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Tensile specimen design for LB-PBF Inconel truss-based lattice structures: Manufacturing and experimental validation

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Abstract
The aerospace industry strives for an optimum between sustainability, cost and resource efficiency. In this regard, additive manufacturing (AM) has established itself as a disruptive technology by offering complex part design, geometrical flexibility and hence a high degree of lightweight grade. An improved competitiveness advantage for AM in an aerospace context, can be achieved using cellular structures such as honeycombs or lattices. However, in engineering practice, lattice structures are still not yet implemented for load-bearing structures. In order to use their lightweight potential and exploit lattice potential, a reliable and reproducible assessment of the mechanical properties of lattice structures for different loading scenarios is essential. On the one hand, test specimens used for material characterization have to be designed so that the required mechanical properties are not falsified by the test specimen geometry or the experiment itself. On the other hand, the small-scale manufacturing of lattice structures and their implementation into bulk parts pose challenges. Any deviation from the initial lattice design geometry may impact the mechanical performance. It is therefore of utmost importance to establish reliable and robust method for design and manufacturing and quality assessment.

Design, Tensile, Test, X-ray

1. Introduction

This paper deals with the additive manufacturing and the experimental validation of Inconel tensile specimens made by LB-PBF.The specimen design is based on load introduction by means of structural grading [1]. This study is divided into several parts. Firstly, the additive manufacturing of structurally graded lattice structures with diameters below 220µm is investigated and assessed by X-CT. The intrinsic quality of the manufactured lattice samples is assessed by performing porosity and wall thickness analyses. Secondly, the lattice-to-bulk transition is investigated. A hybrid manufacturing approach is presented and discussed. Finally, mechanical tests are performed in order to validate the proposed sample design. The functionality of the developed design is proven by comparing graded samples to ungraded ones.

2. Material & methods

2.1. Sample design principle

As thoroughly described in a previous work [1], the sample design principle consists of three distinct areas: the bulk area, the transition area and the target area (Figure 1). The bulk area serves as connection to the testing machine and the target area is the lattice sample to investigate on. The role of the transition area is, on the one hand, to introduce pure tensile loading at the its interface with the target area and, on the other hand, to avoid any stress concentration that can typically occur at the sample's edge.

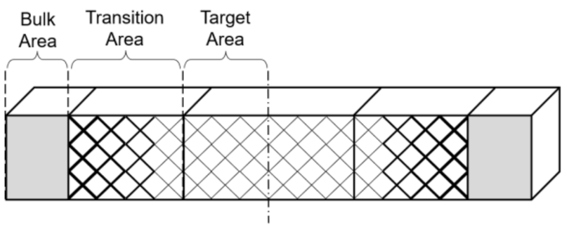

Figure 1. Sample Design principle [1]

In this sample design, the load introduction is made of structurally graded lattice structures. The structural grading can be divided into a vertical grading and a transversal one [1]. Grading parameter have been established in the framework of the design investigation.

2.2. Sample manufacturing principle

In order to avoid any overhanging issue with the sample's upper bulk area during the additive manufacturing, a modular assembly was employed. To do so, a hybrid manufacturing approach was developed (Figure 2). The bulk area is divided into two parts. On the one hand, the height of the lattice sample (including both transition and target areas) is extended to further lattice rows. On the other hand, the bulk part of the machine connection is pocketed so that the supplementary lattice rows can fit in it. The lattices are then embedded with epoxy resin. The pocket is shafted in order to ensure a load introduction through form lock in case of bonding failure of the interface between metal and resin.

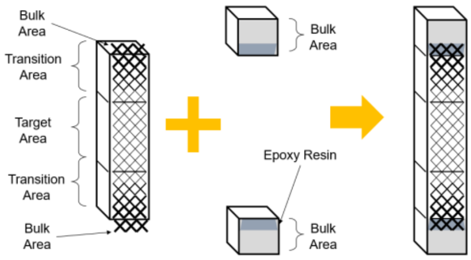

Figure 2. Sample assembly principle

2.3. Investigated configurations

In the framework of this study, the experimental validation of the sample design is performed for the stretching-dominated f2ccz and the bending-dominated bcc cubic truss lattice unit cells (Figure 3).

