Trinity College Dublin
Coláiste na Tríonóide, Baile Átha Cliath
The University of Dublin

Repeatability in additive manufacturing for metamaterials

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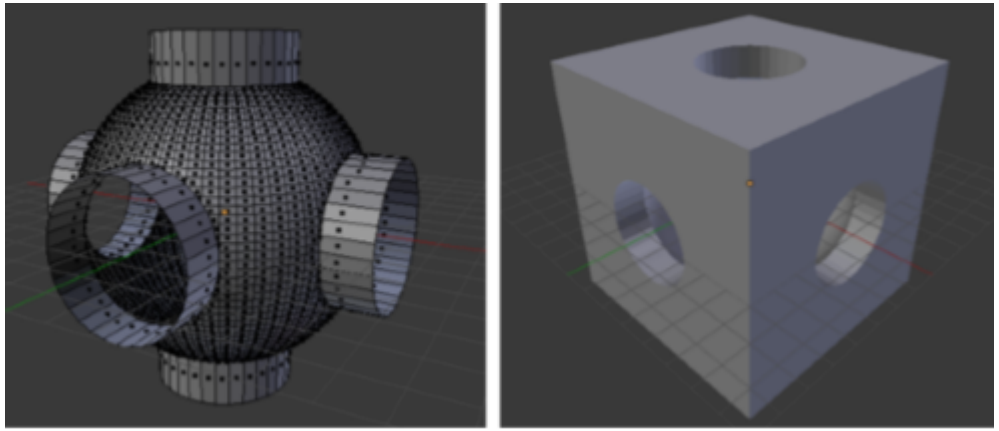
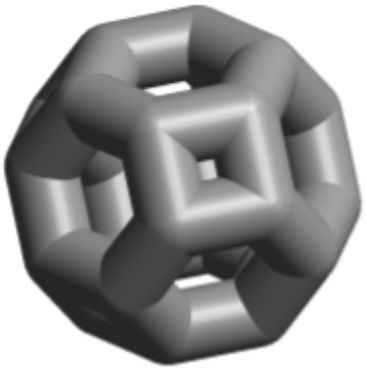
Aerialis

Metamaterial Structure

Metamaterials are usually composed of a lattice of unit cells

These cells can be further broken down to be comprised of struts or holes in specific arrangements and dimensions





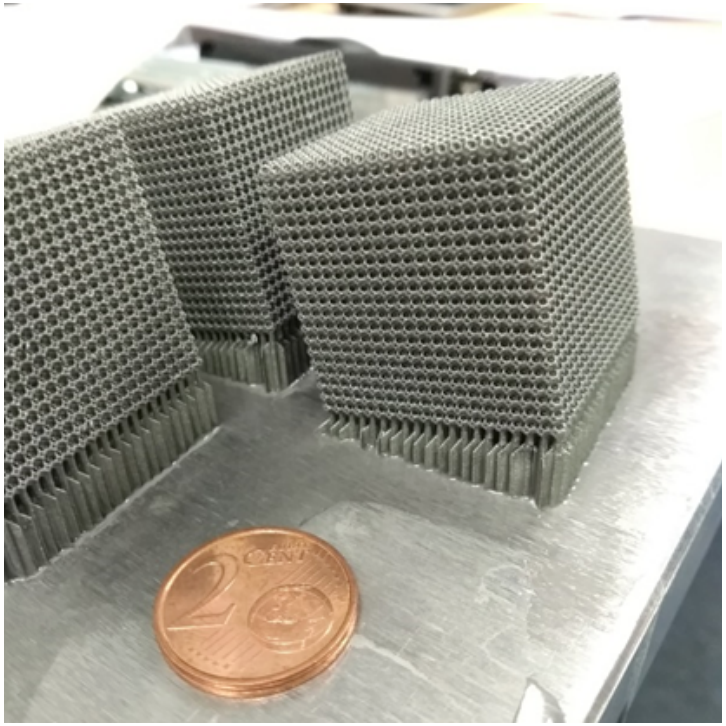
Additive Manufacturing

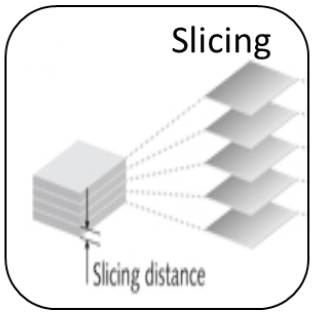
Able to produce complex previously unrealisable parts such as lattice structures

