A Study on the Mechanical Properties According to the 3D Shape of the Internal Structure in Additive Manufacturing

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Abstract
The additive manufacturing (AM) can freely process the shape of the product compared to the conventional subtractive manufacturing(SM), and there is an advantage in reducing the weight of the product. The weight reduction of the product is mainly achieved by making a certain cavity inside the product. Therefore, in addition to the Bravais lattice structure that has been used as a three-dimensional cavity pattern, an additional new lattice structure is proposed, and the stress distribution in the lattice structure will be confirmed through simple compressive stress analysis. Based on this, we will check which structure shows the most universally excellent mechanical properties.

Keywords: Additive manufacturing, bravais lattice, lattice structure, subtractive manufacturing, weight reduction.

1. Introduction

Unlike traditional subtractive manufacturing (SM), additive manufacturing can freely process the shape of a product. In addition, there is an advantage in reducing the weight of the product by forming a cavity inside the outer wall that does not pose a problem to the function of the product. In this case, there is an advantage in that the cavity can be formed three-dimensionally inside, so that appropriate mechanical properties can be individually secured for the force in the three-axis direction. In relation to this, various previous studies have studied various mechanical properties using the 3D lattice structure inside the product. The most common 3D lattice structure is the Bravais lattice structure. In this study, the body-centered cubic lattice (BCC), the face-centered cubic lattice (FCC), and the newly constructed octagonal face-centered cubic lattice (8NFC) are compared and analyzed based on the simple cubic lattice (SC), which is the most basic form of the three-dimensional lattice structure. Through this, we want to check the characteristics of mechanical properties between each lattice and select the lattice that will be used most advantageously in general.

2. Proposed Work

2.1. 3D Lattice Structure Modeling

As mentioned before, three cube-based shapes were modeled among the Bravais lattice, which is the most basic form of a three-dimensional lattice structure. Afterwards, the shape of the octagonal face-centered cubic lattice with several nodes added was newly conceived and modeled from the face-centered cubic lattice structure, which was expected to be the most stable among the three lattice shapes. Figures 1 to 4 below are three Bravais lattice structures and modeling of a new 8NFC lattice.

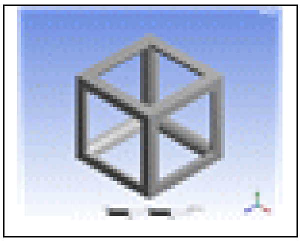

Fig. 1; Modeling of a Simple Cubic Lattice Structure

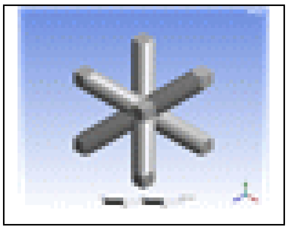

Fig. 2; Modeling of a Body-centered Cubic Lattice Structure

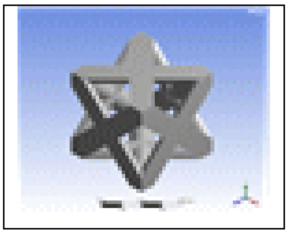

Fig. 3; Modeling of a Face-centered Cubic Lattice Structure

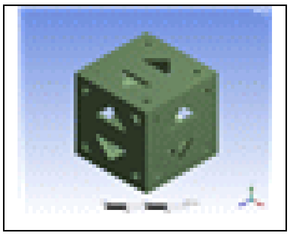

Fig. 4; Modeling of Octagonal Face-centered Cubic Lattice Structure

From now on, Fig. 1 to 4 will be called SC, BCC, FCC, and 8NFC in order from the leftmost. In general, the three lattice structures, which are Bravais lattices, have each vertex of the cube as a basic node. In addition, each node is characterized in that it is connected with each strut in the direction that is the shortest distance from each other. BCC has an additional node in the middle of the body center of the cube, and FCC has an additional node at the center of each face, so it can be seen that the position of each strut is different. In the case of 8NFC, the basic form of FCC was maintained, but a few nodes were added to each side, and additionally, an additional strut was reinforced at the center in one direction of each side. This is a form added by predicting a form that complements each of the disadvantages of the three basic Bravais lattices. For these lattices, Inventor, a commercial 3D modeling program, was used, and by utilizing the parameter function provided by the program, the positions of nodes and struts were maintained, but they were modeled to be deformed by simply entering their dimensions. The values of the parameters used at this time are shown in Table. 1 below.

Table 1. Parameter Values Applied to Modeling of Lattice Structures

Item	SC	BCC	FCC	8NFC
L	5 mm			
D	1.2 mm			

In Table. 1, L is the length of one side of the cube including the lattice, and D is the diameter of each strut. In addition, the relative density of each lattice is shown in Table. 2 below.

