A COMPARISON OF LATTICE STRUCTURES IN METAL ADDITIVE MANUFACTURING

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Abstract

The use of metal additive manufacturing is on the rise. One way to achieve significant weight reductions of components is by deploying periodic lattice structures. Selective laser melting enables the production of complex lattice structures in metallic components. In order to realize the full potential of these structures, their basic properties must be known. There are countless variations of topologies, but not all are suitable for SLM manufacturing. In this context, a comparison of commonly used structures is made in this article. The structures are evaluated by maximum capacity load, and the load directions (x, z) are taken into consideration. The results show significant anisotropy of some topologies. However, these topologies reached higher rigidity than topologies which have lower variations of capacity load depending on the direction.

Keywords: Schoen Gyroid; Lattice Structures; Rigid Constructions; Additive Manufacturing; Selective Laser Melting

1. Introduction

In recent years, certain branches of the mechanical engineering industry have been replacing solid materials with light porous materials. Metal Additive Manufacturing (MAM) opens new possibilities in the production of complicated components like lattice structures. Since the manufacturing is less constrained by the limits of traditional techniques, printed components can be smaller and more complicated. This is one of the reasons why the interest in additive manufacturing continues to grow. [2]

However, MAM has limits as well. Complex components with overhangs usually require support to hold the critical areas during the process. These support structures are built together with the component, and help prevent distortion from thermal stresses and anchor the overhang to the building platform. The support structures are removed after the production is complete. [1]

In some cases, the removal of the support structures can be very difficult, especially where the topology is very complex. This means that the choice of suitable lattice structures for MAM is narrow. Lattice structures with irremovable support structures would be counterproductive. A change to the orientation of the lattice structure can reduce the need for support structures. For these reasons, lattice structures based on self-supporting unit cells are in high demand and are used in additive manufacturing. [3]

Cellular lattice structures find wide range of usage due to their unique properties. They are used in applications where high strength accompanied by a relatively low mass is required. Porous structures also have other advantages such as thermal insulation properties and suppressed vibration. [7][11]

The interest in cellular lattice structures continues to grow, and a number of scientific articles have already been published dealing with this area of research and development. The authors in [9] and [10] focus on FEM analyses of different kinds of cellular lattices and the results were verified by practical experiments.

This article deals with a comparison of structures which are commonly used in additive manufacturing due to their self-supporting properties. The structures are evaluated by maximum capacity load, and the load directions (x, z) are taken into consideration.

2. Lattice structures with self-supporting cell units [2]

The experiment includes seven topologies with self-supporting unit cells, see Figure 1. All of the samples have 5 mm unit size and volume fraction is set at 13.5%. Cubic units such as Body Centred Cubic (BCC) and Face Centred Cubic (FCC) form the basis for the other variations such as PFCC and BCCz, where struts are added to gain stiffness along the z axis. F2BCC is created by combining BCC and FCC units.

Since the struts of BCC enclose a 45° angle with the main axes, BCC topology respects the rule of MAM and is self-supported along the main axes. The other topologies meanwhile are self-supported only in one z direction due to the added struts. While these lattices build along x or y direction, the MAM could fail on the horizontal struts. A typical representative of a fully self-supporting topology is a single gyroid, which does not require supports in a minimum range of cell size 3-8 mm. [7] [8]

The lattice structure marked as “Rhombic” does not respect the general rules of MAM and is therefore not self-supported. However, it is known from theory that AM is able to bridge an overhang of short distance without support structures. [4] Therefore its topology could also be built using this technology with the following parameters set.

Fig. 1. Compared unit cells topologies

3. Production of Lattice Structure

The samples were made using an EOS M290. The construction material was EOS MaragingSteel MS1 and the layer thickness was set to 40 μm . Default process parameters were used from EOS. The set consisted of 11 sample types. Samples with a rotated porous core of about 90° were included. Some samples without a rotated core had a less suitable orientation for additive manufacturing of lattice structure topologies due to the existence of horizontal struts without support structures. All of the samples had rigid plates on the contact surfaces with the test machine. To ensure reliable production, the rigid plates were built vertically and therefore the axis z was oriented horizontally during AM, whereas the axis x was vertical. Some samples are shown in Figure 2.