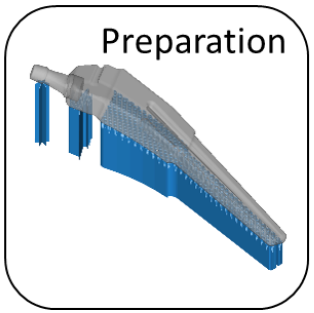
Produces using a layer by layer process

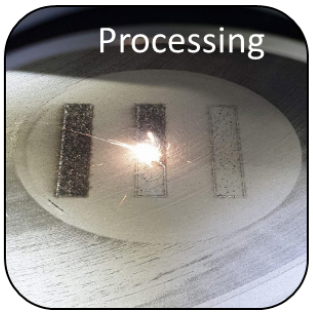
Multiple Technologies

- SLM,SLA,FDM,DLP









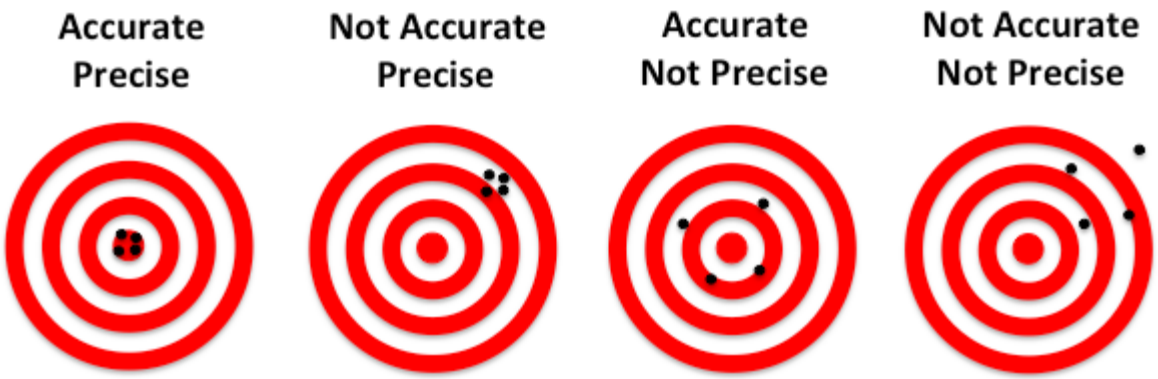
Technologies

- Selective Laser Melting (SLM)
  - Laser scan to melt metal powder
- Stereolithography (SLA)
  - Laser scan causing photopolymerisation
- Direct Light Processing (DLP)
  - UV Flash screen causing photopolymerisation
- Fused Deposition Modelling (FDM)
  - Melting and depositing a polymer filament

Repeatability

Repeatability is the ability to produce identical parts with the same properties

Repeatability is a measure of precision



The current state

Repeatability Issue evidence

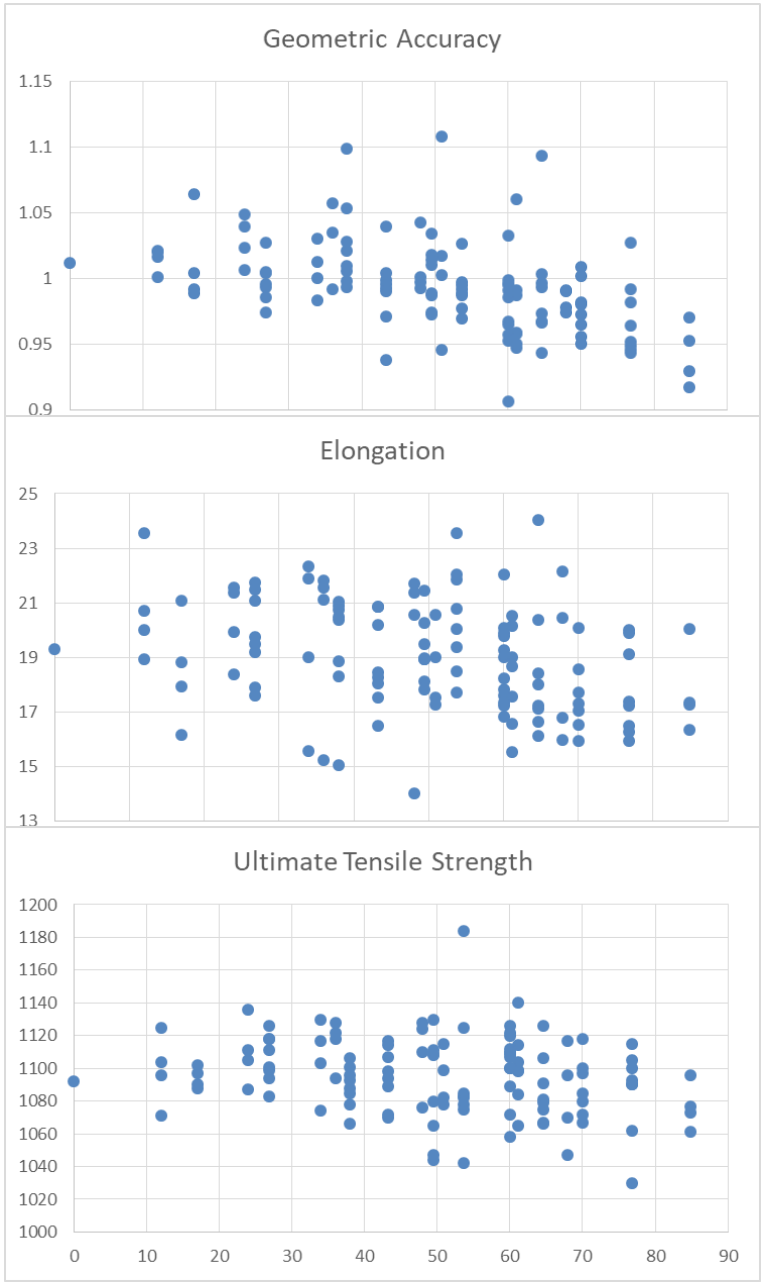
This issue is pervasive in both the literature and in our own experience.