Table 2. Relative Density of Lattice Structures

Item	SC	BCC	FCC	8NFC
Relative Density [%]	19.361	40.951	48.245	77.141

2.2. Stress Distribution in Lattice Structures

The physical properties applied to the lattice structure in this study were applied to those of PLA filaments commonly used in additive manufacturing. The corresponding physical properties are shown in Table. 3 below.

Table 3. PLA Properties Applied to the Lattice Structure

Item	Properties
Density	1.24 g/cc
Tensile Strength	45.6 MPa
Tensile Modulus	2.3465 GPa

The commercial analysis program used for stress distribution analysis is Ansys, and the shape of the stress distribution was observed when the lattice structure was subjected to a compressive load. The boundary conditions of each lattice structure are shown in Table. 4 below.

Table 4. Boundary Conditions Applied to Lattice Structure Analysis

Item	SC	BCC	FCC	8NFC
Load	10 N [-y direction]			
Gravity	9.81 m/s^2 [-y direction]			

The results of stress analysis by applying the conditions of Table. 3 and Table. 4 above are shown in Fig. 5 to 8 below.

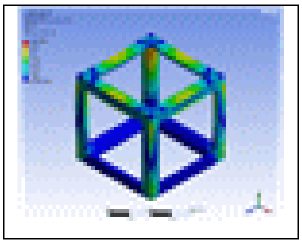

Fig. 5; Stress Distribution Result of SC Lattice Structure

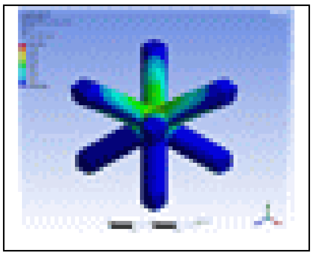

Fig. 6; Stress Distribution Result of BCC Lattice Structure

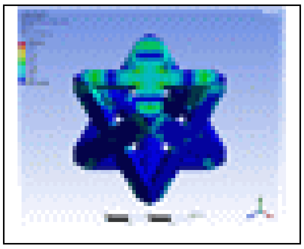

Fig. 7; Stress Distribution Result of FCC Lattice Structure

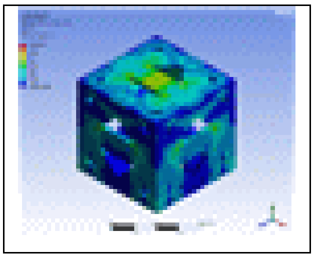

Fig. 8; Stress Distribution Result of 8NFC Lattice Structure

The maximum stress values shown in each lattice structure are shown in Table. 5 below.

Table 5. Maximum Stress Values for each Lattice Structure

Item	SC	BCC	FCC	8NFC
Maximum Stress [MPa]	49.341	46.133	40.821	12.765

In addition, the comparison of the maximum stress values according to the relative densities of each lattice structure is shown in Table. 6 below.

Table 6. Maximum Stress Values for each Lattice Structure as a Function of Relative Density

Item	SC	BCC	FCC	8NFC
Stress per RD [MPa]	9.553	18.892	19.694	9.847

The values in Table. 6 are the values obtained by multiplying the maximum stress value of each lattice structure by the relative density value.

3. Conclusion

As a result of the stress analysis of each lattice structure, the lattice showing the overall even stress distribution is an 8NFC lattice. In the case of SC, excessive stress concentration was observed at the contact point between the strut constituting the upper surface and the load and the strut in the horizontal direction. In the case of BCC, it was confirmed that the stress was excessively concentrated on the body center due to the structure where all struts are gathered at the center point of the volume. In the case of FCC, the stress distribution on the upper surface tends to be more evenly distributed compared to other Bravais lattices. However, the struts on the side in the same direction as the load did not distribute the load properly, so the stress was not evenly distributed. Lastly, in the case of 8NFC, the stress distribution appears the most even on the side receiving the load vertically, and as the stress is evenly distributed on the side struts, it can be confirmed that the stress due to the vertical load is evenly distributed throughout the lattice. Combining these results, it can be confirmed that 8NFC is the most evenly distributed form of stress in the lattice structure. Considering the relative density, the 8NFC lattice has the highest relative density. However, if this is related to the maximum stress, it can be seen that the 8NFC lattice has a low maximum stress compared to the high relative density. If the relative density is not taken into account, the lattice structure with the lowest maximum stress is 8NFC. This result can be seen that the 8NFC lattice structure generally has the best mechanical properties. For weight reduction, the most advantageous lattice structure is expected to be the 8NFC lattice structure if the size and physical properties of the lattice are adjusted according to the allowable stress desired by the designer by additionally adjusting the L and D values of the lattice. In subsequent studies, it is thought that it would be good to find out how much difference from the general structural analysis occurs through a load test on the product filled with the actual lattice structure.

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