March - April 2020
ISSN: 0193-4120 Page No. 4195 - 4201

FEM Analysis of Lattice Structures Using Parametric Modeling

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Abstract
Establishment and focus: There is a great deal of interest in additive manufacturing that is less wasteful of materials and easier to produce complex shapes. Therefore, it is easy to manufacture a light part by filling the inside of the part with a three-dimensional lattice. In this case, we will perform FEM analysis on several lattice structures filling the interior. Apply self-weight and uniform vertical stress to simple cubic lattice, body centered cubic lattice, and modified face centered cubic lattice. FEM analysis is performed to check the stress distribution and deformation amount.

System: The higher the internal filling rate, the more uneven the stress distribution and the smaller the deformation. Simple cubic lattice and centripetal cubic lattice produced different results than expected. In contrast, the modified face-centered cubic lattice resulted the best stress distribution and low deformation. It is easy to generate the lattice structure according to the change of variables through the lattice structure using parametric modeling. In addition, this study may be useful for the optimization of parts consisting of various lattice structures.

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1. Introduction

Representative methods of processing metal are subtractive manufacturing or casting. This method wastes a lot of material, and it is difficult to manufacture a light part compared to the same volume. Therefore, in recent years, the additive manufacturing with little waste of material has attracted much attention[1-3]. The cheapest and most widely used method of additive manufacturing is the FDM(Fused Deposition Modeling), and ABS(Acrylonitrile Butadiene Styrene) and PLA(Polylactic Acid) are mainly used materials[4,5]. Such additive manufacturing is advantageous for producing complex shapes over traditional machining methods[6-8]. In addition, filling the inside of the object with a lattice structure makes it easy to produce light parts with the same volume[9]. The most commonly used method of manufacturing these parts is to make a product using a certain pattern inside. Patterns used here include not only simple grid shapes, but also honeycomb shapes, which are traditionally rigid structures, and create unique physical properties[10]. However, since these shapes are two-dimensional stacked structures, it is difficult to secure similar strength along each axis direction. In this study, we performed FEM analysis on simple cubic lattice, body-centered cubic lattice, and modified face-centered cubic lattice. Ansys Workbench was used for FEM analysis and Inventor was used for lattice modeling. This study focuses on the stress distribution, stress concentration, and deformation that occur when the interior is filled with a three-dimensional lattice structure.

2. Materials and Methods

• Generate Lattice Structure

In general, the lattice structure means a unique arrangement of the atoms that make up an object. Representative lattice structures include simple cubic lattice, body-centered cubic lattice, and face-centered cubic lattice. In the lattice structure, when atoms are spherical with the same diameter, a point where each atom is in contact with each other is created. In this case, it is assumed that the atoms in each lattice are one node, and the lattice is formed by forming the struts in the form of cylinders. At this time, parametric modeling is performed in which the diameter of the strut of the lattice is d and the length of one side of the lattice is l. In this way, simple cubic lattice, body-centered cubic lattice, and face-centered cubic lattice are generated to check the stress distribution of each lattice. However, in the case of the face-centered cubic lattice, the shape is similar to that of a simple cubic lattice. Therefore, the comparison is made with the modified face-centered cubic lattice in which the nodes in the center of each face and the nodes in the center of the lattice are connected by struts.

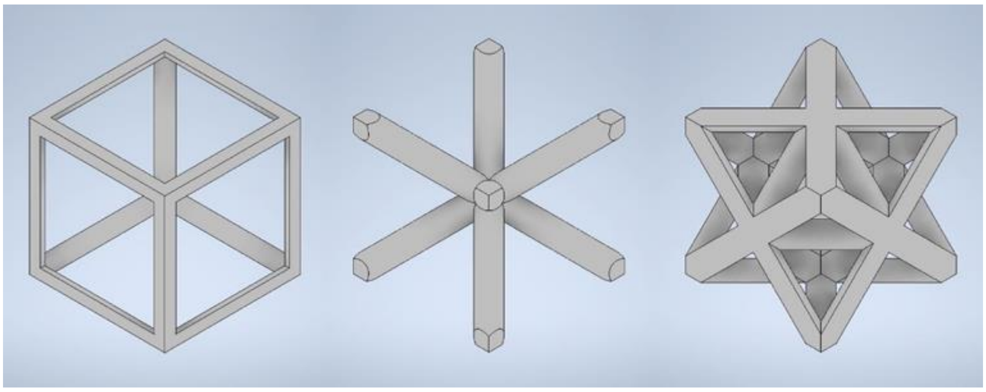

Figure 1. (a) Simple Cubic, (b) Body Centered Cubic, (c) Modified Face Centered Cubic.

As shown in Figure 1, parametric modeling was performed with the three lattices set at d=1.2mm and l=10mm. The parameters in Figure 1 are set to better illustrate the characteristics of the lattice. Actually, this study analyzed the parameters with d=2.4mm and l=10mm.