121 Samples covering the full build plate area.
Using the suppliers recommended parameters

1mm hole
0.989mm Mean, 0.04mm SD, 0.28mm Range

Elongation
18.9% Mean, 2.38% SD, 10% Range

Ultimate tensile Strength
1093MPa Mean, 28.7MPa SD, 154 MPa Range

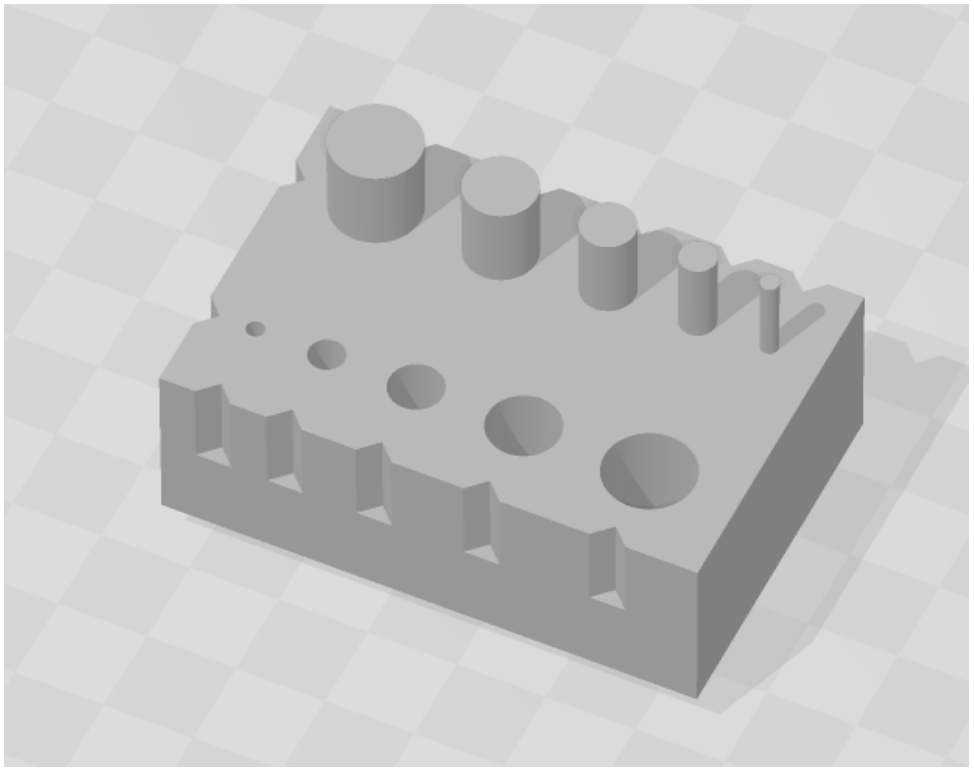


Geometric benchmark sample

Geometric Sample

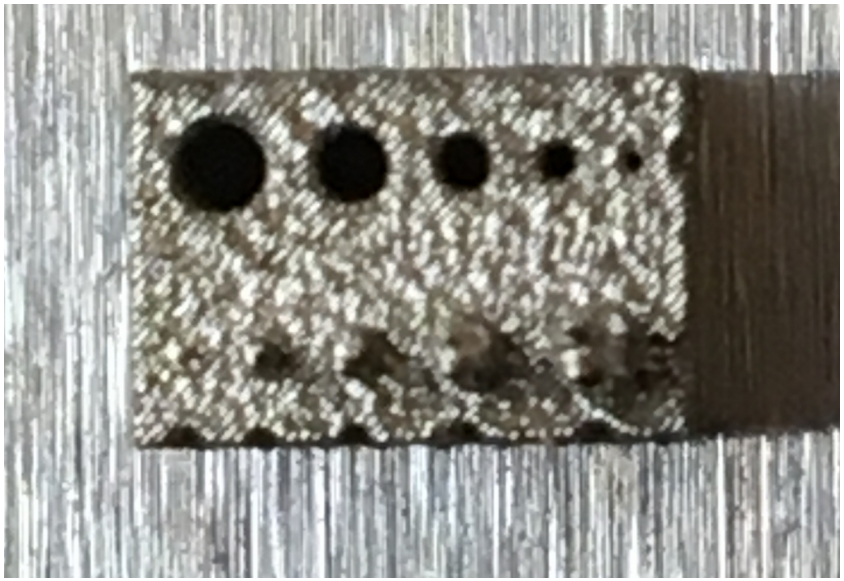
