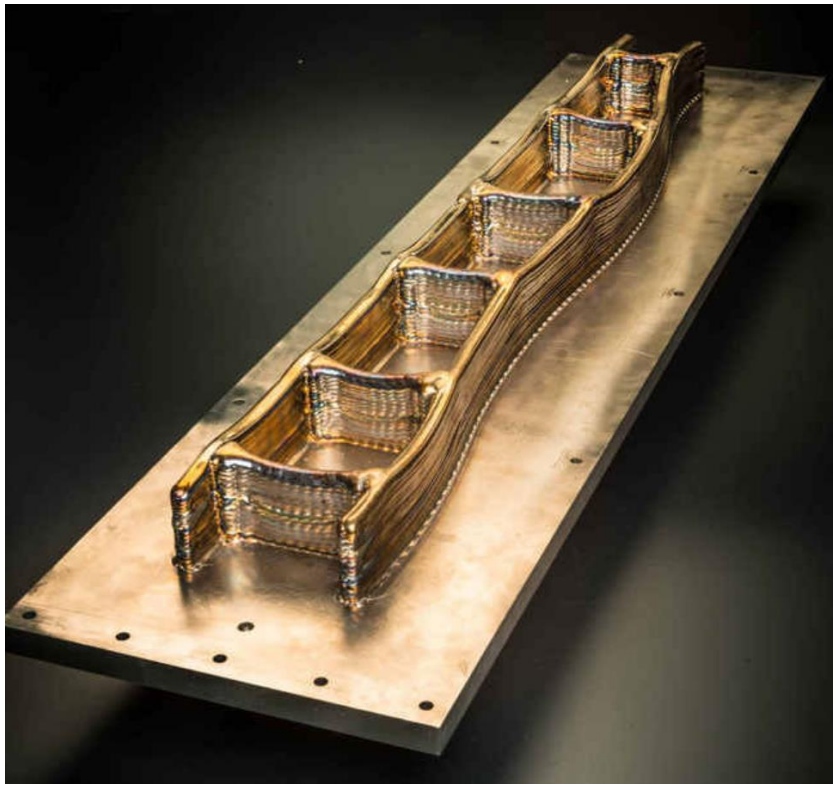
# Example

20 kg titanium wing spar for BAE Systems (two built back-to-back)





https://www.aero-mag.com/welding-makes-its-mark-in-3d-printing/

https://www.cranfield.ac.uk/case-studies/research-case-studies/waammat

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# Part Rotation

Using a symmetrical deposition strategy where the substrate is positioned at a plane of symmetry on the part and layers are deposited alternately on each side of the plate by rotating the part between  layers. This balances the build-up of the residual stresses avoiding distortion during the manufacturing  process (Williams et al. 2015)

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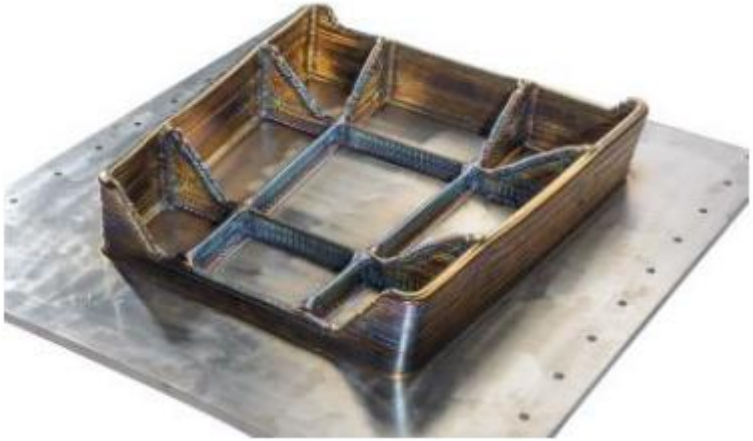
# Depositing single part around access of symmetry



