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Mechanical analysis of additively manufactured hybrid lattice structures

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Abstract

Additive manufacturing enables the production of lightweight and complex components. The use of lattice structures, defined as repeating geometric patterns, is becoming an increasingly important method for reducing weight and optimising mechanical properties. These lattice structures are composed of numerous interlocking grid nodes, which are also referred to as 'cells'. By using lattice structures, the mass of components can be reduced or specific damping properties can be achieved. In this study, a variety of lattice structures were analysed and combined with one another to create hybrid multi-zone lattice structures. The lattice-structures were additively manufactured using digital light processing and were then mechanically analysed under pressure. Within those investigations the influence of structural patterns, material thickness and the potential for combined structures on failure prediction are presented.

Keywords: additive manufacturing, 3d printing, digital light processing, lattice structures

1 Introduction

Additive manufacturing has established itself as a key technology for the production of complex and function-oriented components. Due to their characteristic geometry, lattice structures in particular offer significant advantages in terms of weight savings, mechanical performance and design flexibility. [1, 2] They enable an optimised material distribution and therefore a specific adaptation to local load conditions. This makes them suitable for numerous technical applications, as for example in lightweight construction and energy absorption.

This study investigates the mechanical properties of lattice and hybrid structures produced using digital light processing (DLP). In addition to the evaluation of classic lattice structures, the potential of hybrid models is analysed, in which different types of lattice are combined in order to investigate further functions. The aim is to evaluate their performance under mechanical loads and to identify possible areas of application.

2 Lattice structures for additive manufacturing

Lattice structures are a class of periodic geometries which are characterised by high specific strength, energy absorption capacity and good adaptability to various mechanical requirements. Strut-based lattice structures are among the most commonly used designs in additive manufacturing, consisting of struts that are connected at nodes to form a repeatable unit cell. The configuration of these struts enables the precise calibration of mechanical properties such as load-bearing capacity and stiffness, thereby ensuring the optimal balance between lightweight and high-strength characteristics. Examples of typical lattice types include 'Kelvin' cells, 'Simple' lattices and 'body-centred cubic' (BCC) lattices, which possess different mechanical properties. These properties make them particularly suitable for a range of applications in fields as diverse as aerospace, automotive engineering and medical technology. [2, 3, 4]

Digital Light Processing (DLP) technology is a precise additive manufacturing method that enables the photopolymerisation of resins by projecting digital light patterns. It is characterised by high resolution and repeat accuracy, which allows the production of extremely fine lattice structures. The combination of design freedom and manufacturing accuracy makes DLP ideal for analysing complex geometries.

3 Experimental setup

The aim of the investigations is to evaluate the mechanical performance of additively manufactured lattice and hybrid structures as shown in Figure 1 under axial compressive loading. For this purpose, samples with a unit cell size of $V_c = 2.5\text{mm} \times 2.5\text{ mm} \times 2.5\text{ mm}$, a bar thickness of $b = 0.5\text{ mm}$ and a total sample volume of $V_S = 20\text{ mm} \times 20\text{ mm} \times 20\text{ mm}$ were produced. The grid geometries were designed using the nTop software (NTOPOLOGY INC., New York, USA).

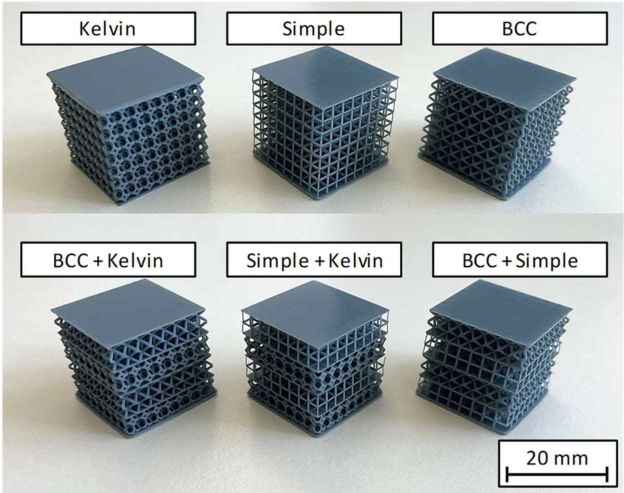

Figure 1 Hybrid structures from the single cells Simple, BCC and Kelvin

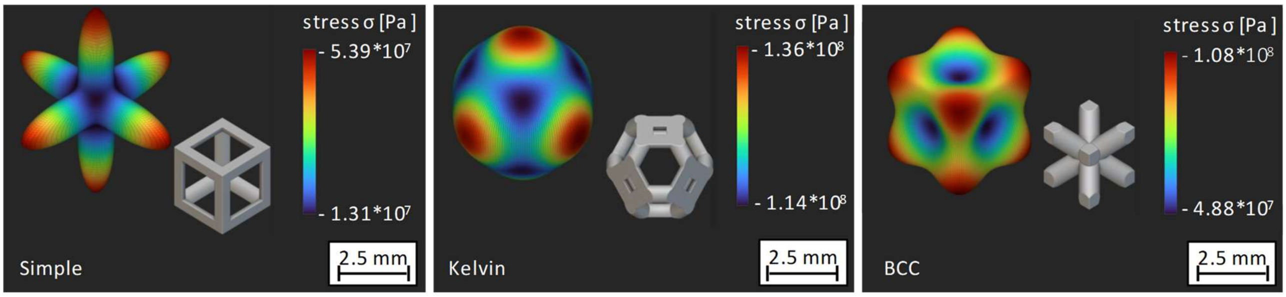

Figure 2 Homogenisation analyses of the lattice unit cells using the nTop software (NTopology Inc., New York, USA)

The samples were produced with the Elegoo Saturn 3 Ultra printer using Elegoo 8K standard resin (ELEGOO, Shenzhen, china). The layer height was set to $h_l = 0.05$ mm and the exposure time was set to $t_e = 3$ s per layer. The mechanical characterisation of the samples was then conducted using a Z150 universal testing machine (ZwickRoell GmbH & Co. KG, Ulm, Germany). In addition to the experimental investigations, the individual elementary cells were examined using a homogenisation FEM in order to analyse the stress distribution and homogenisation properties of the lattice structures. In this method, unit loads are applied to the unit cell in tension (X, Y, Z) and sher (XY, XZ, YZ) in order to calculate the effective stiffness k of the cell. Furthermore, hybrid structures, consisting of a combination of different lattice types, were investigated with the focus on their mechanical interactions and failure behaviour.