- 1mm, 0.8mm, 0.6mm, 0.4mm and 0.2mm holes and pins

- Index indents to allow for failed features



SLM deviations and defects

All holes and struts are present and distinct



Standard deviation of all measurements are in the range of 50 µm independent of what feature series was measured

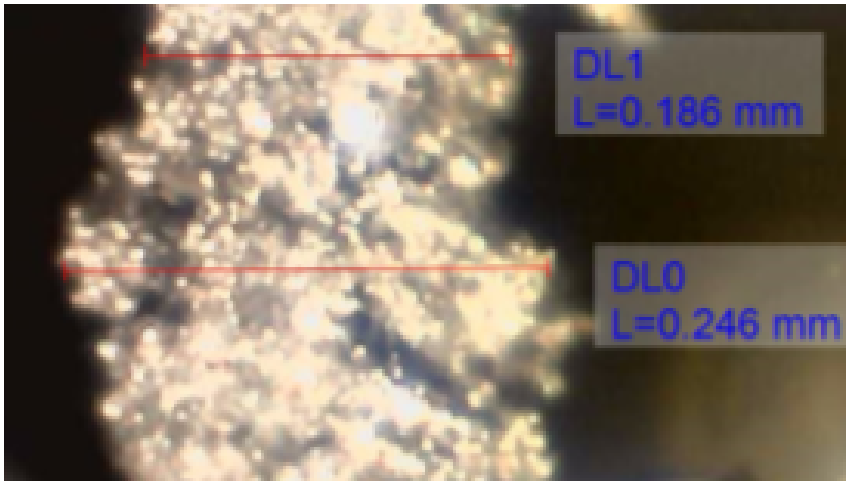
SLM	1mm	0.8mm	0.6mm	0.4mm	0.2mm
Hole					
Strut					