https://www.cranfield.ac.uk/case-studies/research-case-studies/waammat

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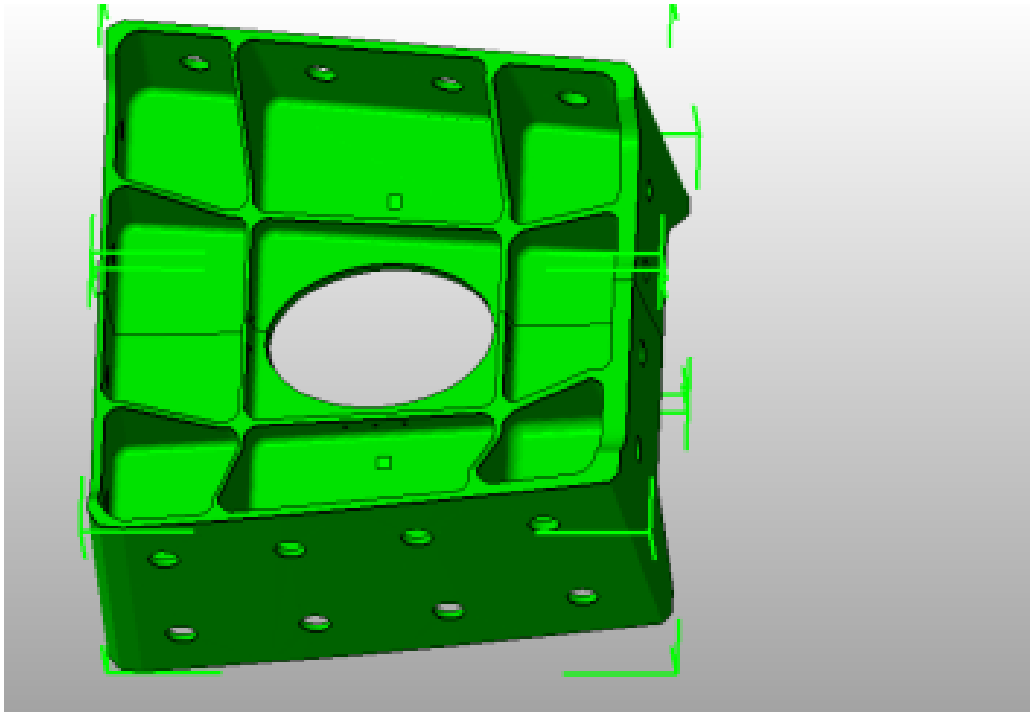

ACcelerated CLAdding and Integrated Machining Collaborative project

TSB: ADMA – Inspiring new design freedom through Additive Manufacturing

acclaim

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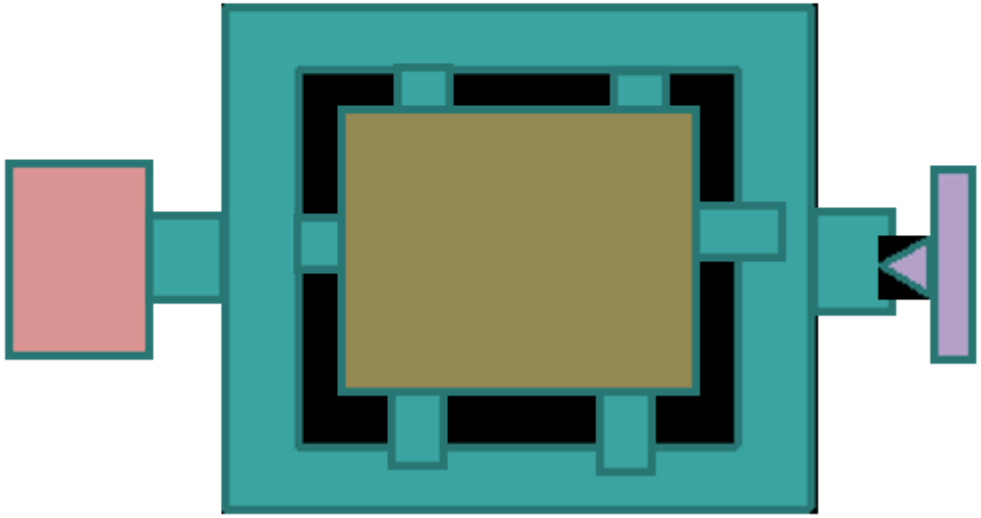
# Designing turnover fixture

Starter plate ~ 500x500x12mm thick ~15kg
Additional build ~ 45kg
Final part weight before machining ~60kg
Need to give 200mm around the plate so inside dimension of window frame (fixture) is 900 x 900mm



