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Design and measurement strategy of additive manufacturing lattice benchmark artefact

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Abstract
Currently, no additive manufacturing (AM) benchmark artefact has been solely made for lattices. The objective of this research is to design an AM lattice benchmark artefact that AM users can use to assess their machine's capability, accompanied by a measurement strategy to evaluate the lattice characteristics using X-ray computed tomography (XCT). This novel AM benchmark lattice artefact design allows for a simplified method to evaluate the machine's capability in manufacturing different strut thicknesses or type of unit cells by only having to print one part. The parametric and gradient nature of the design allows engineers to easily choose and merge different types of lattices and strut thickness ranges. This method removes the need of printing multiple parts, resulting in decreased powder use, reduced print/measurement time while limiting chances of a print failure.

Keywords: Lattice structures; Additive Manufacturing; Benchmark artefact; X-ray Computed Tomography; Metrology.

1. Introduction

When commissioning a new additive manufacturing (AM) machine or when using a new powder material, it is common practice to additively manufacture different types of benchmark artefacts for different purposes such as assessing the mechanical properties of the produced part, optimising the different printing/post processing workflows, or to evaluate the AM machine geometric resolution limits, surface roughness and more. While more than 65 AM benchmark artefacts have been reported in literature [1], only a few have included a lattice as a complimentary design. The objective of this research is to design an AM lattice benchmark artefact that AM users can use to assess their machine's capability, accompanied by a measurement strategy to assess the dimensional, surface and porosity of the produced lattice using X-ray computed tomography (XCT).

2. Methodology

This paper starts by analysing the previous AM geometric benchmark artefacts and assessing their strengths and weaknesses. Secondly, this research investigates and uses ISO/ASTM 52902 [2] "Additive manufacturing - Test artifacts - Geometric capability assessment of additive manufacturing systems" as a guide to develop design constraints, features, and measurement strategies that are optimised for lattice structures. These features include, but are not limited to strut diameter resolution, node positioning error, surface roughness and porosity. Measurement strategy was optimised for XCT as it could match the measurement complexity needed to assess internal features or porosity of lattices.

A lattice is composed of uniformly repeated unit cell designs composed of different nodes and struts forming the general geometry. While ISO/ASTM 52902 does not provide information about measuring lattices, some suggested designs and measurement methods can be translated to achieving the task.

For example, the pin diameter resolution, hole resolution and linear axis accuracy from the standard can be translated respectively to strut resolution, external porosity (designed internal lattice spacings) resolution and linear node positioning error.

Figure 1. Example of ISO/ASTM 52902 suggested reference geometries as shown from left to right the pin diameter resolution, hole resolution and linear axis accuracy [2].

To represent the features shown in figure 1, the suggested design in this study has a gradient field to incorporate into one design, a range of lattice strut diameters and external pores sizes as can be seen in figure 2. This gradient approach is different from previously suggested designs in literature where multiple lattices with different strut and cell sizes have to be produced.

2.1. Results and discussion

The resulting design has Body Centred Cubic (bcc) type unit cell, this being one of the most used type of lattices in literature [1] and a box size 18.7 x 18.7 x 27 mm. Ntopology software was used to design a gradient that resulted in a varying strut diameter and cell size seen in figure 2.

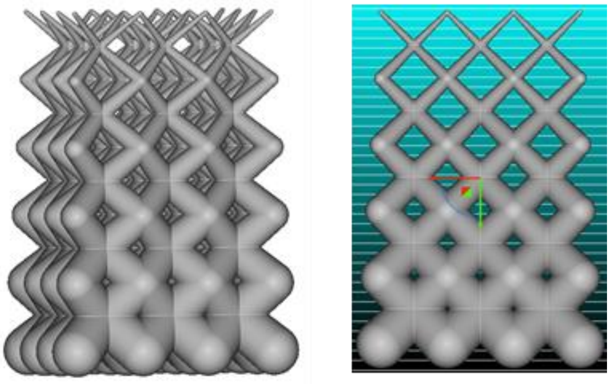

Figure 2. Suggested AM lattice benchmark artefact showing the gradient strut thickness and cell size.

The measurement strategy relies on using X-ray computed tomography (XCT) to image the additive manufactured part. While the gradient design allows for a visual and qualitative inspection, a quantitative inspection using XCT will be more thorough, especially when it comes to internal features that are inaccessible using conventional measurement instruments.