SLM Sources

Deviation is due to scan spacing and partially bound powder particles

The unmelted particles adjacent to the melt pool get connected to the strut

Similar effect causes the holes to be smaller than anticipated

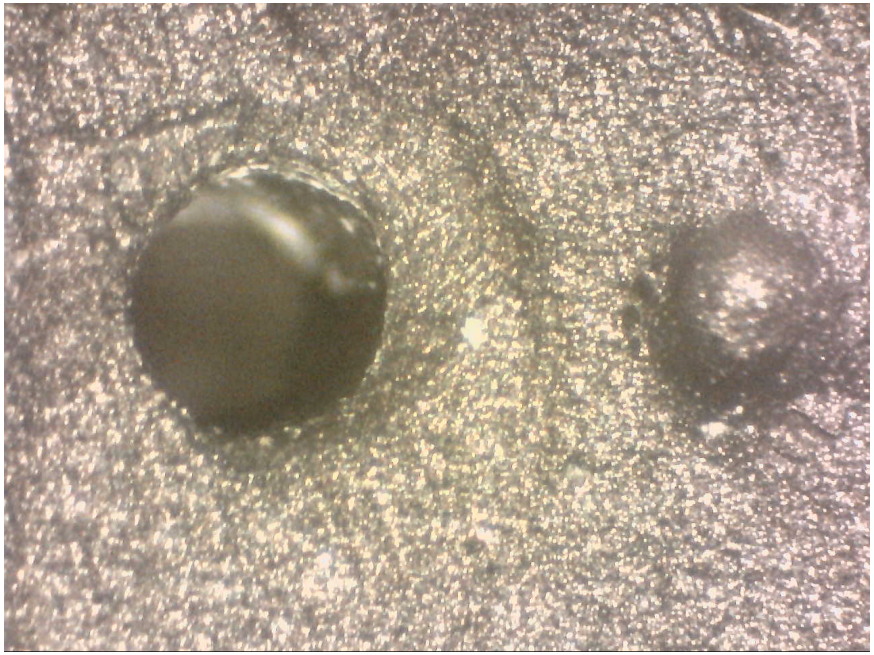


SLA deviations and defects

All struts printed

Holes were completely blocked by resin

Standard deviations in the 70 µm range, no pattern of feature size dependence



SLA	1mm	0.8mm	0.6mm	0.4mm	0.2mm
Hole					
Strut					

SLA Sources

High viscosity resin in the tight channels forms blockage, the blockage is then solidified by diffuse UV light from near laser passes or after printing.

Does not have the partially bound particles issue as precursor is at a molecular level

Laser spot of 140 µm is smaller than the smallest strut

DLP deviations and defects

Either faithfully replicates feature or the feature is completely removed

Standard deviations in the 70 µm range, no pattern of feature size dependence

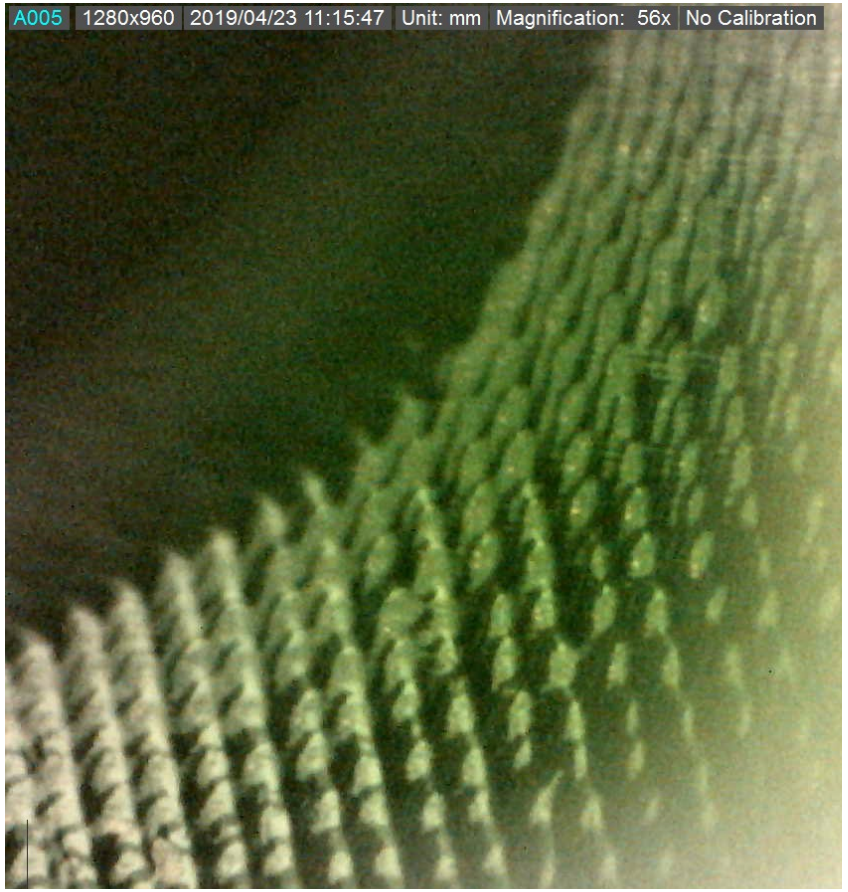
DLP	1mm	0.8mm	0.6mm	0.4mm	0.2mm
Hole					
Strut					

DLP Sources

Lower viscosity monomer to SLA reducing the entrainment issue

Struts are pixel limited, as the flash lamp has a pixel level features at or near this limit are prone to failure