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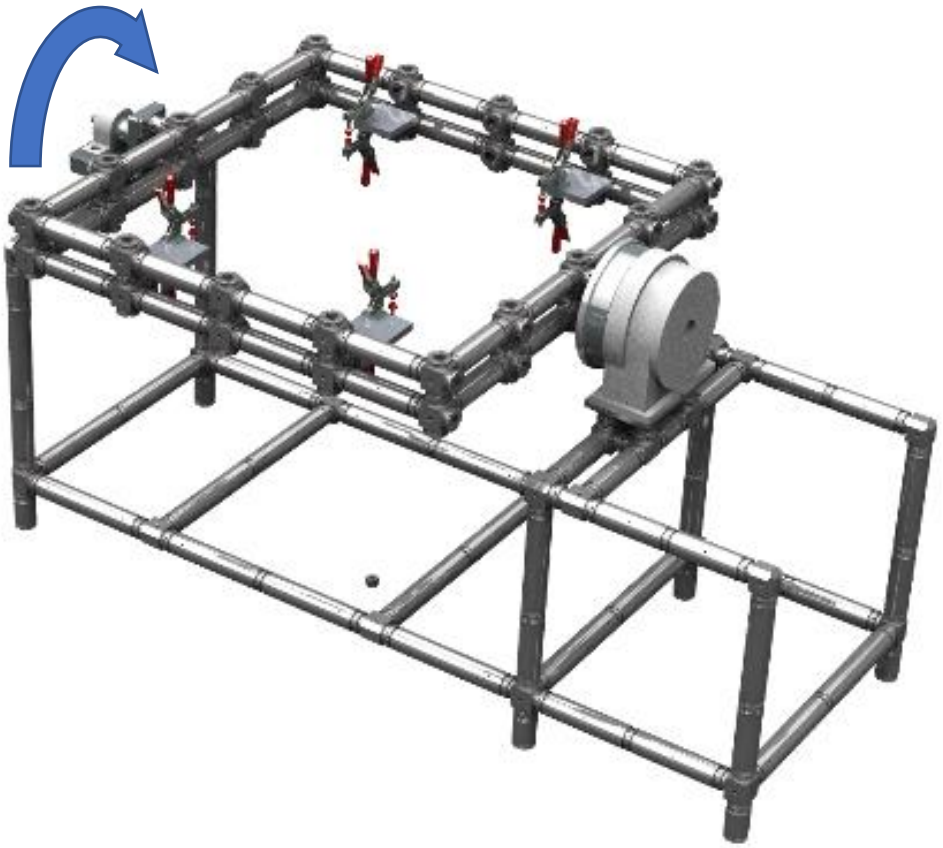
# Final design



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[Demonstration of additive manufacture of real landing gear component - YouTube]

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# In process stress relieving

Several potential in-process stress relieving methods including;

- Rolling
- Peening
- Thermal stress relieving

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# Rolling

- Pressure is applied to each bead using a roll
- Residual stress reduct MPa to 250 MPa
- Produces a smoothen top surface to layer
- Improved mechanical such as tensile strengt and yield strength by 2
- Also has the benefit of the microstructure

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ScienceDirect

Procedia CIRP 37 (2015) 48 – 53

www.elsevier.com/locate/procedia

CIRPe 2015 - Understanding the life cycle implications of manufacturing

## "Designing a WAAM Based Manufacturing System for Defence Applications"

Alessandro Busachi[a]*, John Erkoyuncu[a], Paul Colegrove[b], Filomeno Martina[b], Jialuo Ding[b]

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[b]Operations Excellence Institute, Cranfield University, Cranfield, United Kingdom
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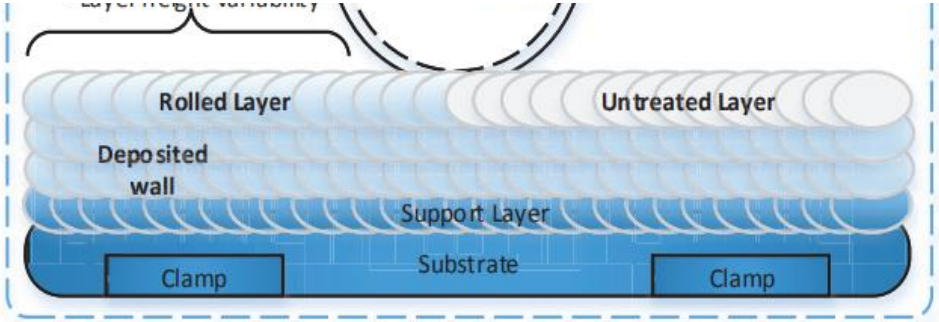