4 Analyses of lattice structures models

Figure 2 shows the analyses of the homogenisation of the individual unit cells and Figure 3 and Figure 4 show the representative pressure loads of the different models. As demonstrated by the compressive loading of the 'Simple' lattice, the compression loads F_c are minimal, with indications of early localised failure being evident in the form of peaks and valleys. Failure is characteristically initiated at the upper section of the specimen, where the applied force F_c is introduced. The simulations demonstrate high compression loads F_c at the vertical connections, leading to the rapid absorption of energy and subsequent failure.The structure shows a heightened response to non-axial loads and therefore a weakness. In comparison, the 'Kelvin' lattice demonstrates the highest compression load F_c and a uniform stress distribution. Failure typically occurs through cracks in the area of the applied force F_c, resulting in collapse. The configuration of the 'Kelvin' lattice, with its complex geometry, ensures efficient load distribution and reduced maximum loads F_c. The 'BCC' structure, while exhibiting diagonally stable characteristics, is also axially weaker, therefor offering a balance between structural strength and the controlled failure process.

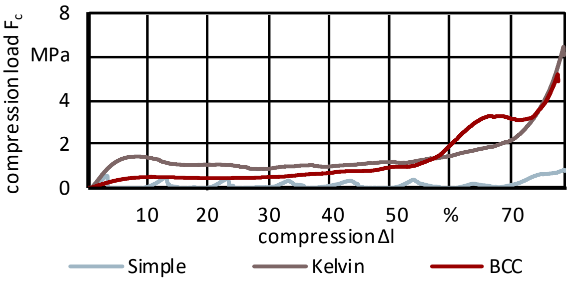

Figure 3 Exemplary curves of the pressure tests of the homogeneous lattice structures

The properties of the individual models are combined in the hybrid models. For instance, the 'BCC + Simple' model shows intermittent peaks due to layer failure caused by the vertical struts of the 'Simple' lattice. The 'BCC + Kelvin' configuration has the highest strength and uniform load distribution prior to the first crack of $F_{c,max} = 0.95$ MPa for hybride models as the advantages of both structures are combined. The 'Kelvin + Simple' model has a uniform load distribution, but weaknesses due to the lower load capacity of the 'Simple' part. Simulations confirm that geometry determines load distribution and failure patterns. Basic structures such as the 'Simple' unit cell fail early, while complex structures such as the 'Kelvin' unit cell offer better load-bearing capacity. The utilisation of the strengths of the individual components in hybrid structures enables the creation of robust, balanced systems.

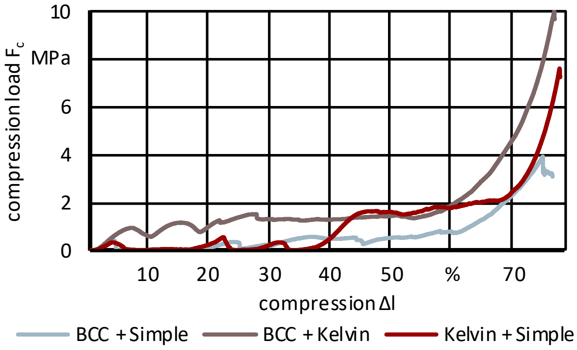

Figure 4 Exemplary curves of the pressure tests of the hybride lattice structures

5 Conclusion and outlook

This representative study demonstrates that the selection of grid structure, whether a single cell or a hybrid model, is depending on the requirements of the specific application. For applications requiring high compressive strength and uniform stress distribution, hybrid structures such as 'BCC + Kelvin' are ideal. Conversely, basic structures such as 'Simple' are advantageous in scenarios where predictable failure is desired. The study shows the usability of lattice structures and highlights the significance of unit cell and hybrid model analysis in optimising design and enhancing material efficiency. By improving these initial analyses, future researchs involving material selection and the development of advanced hybrid models have the potential to produce even more robust and technical useful structures.

References

[1] Park, S. J., Lee, J. H., Yang, J., Moon, S. K., Son, Y. & Park, J. En-hanced Energy Absorption of Additive-Manufactured Ti-6Al-4V Parts via Hybrid Lattice Structures. Micromachines, (2023) 14(11).

[2] Daniel, V. A. Benefits of 3D printing technologies for aerospace lattice struc-tures. Scientific Bulletin, (2021). 24(1).

[3] Liu, J., Xu, M., Zhang, R., Zhang, X. & Xi, W. Progress of Porous/Lattice Structures Applied in Thermal Management Technology of Aerospace Applications. Aerospace, (2022). 9(12).

[4] Müller, P., Synek, A., Stauß, T., Steinnagel, C., Ehlers, T., Gembarski, P. C., Pahr, D. & Lachmayer, R. Development of a density-based topology optimization of homogenized lattice structures for individualized hip endoprostheses and validation using micro-FE. Scientific Reports, (2024) 14(1).