50µm pixel size with discrete on/off

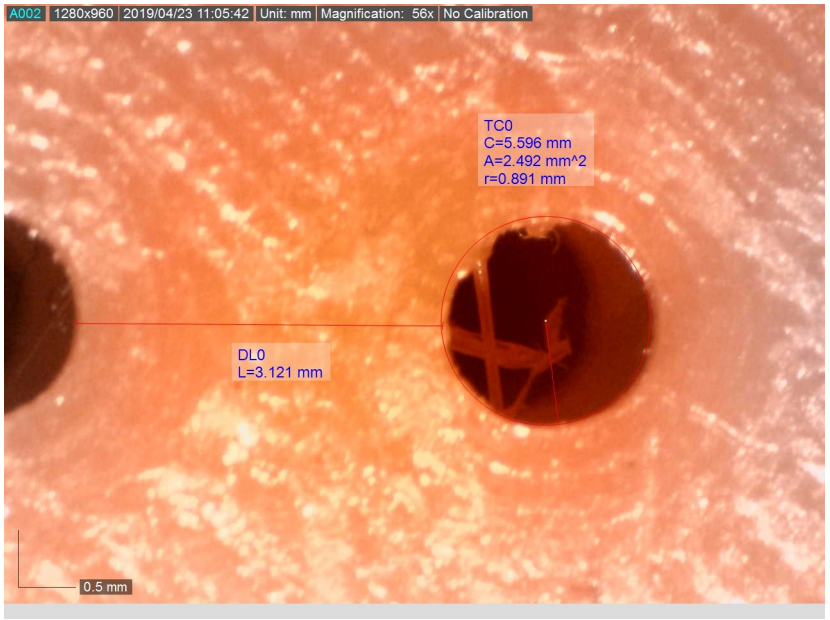


FDM deviations and defects

Features are produced with varying degrees of excess filament

Smaller features had a greater amount of filament defects

Sub-nozzle diameter features are produced as nozzle diameter size creating large errors



FDM	1mm	0.8mm	0.6mm	0.4mm	0.2mm
Hole					
Strut					

FDM Sources

0.4mm nozzle deposition means that strut less than this can't be created, 0.4mm struts prone to failure as it is a point deposition

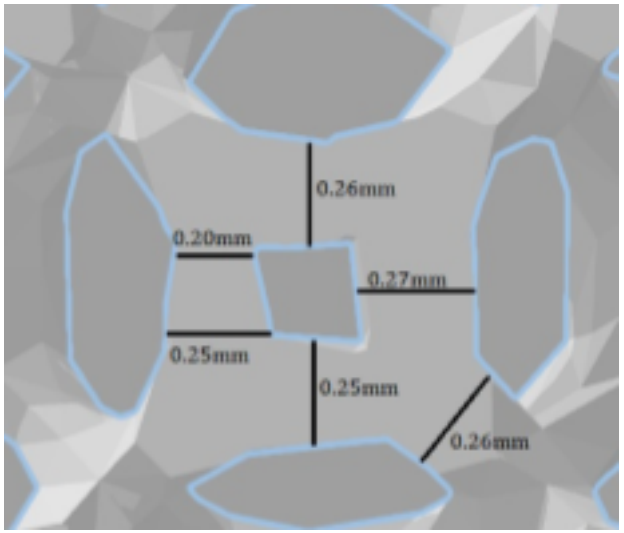
Trailing filaments as the nozzle moves about the print can cause the small holes t be blocked (Stringing)

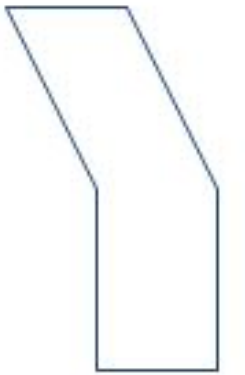
Common Error

The .STL used in additive manufacturing is not perfect.