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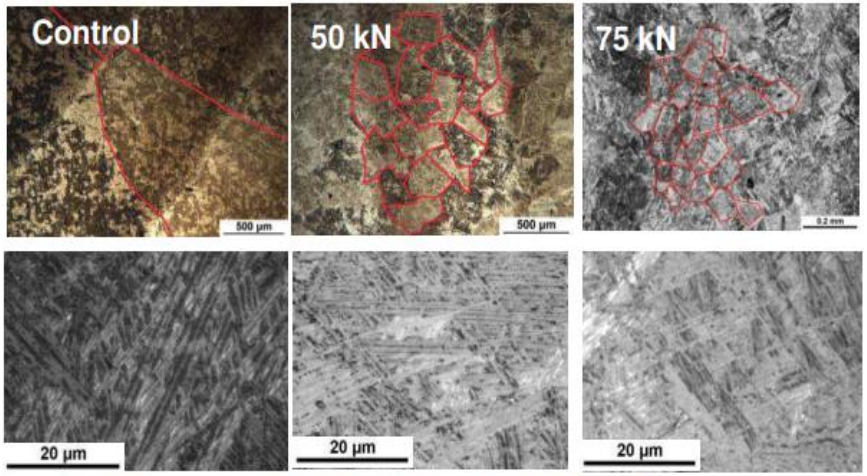
# Affect of rolling on microstructure

**Reduction in grain size**

Cranfield UNIVERSITY

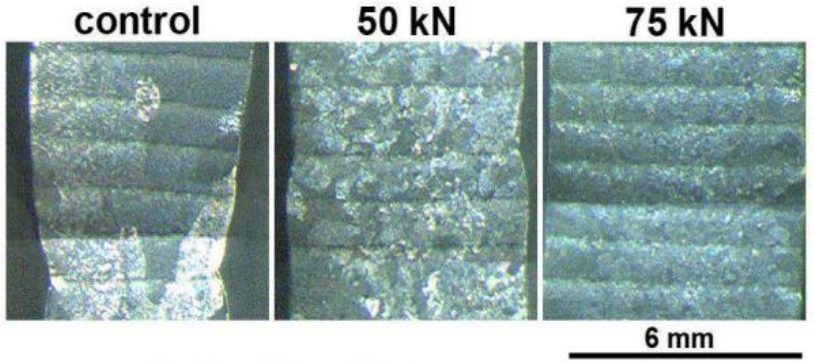



| Grain size | Control | 50 kn | 75 kN |
|---|---|---|---|
| Primary grains | 3 x 30 mm | 124 µm | 89 µm |
| Alpha laths length | 21.1 µm | 15.5 µm | 7.7 µm |
| Alpha laths width | 1.2 µm | 1.0 µm | 0.7 µm |

www.cranfield.ac.uk

**WAALM – latest results – rolling - effect on microstructure**

Cranfield UNIVERSITY




Rolling introduces **deformation**, **nucleation sites** and **stored energy** into the large beta grains, thus inducing **recrystallisation** when layers are reheated during the subsequent deposition

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| | Yield Strength (MPa) | Ultimate Strength (MPa) | Elongation (%) |
|---|---|---|---|
| Specification minima AMS 4985 Cast and HIP | 824 | 896 | 6 |
| Wrought Ti64 | 950 | 1034 | 11.7 |
| WAAM Vertical | 805 | 918 | 14 |
| WAAM Horizontal | 865 | 965 | 8 |
| WAAM Rolled Horizontal (50 kN) | 911 | 1006 | 11.5 |

Even more improvement likely for vertical direction

Grain size change tens of mm to ~ 130 µm

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- Video of rolling process

Rawfeed additive manufacturing of titanium structures - YouTube

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# Challenges with Rolling

- Requires a very stiff automation platform capably of applying the load
- Also it introduces a significant delay in the process if rolling is performed for every deposited layer
- And the method struggles in terms of complex part geometry
- Tall – thin walls are likely to buckle unless stiffening features added
- Effect is high focused on the top surface on bead

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# Peening

- Cold working process
- Surface of component is deliberately deformed
- Surface layer attempts to expand laterally but prevented from doing so by the elastic nature of the sub-surface, bulk material.
- Results in development of beneficial, compressive residual stresses in the surface layer, which are balanced by tensile residual stresses elsewhere.
- The layer of compressed surface material produced by peening resists the development and propagation of cracks and increases resistance to fatigue failure, corrosion fatigue, stress corrosion and cavitation erosion. The main peening techniques are:
  - shot
  - needle
  - hammer