None of the samples exhibits any defects. Only the horizontal struts in the samples with load direction z show an impaired quality of the lower surfaces and their diameters are slightly increased. This is attributed to overheating of these areas due to the absence of a support structure, resulting in the partial welding of powder particles to the bottom.

Fig. 2. Samples of lattice structures

4. Experiment

The porous samples were subjected to compression tests on the Zwick/Roell Z 250 testing device. The results of the load capacity for uniaxial loading along direction z and x are shown in Figure 3. Values of the load capacities have been determined for a 0.2% permanent deformation.

Fig. 3. Load capacity of the different topologies

The lattice structure with the PFCC unit achieved the highest rigidity in both load directions, but also exhibits the highest anisotropy along the investigated direction. Deformation curves which were obtained from the tests differed from each other significantly. The load along direction z increased until the yield point, then came a slow load reduction. The sample with rotated PFCC topology (load direction x) showed a different course of load. After attaining load peak, the load force fell sharply due to the collapse of one cell row. The peak of maximum local load was contained five times in the deformation curve since the sample had five rows of units. All the other topologies have deformation curves similar to the first one. A closer look at the deformation curves of the PFCC topology is shown in Figure 4.

Fig. 4. Deformation curves of lattice with PFCC unit (a) direction z (b) direction x

5. Conclusion

This article deals with a comparison of self-supported lattice structures. The structures are evaluated by maximum capacity load, and the load directions (x, z) are taken into consideration. SLM is evidently very useful in the production of complex lattice structures. A set of porous samples with different topologies were all manufactured without defects. Since volume fraction and unit size were set as constant, the strut diameters were not constant and ranged from 0.64 mm to 0.96 mm in the different 3D models of the samples.

In general, the horizontal straight struts can distort self-supporting properties of cell unit because these struts do not respect the minimum building angle (40°) without supporting elements, and production may become risky. It was proved on the sample set that additive manufacturing could bridge a distance of 4.3 mm in the case of melting of horizontal struts with a minimum impact on the surface quality. The situation may be different where struts are slightly inclined from the horizontal position due to the absence of constraints on both ends of the struts during metal additive manufacturing. A consequence of this may be a deviation of the unconstrained end above the level of the melted layer under the influence of internal tensions. A collision of the recoater and strut end could follow. In this respect, the Gyroid is the most suitable for MAM, because its manufacturability does not depend on its orientation. [6]

The BCC, Rhombic and Gyroid structures have consistent mechanical properties along three orthogonal axes (x, y, z). [5] Therefore, the samples with these topologies were tested only in one z direction. These types of structures, including F2BCC can be used in applications where homogeneity of rigidity is required and could be useful in applications with combined stresses.

A higher load capacity was reached by BCCz and FCC topologies. Adding struts to BCCz gave it a higher load capacity in both directions than BCC. The PFCC topology was the stiffest with the least aligned results. This may suggest that its mechanical properties will degrade faster compared to other topologies, when the load is combined as pressure-torsion. However, some components are stressed along one direction and there the PFCC could be beneficial.

This conclusion corresponds with the results in article [3]. The authors focus on FEM analyses of different kinds of self-supported cellular lattices. It was confirmed that a double gyroid is particularly suitable for applications with multiaxial loading, since it provides identical rigidity of the porous sample in the x and z load axis. This also applies to a single gyroid, although achieving less rigidity. Geometrically simpler cellular lattices (such as BCCz, FCC, PFCC) have significantly increased stiffness in one of the main direction.

Additional mechanical tests, such as bending strength or cyclic fatigue, will be added in the following research activities.

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