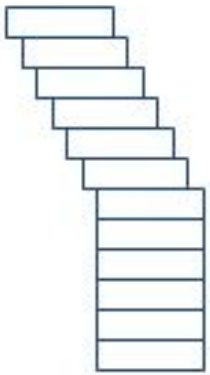
- Triangles struggle to approximate round objects accurately
- Loss of fidelity to CAD through processing

Staircase effect leads to smaller parts and increased variations particularly at feature sizes approaching the layer height





CAD design



Actual print

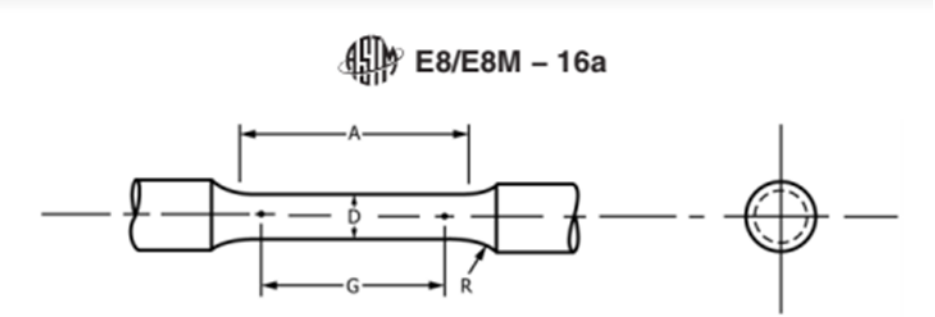
Mechanical properties

ASTM standard sample

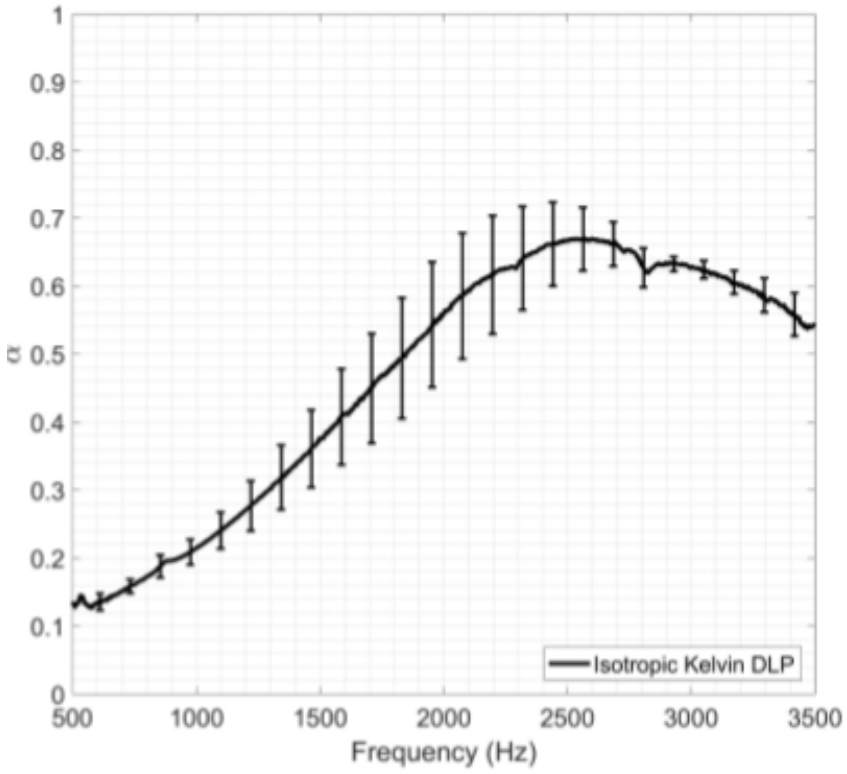
Can be produced within the build volume of all the machines

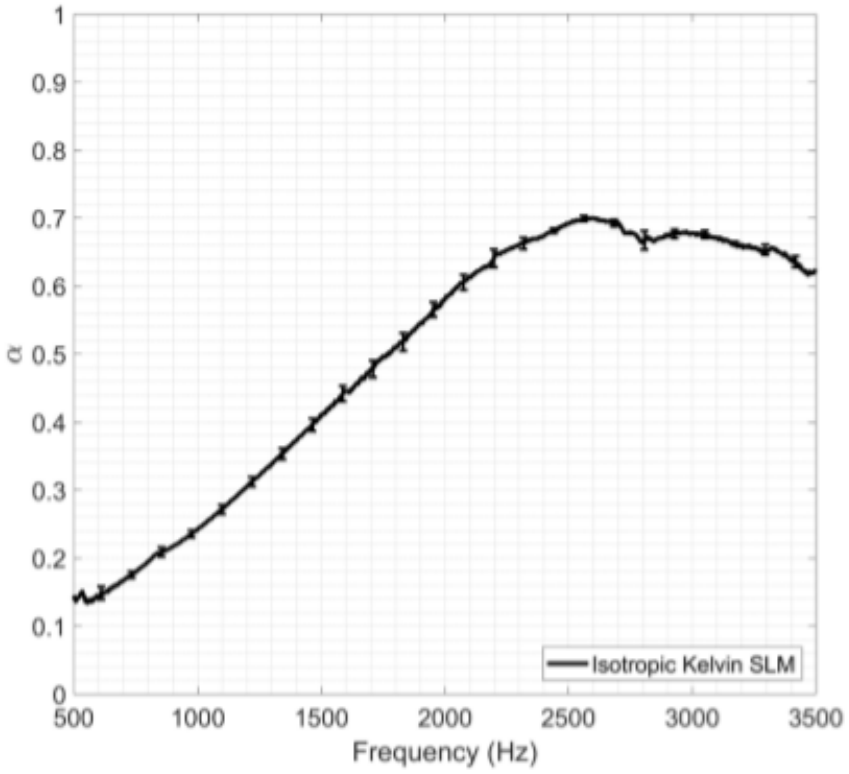
Shown to be as variable as the geometric properties