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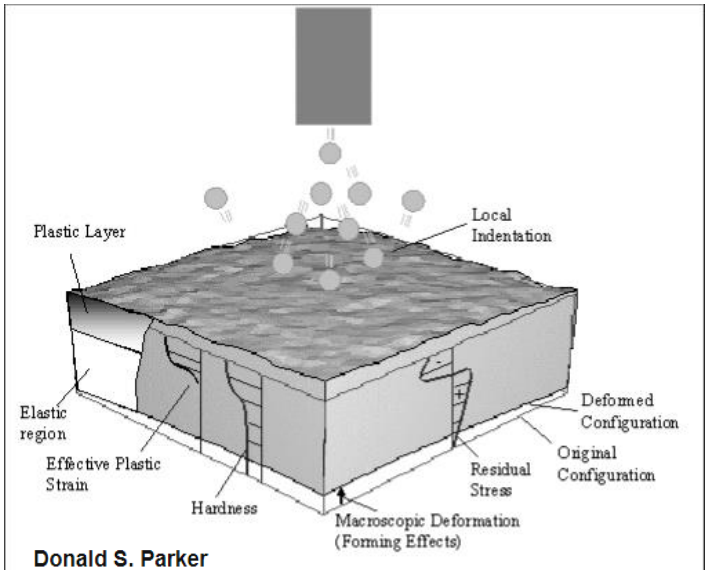
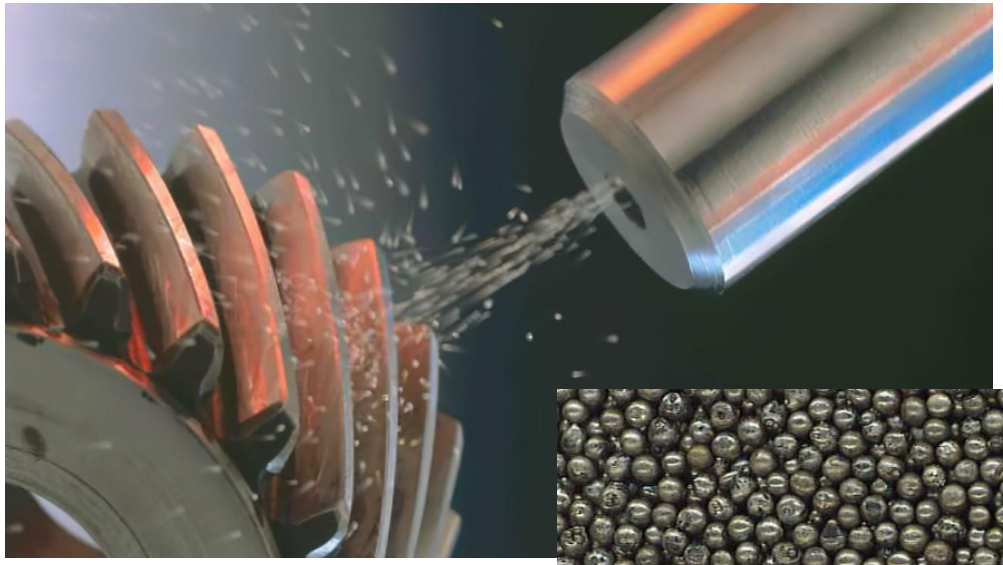
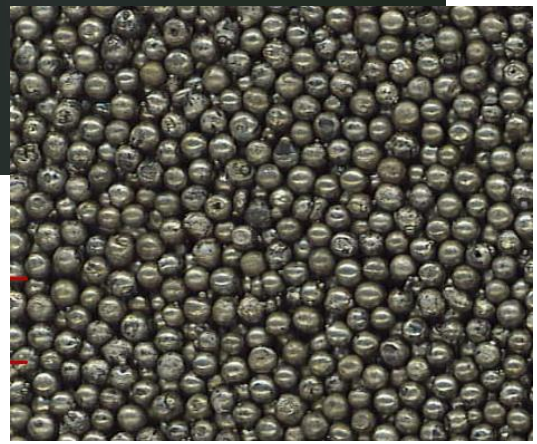
# Shot peening

Impact of steel shot on surface introduces compressive stress which counteract tensile stresses and thus increase fatigue life




**Donald S. Parker**
Kennedy Space Center





https://www.lsptechnologies.com/resources/what-is-shot-peening/

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# Needle peening


*ACcelerated CLAdding and Integrated Machining*

*Collaborative project*

*TSB: ADMA – Inspiring new design freedom through Additive Manufacturing*

**D3.2b**

**Captive Mechanical Peening (Additional Trials)**

**(Riccardo Tosi)**

Revision: 1st April 2015 (almost 8 years ago)