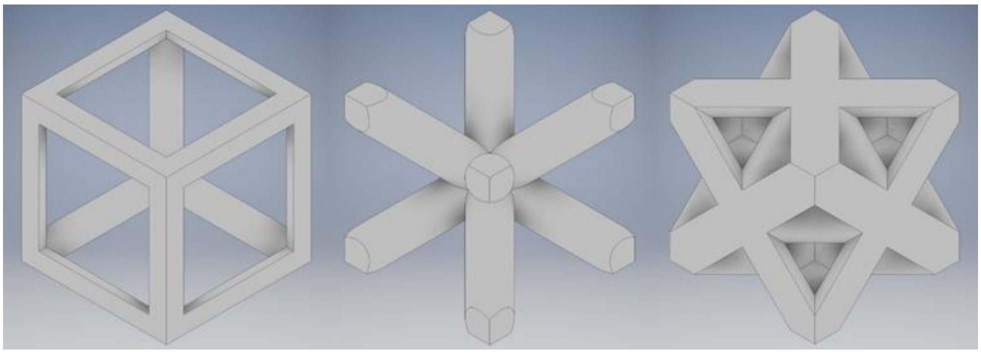

Figure 2. lattice structures with d=2.4mm and l=10mm.

Figure 2 shows lattices with d=2.4mm and l=10mm. Each lattice in Figure 2 will have a different lattice fill factor. This is shown in Table 1.

Table 1. Internal Fill Rates for Each Lattice.

Item	Filling Rates(%)	Note
Simple Cubic	11.7	Parametric Value d=2.4mm / l=10mm
Body-Centered Cubic	24.6	
Modified Face-Centered Cubic	50.0	

In order to secure the visibility of the analysis results, the modeling is composed of 1,000 units lattices consisting of 10 lattices in the same width, length, and height. This is shown in Figure 3.

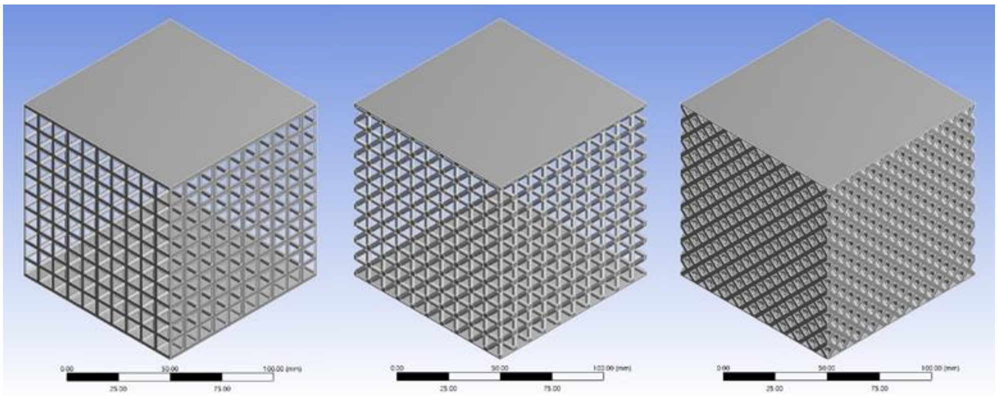

Figure 3. A lattice of 1,000 units (a) SC, (b) BCC, (c) modified FCC2.

For the lattice structures shown in Figure 3, the FEM analysis was performed under the uniform pressure by applying the self-weight. The physical properties applied in this study are those of general PLA, which are shown in Table 2.

Table 2. PLA Properties Applied to FEM Analysis.

Item	Value
Density	1240 [kg/m^3]
Young's Modulus	2824 [MPa]

• Applied Boundary and Loaded Condition.

The boundary conditions applied to perform the FEM analysis on the lattice structure are shown in Table 3 below.

March - April 2020
ISSN: 0193-4120 Page No. 4195 - 4201

Table 3. Boundary Conditions Applied to FEM Analysis

Item	Value	Note
Load (Pressure)	0.5 [MPa]	Top surface / -y direction
Fixed Support	All DOF	Bottom surface
Gravity (Self-weight)	9.81 [m/s^2]	-y direction

As shown in Table 3, the gravitational acceleration was applied to all grid structures in the -y direction. In addition, all degrees of freedom were constrained to the bottom, and a uniform pressure of 0.5 MPa was applied to the top. We want to check the stress distribution and deformation of all the lattices.

3. Results

The analysis results for each lattice to which the boundary condition is applied are shown in Figure 4 to 11. Each analysis result is a simple cubic lattice, a body-centered cubic lattice, and a modified face-centered cubic lattice in order from the left.

