A Study on the Topology Optimization of 3D Lattice Structure According to Stacking Direction

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적층방향에 따른 3차원 격자구조의 위상최적화에 관한 연구

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Abstract
A lot of research has been conducted on the additive manufacturing method that compensates for the disadvantages of the previous processing method. Among them, FDM has the advantage that production facilities and materials are inexpensive. In addition, the AM process has the advantage of being able to create various types of cavities inside the product. This is characterized in that it can show different mechanical properties even though it is a product using the same material with the same appearance. Therefore, in this study, the change in stress for axial force compared to the relative density according to the type of three-dimensional lattice structure was confirmed through experiments. In addition, a topology optimization study was conducted to properly arrange the 3D lattice structure inside the product to maximize the advantages of AM.

1. Introduction

Additive manufacturing is a processing method that is reexamined to compensate for the disadvantages of existing processing methods[1]. According to the ISO/ASTM 52900 standard enacted after 2015, additive manufacturing methods are largely classified into 7 processes, and detailed processes for these have been developed by several companies or research institutes. These different additive manufacturing processes require different types of materials.

Unlike conventional processing methods, additive manufacturing including FDM has an advantage in that raw materials can be prepared in the form of filaments or powders and manufactured into desired shapes by producers. Therefore, there is a very advantageous point in reducing weight compared to the same shape by implementing a certain hollow shape inside the product. It is relatively easy to produce products with topology optimization applied compared to the existing processing method because it can be printed in various materials for the load that the product receives[2].

In this paper, when designing a product, according to the mechanical properties of the 3D lattice structure, the lattice structure inside the product is to be used with a topology optimization technique. In particular, by constructing products with different types of lattice structures, the mechanical properties of products are improved compared to products using general phase optimization. Unlike conventional cutting, additive manufacturing is a point where the cavity inside a product can be filled in a desired shape, and by utilizing this, we intend to design a product that increases weight reduction by using the mechanical properties of various grids.

2. Lattice Geometry Modeling and Analysis

2.1 Modeling of 3D Bravais Lattice Structures

The cube of the length of one side of the cubic system becomes the volume occupied by the lattice in the object, and using this, the relative density of each lattice in the same volume can be confirmed. The shape of each grid is shown in the figure below, and the parameters required for modeling and the relative density of each grid are shown in Table 1 and Table 2[3].

[Table 1] Parameters applied to the 3D Bravais lattice

Parameters	Size
l : The length of one side of a cubic gric	4 mm
d : Diameter of the strut connecting the lattice points	1.6 mm

[Table 2] Relative density of a 3D Bravais lattice structure

	P Grid	I Grid	F Grid
Relative density [%]	28.6	55.7	62.9

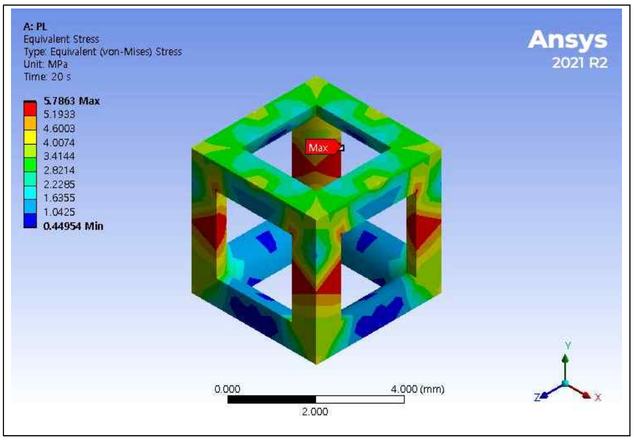
2.2 Stress Distribution and Deformation Behavior of 3D Bravais Lattice Structure

In this paper, the assumption that the isotropic condition of the 3D stress state is equally applied to products manufactured by additive manufacturing was used. The starting point is to find a certain degree of difference between the actual additively manufactured product and the conventional isotropic material property, and to find an axial correction factor to correct this difference. Therefore, three types of Bravais lattices with constant volume were targeted, and the mechanical properties of each lattice were visually identified first by identifying the three distributions of stress, strain, and amount of deformation. The material used for all lattice and additive manufacturing is PLA, and the physical properties of the material are shown in Table 3.