To simulate the measurement strategy beforehand, the measurements were applied on the produced CAD. For example, the lattice strut resolution can be measured using a wall thickness analysis as seen in figure 3. The external pore resolution can be measured using foam analysis module here performed using VGStudio MAX 3.4.3 as seen in figure 4.

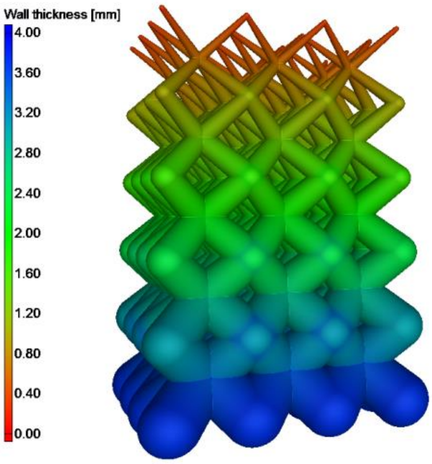

Figure 3. Wall thickness analysis performed on the AM lattice benchmark artefact CAD showing the strut resolution.

To evaluate the node positioning axis error, and instead of adding spheres to the design, the nodes can be thresholded from the wall thickness analysis to isolate the spheres already existing in each node. The measurement strategy in this case can include measuring the centre distance between multiple spheres in each X, Y and Z axis to evaluate the axis node positioning error. Another measurement can include the overlay of CAD and produced AM node spheres and compare their centre-to-centre distance. Example of spheres thresholded from the CAD nodes can be seen in figure 4.

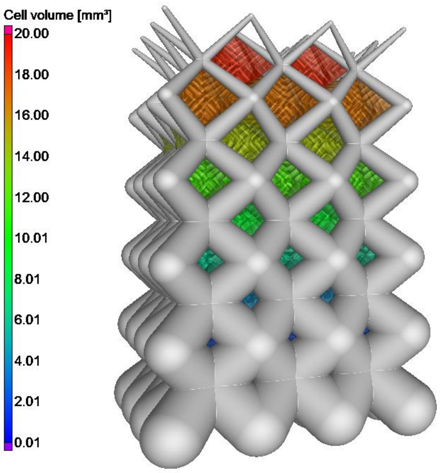

Figure 4. Foam analysis performed on the AM lattice benchmark artefact CAD showing the external porosity resolution.

Finally, deviation analysis can also be performed as well as surface data analysis as previously completed by the author [3]. Also, and while not mentioned in ISO/ASTM 52902, porosity analysis can also be performed on the produced AM lattice since the small geometry can be easily affected by the existence of internal pores.

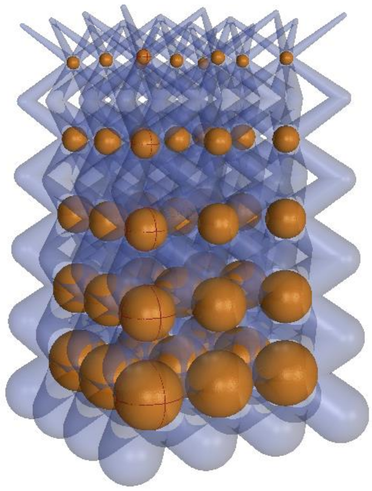

Figure 5. Isolated spheres existing in every lattice node used for node positioning error measurement.

3. Conclusion and future work

This study suggests a novel AM lattice benchmark artefact that can be used for assessing the machine capability using for example different hatching methods and layer height to evaluate parameters like the smallest achievable lattice strut or external pore. Process repeatability and stability can also be assessed since lattice designs already have duplicated features across each layer.

Instead of producing multiple lattices, each with a fixed strut and cell size, the suggested design is based on a gradient that allows for reduction of the number of specimens and print time making the process cost efficient. The suggested design also minimises the chances of print failure since the fine features are at the top and are printed last. The paper also suggests, a measurement strategy based on XCT and applied as seen above on the CAD design converted to a virtual volume.

Future work will include the additive manufacturing of the AM lattice benchmark design and demonstration of the suggested measurement strategy. Dimensional deviations and defects are expected to be predominant at the top part of the lattice due to minimising lattice strut diameter.

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