Is globally different to traditionally produced material



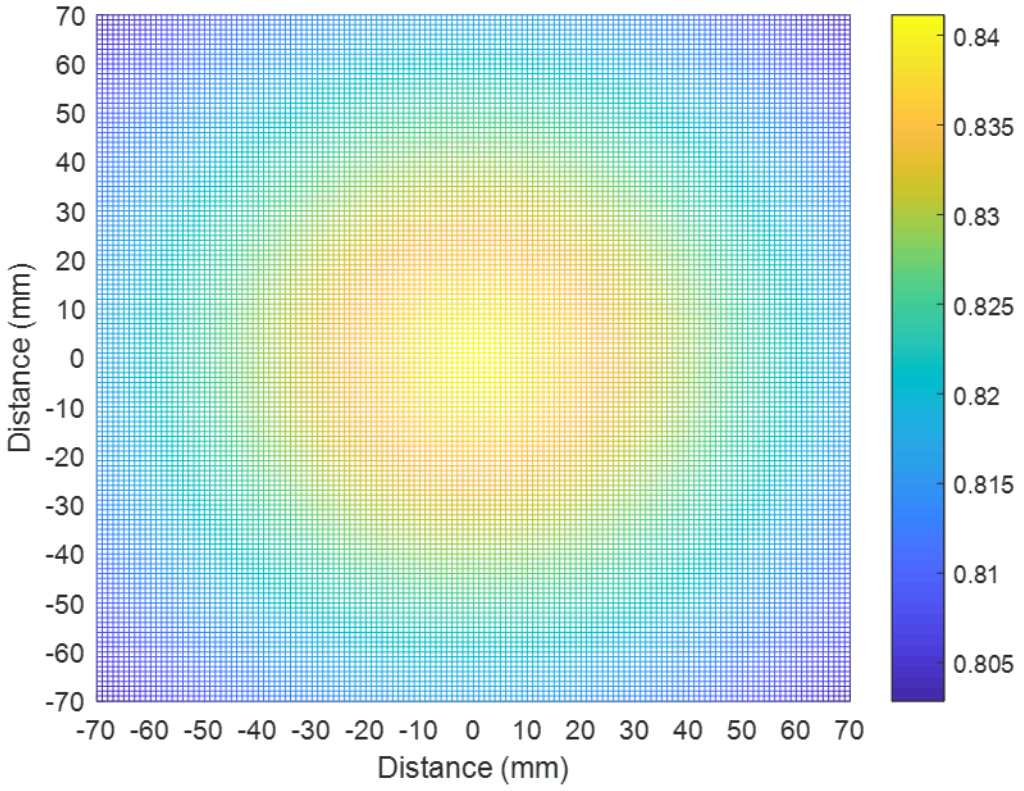
How this effects acoustics





Simulating the Process

- Numerical simulation following theoretical models of laser interactions
- Allows detailed predictions of spot size and energy input at any point on a build
- These predictions allow a more controlled process



Mecahincal Results to Date

Base Case

UTS deviation 28.6 MPa

Strain deviation 2.33 %

Improved Case

UTS deviation 16.7 MPa

Strain deviation 1.41 %

An improvement of 40% reduction in standard deviation

No significant difference between centre and edge

Non-significant change in overall performance

Areas to address and improvements

The technology that will be used to produce experimental samples, needs when designing metamaterials.

The numerical models and experiments will struggle to be matched without the variable nature of the manufacture being accounted for in the model.

The mechanical properties variation was reduced by 40% demonstrating that improvements are possible. The variation in geometric accuracy has been quantified and efforts to improve are on going

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Thank You

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