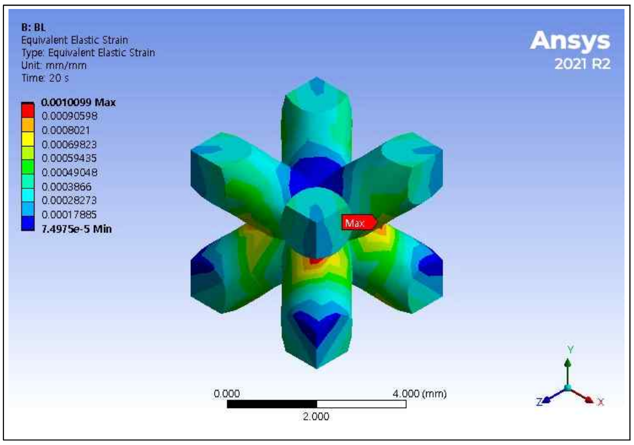
[Table 3] Mechanical properties of PLA

Property	Value
Density	1255 kg/m^3
Young's Modulus	3.447 GPa
Poisson's ratio	0.3899
Yield Stress	52.44 MPa
Max. Stress	62.93 MPa

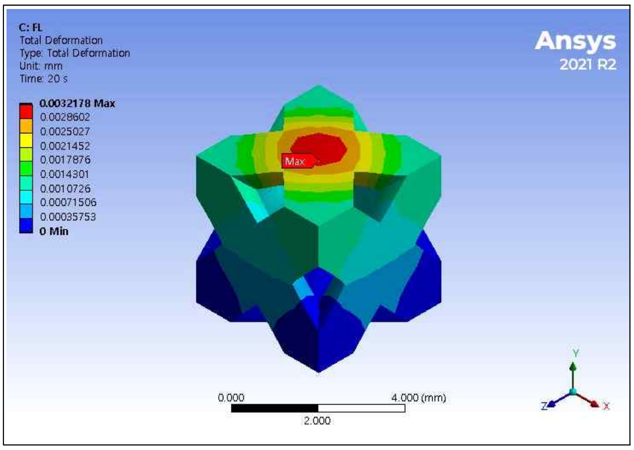
Boundary conditions and loads for three types of three-dimensional Bravais cubic lattices: primitive cubic lattice (P), body-centered cubic lattice (I), and face- centered cubic lattice (F), and results of stress, strain, and deformation analysis is shown in Fig. 1 to Fig. 3.



[Fig. 1] Stress distribution in primitive-cubic lattice



[Fig. 2] Strain distribution in a body-centered cubic lattice

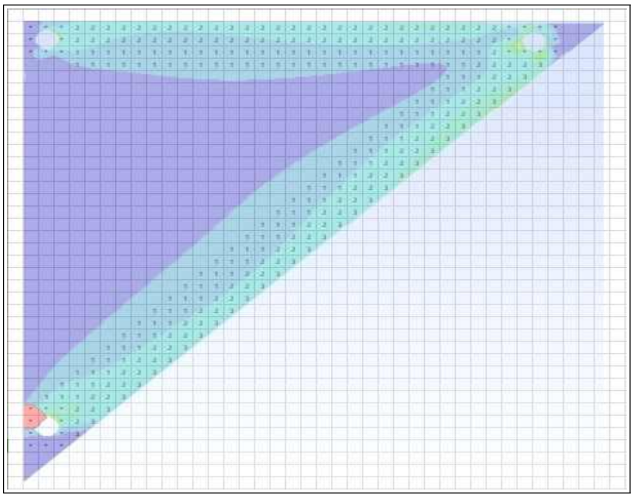


[Fig. 3] Deformation distribution of a face-centered cubic lattice

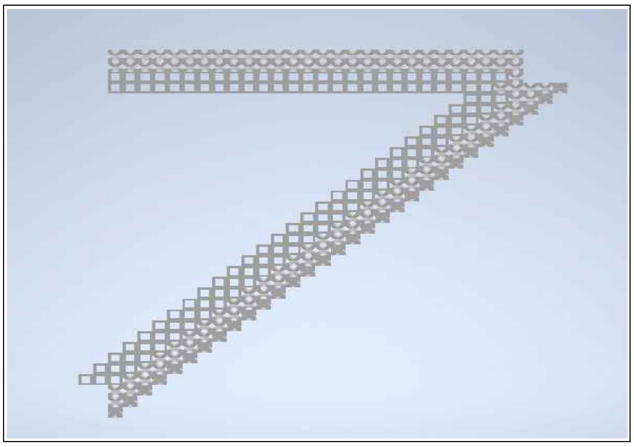
3. Topology Optimization

Based on the relative density and maximum stress and strain of the three-dimensional lattice structure P, I, F lattice, the weight for the lattice was set, and based on this, the weight of the lattice to be applied to the design shape is shown in Fig. 4. Fig. 5 and