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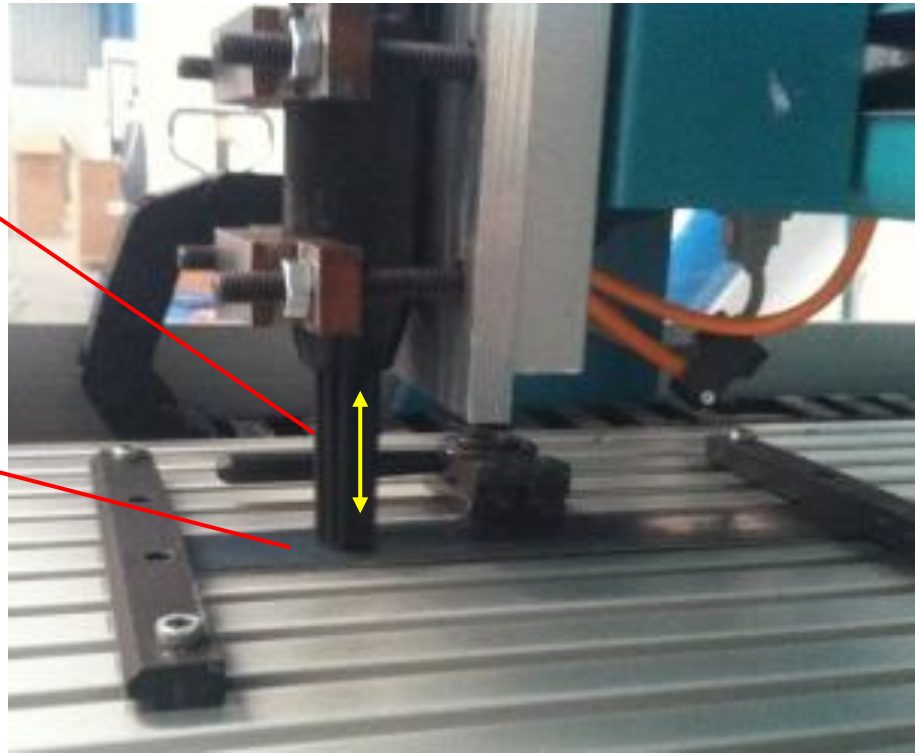
# Needle Peening head

Air is applied and pins virbrate up and down

Substrate



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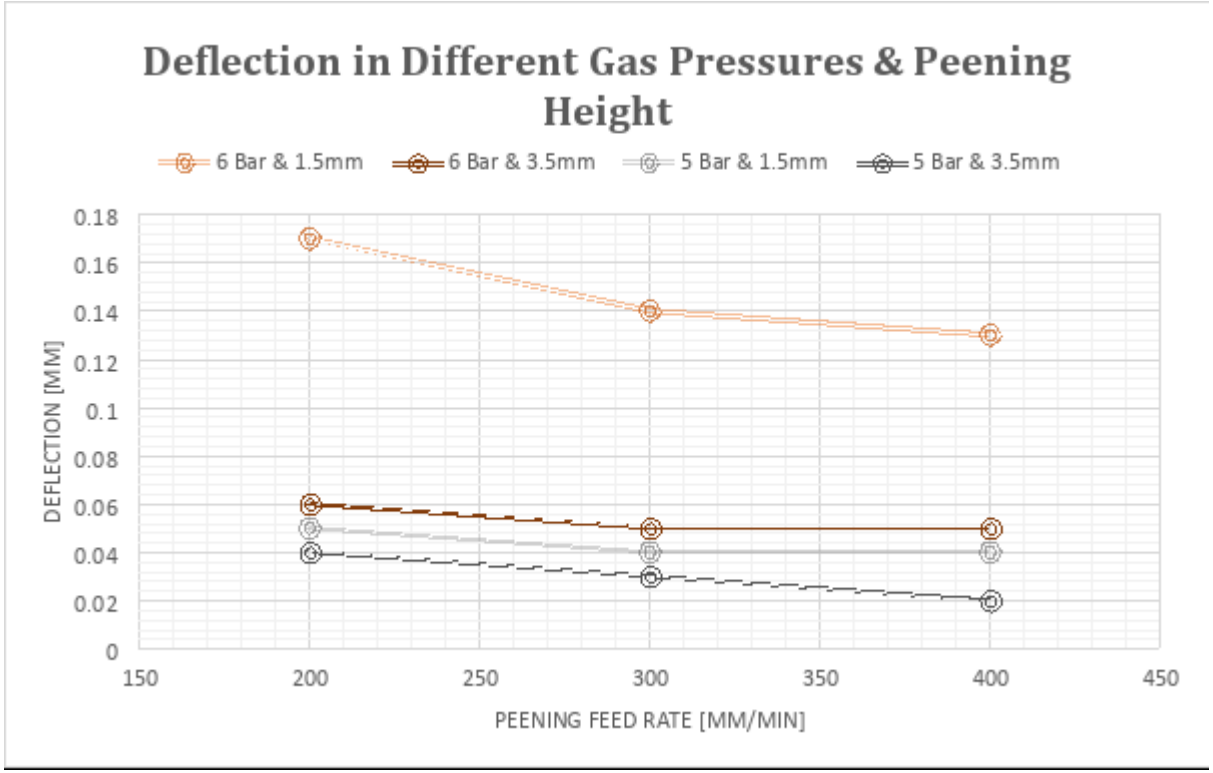
# Initial trials on flat titanium plate