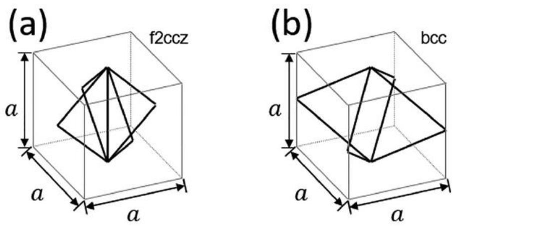

Figure 3. Considered cubic unit cells of cell size a - recompiled from [1]

In order to remain in the limits of the available build space, all lattice structures were printed for the unit cell length *a* of 2 mm. The investigated aspect ratios (AR), which are the relationship between cell length and strut diameter, are AR = 6 and 8 mm. This results in strut diameters varying from 431 µm down to 141 µm, depending on the sample and grading configuration.

2.4. Investigation setup

The parts are produced on a Renishaw AM400 single laser LB-PBF system with reduced build volume in Inconel718 and are investigated with a Nikon XTH 225 computed tomography system achieving a voxel resolution of 41µm. The CT data is analysed using VGSTUDIO MAX using a nominal/actual comparison and wall thickness analysis. Uniaxial static tensile tests are conducted in accordance with the German engineering norm DIN 50099 [2] using a Zwick/Roell Z100 testing machine.

3. Preliminary results & conclusions

The mechanical results of the ongoing investigation will be presented during the conference.

3.1. Sample manufacturing

At the time this contribution has been written, samples have successfully been printed and need to be assembled (Figure 4).

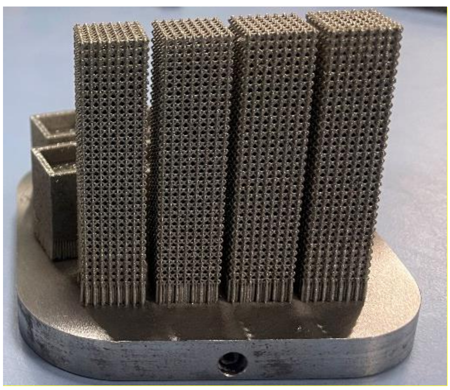
Figure 4. Preliminary results – Manufactured Inconel samples

Figure 5 shows the deviations between as-designed and as-built dimensions for a representative lattice sample (bcc AR06, graded). Nodal areas and support structures excepted, the printed strut diameters yield a maximum of ca. 20 µm deviation with the intial design. This means that the main load paths predicted by the numerical model [1] will be respected within the lattice structure.

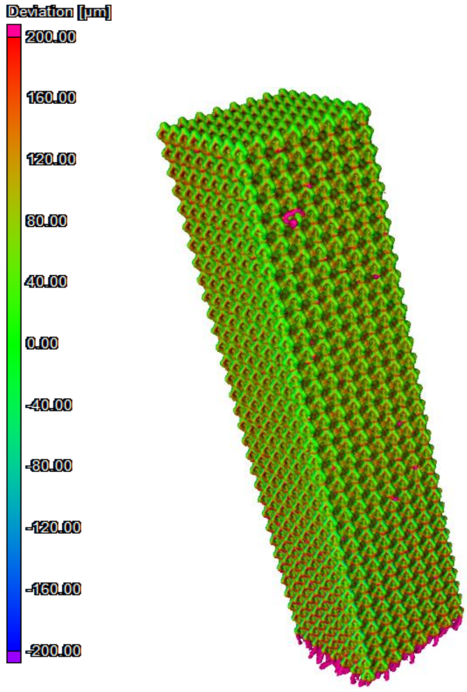

Figure 5. Preliminary results - CT scans, deviations with STL (bcc AR06, graded)

3.2. Preliminary tests

Perliminary tests have been performed for AlSi10Mg samples as an initial proof of concept. Initial results have shown that the graded lattice offers a load introduction that ensures a systematic failure in the gauge area compared to ungraded lattice. Figure 6 shows representatively a failed graded bcc sample. The sample has been reworked to highlight the successful hybid manufacturing as shown on the right hand side of Figure 6.

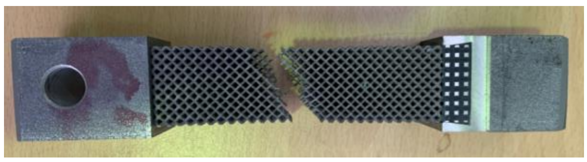
Figure 6. Preliminary results - Hybrid sample (bcc AR6 - AlSi10Mg)

From these preliminary investigations, it can be concluded that the manufactured samples show good agreement with the developed design. Manufacturing defects are therefore expected not to interfere with the functionality of the structural grading in the static range.

References

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