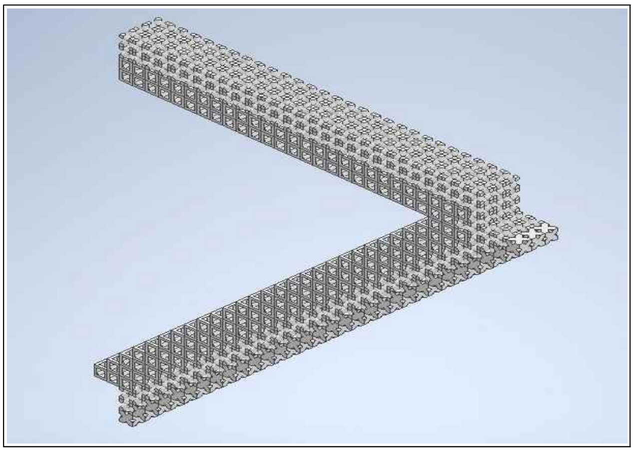
Fig. 6 show the shapes created by determining the type and position of the grid through weight calculation.



[Fig. 4] Calculation of weights to apply the lattice structure

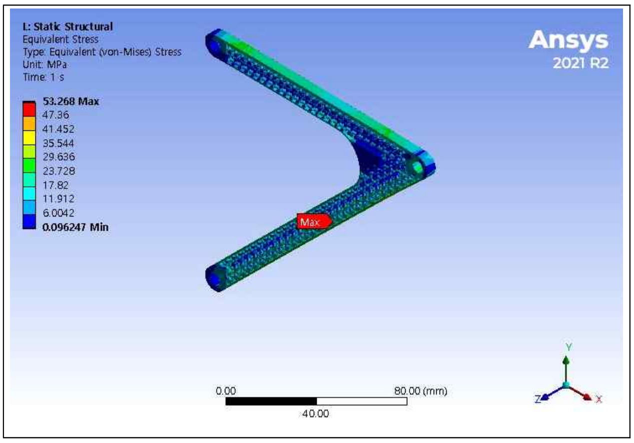


[Fig. 5] Internal lattice structure shape according to weight 1

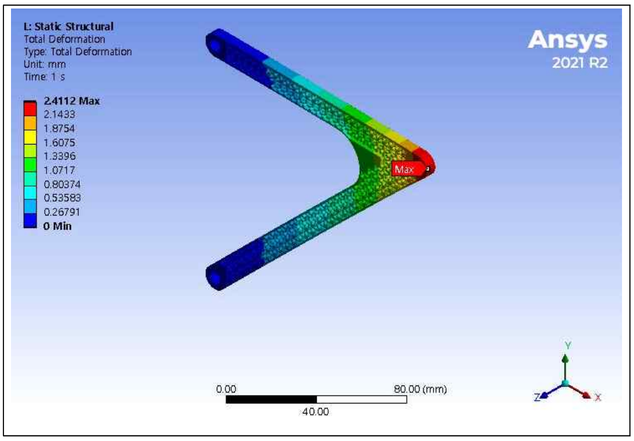


[Fig. 6] Internal lattice structure shape according to weight 2

Fig. 7 and Fig. 8 show the simulation results with the same boundary conditions and load conditions applied after properly inserting the lattice structure in the internal cavity.



[Fig. 7] Lattice structure optimization tripod stress distribution



[Fig. 8] Lattice structure optimization tripod deformation distribution

As a criterion for rigid design, the lower the mass, the higher the natural frequency, so it can be seen as a better design. Therefore, in terms of mass, the simple optimized shape has the lowest weight at 19.95 g, but it can be regarded as an incorrect design because it exhibits a stress exceeding the maximum allowable stress of the material of 52.44 MPa. Therefore, the grid-optimized shape that has the next lowest mass and does not exceed the allowable load applied with the correction factor according to the stacking direction can be evaluated as the best design.

4. Conclusion

In this paper, the topology optimization design of the 3D lattice structure according to the stacking direction was carried out. Assuming that the mechanical properties would be different depending on the shape of the 3D lattice structure, the maximum stress was different according to the stacking direction. In addition, it was able to withstand a higher maximum stress compared to the relative density in the directions other than the z-axis direction.

Also, A topology optimization design was performed by applying the characteristics of 3D lattice casting, and a processing method that can be used for additive manufacturing while reducing weight and increasing rigidity was presented.

5. Acknowledgement

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