It was demonstrated that peening induced a compressive stress in the top surface of the plates causing them to bend downwards

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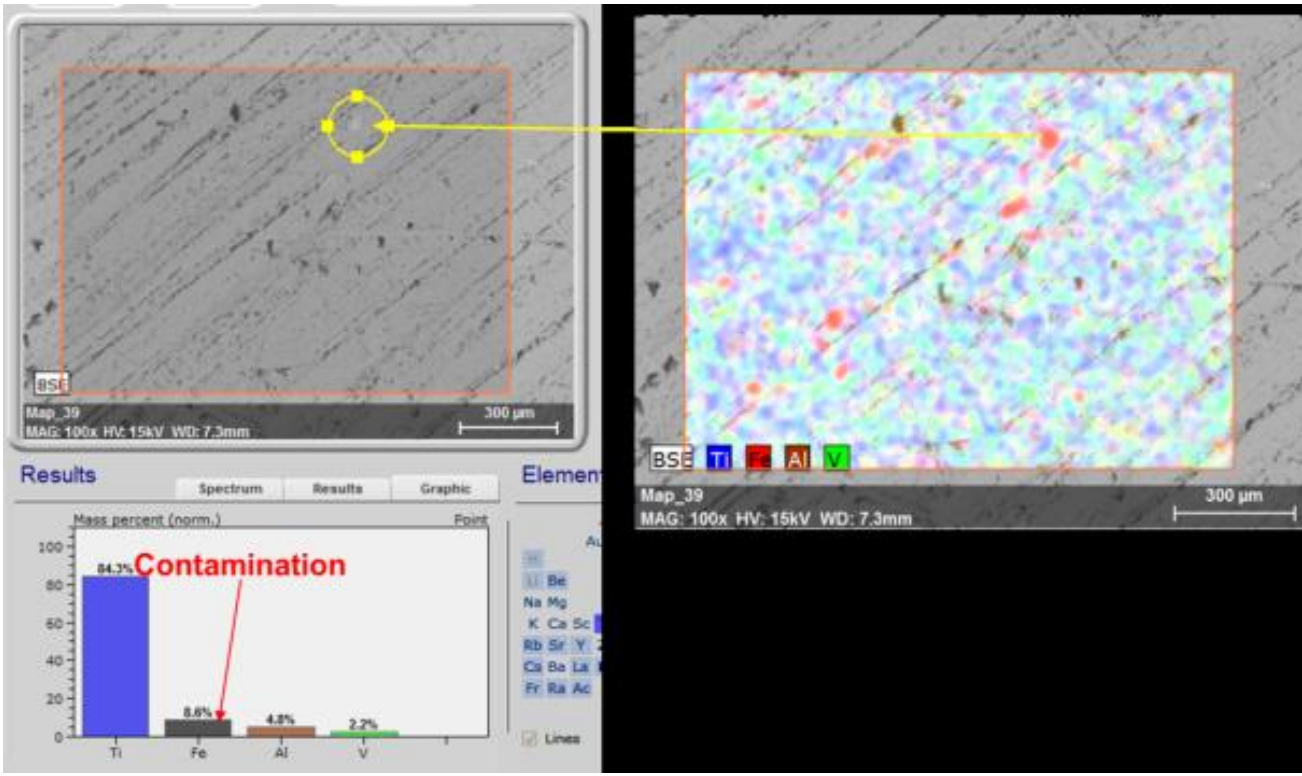
# Surface contamination

Contamination of Ti64 surface – Ferrous deposits from the tips of peening needles

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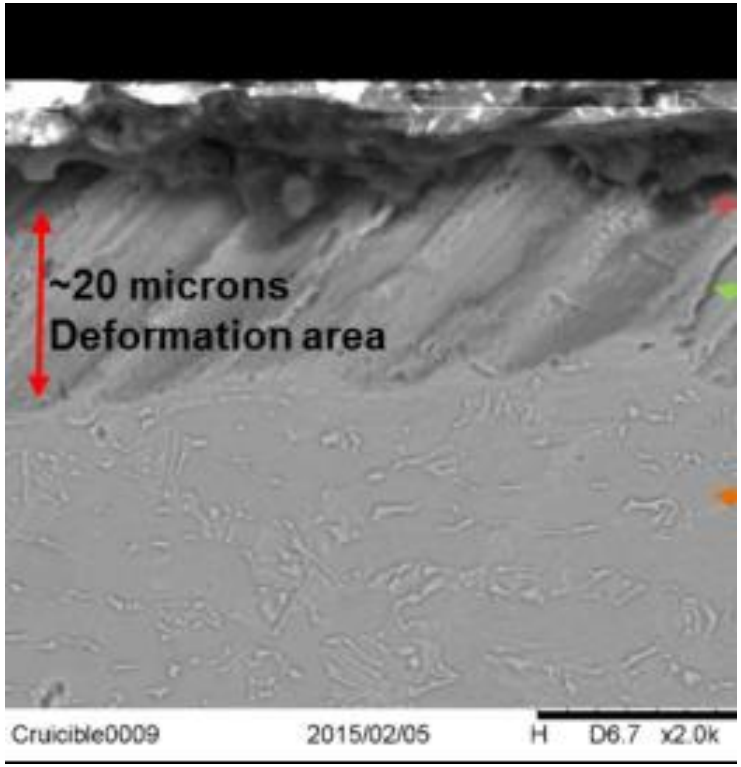
# Microstructure

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# Peening of beads

PTA (Plasma Transferred Arc)

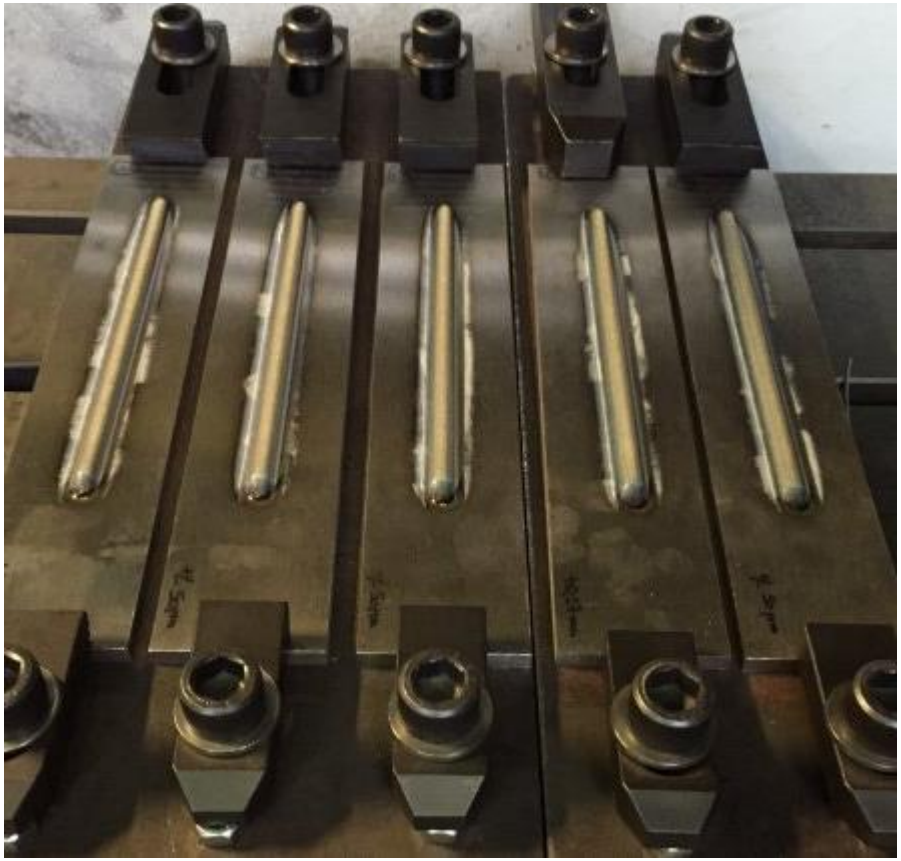
Single linear bead each time

Current: 100A

Wire feed rate: 1.5m/min

Torch traverse velocity:150mm/min

Plasma gas flow rate: 1.0l/min



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# Peening of top surface

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# Hammer Peening

- https://youtu.be/E4zfizO65xo

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# In-situ thermal stress relieving

- Number of research projects have explored the potential to undertake locally reheating of the surface – inconclusive results to date

- One potential solution to thermal stress is to deposit at an elevated temperature (similar to PBF-EB process from GE Additive) But this would require the part and the equipment to be subjected to elevated temperatures (for example 760$^{o}$C for Ti64)

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# Post process stress relieving

- Parts together with the build plate can be thermally stress relieved

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# *Thank you & Questions ?*

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