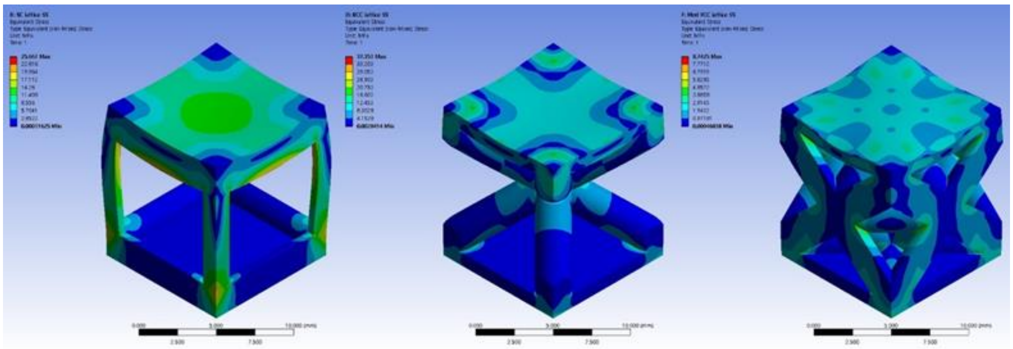

Figure 4. Stress distribution of single unit lattice.

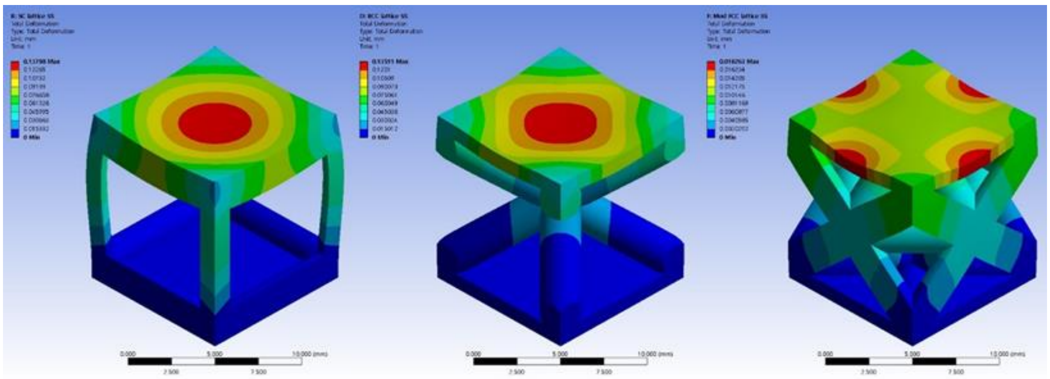

Figure 5. Deformation of single unit lattice.

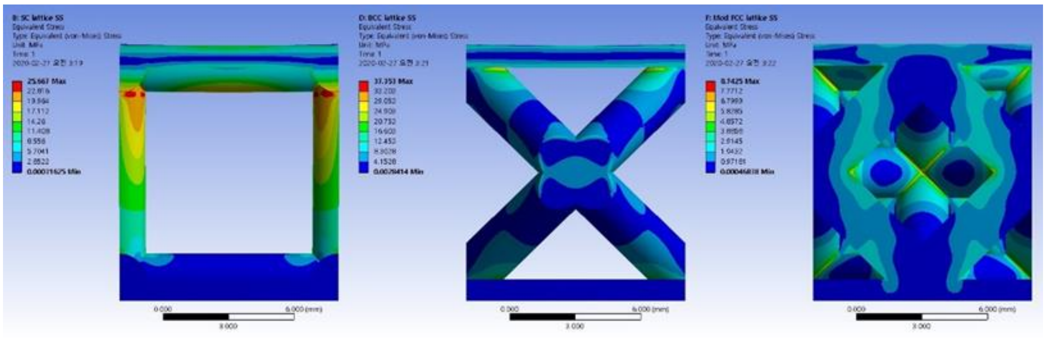

Figure 6. Stress distribution of single unit lattice in the middle plane.

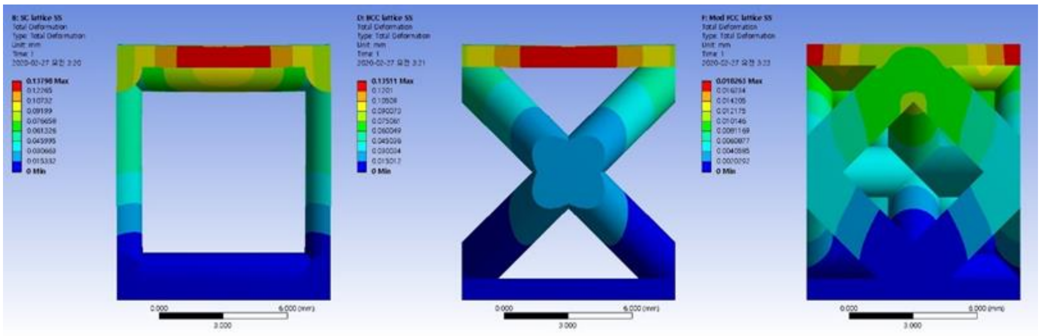

Figure 7. Deformation of single unit lattice in the middle plane.

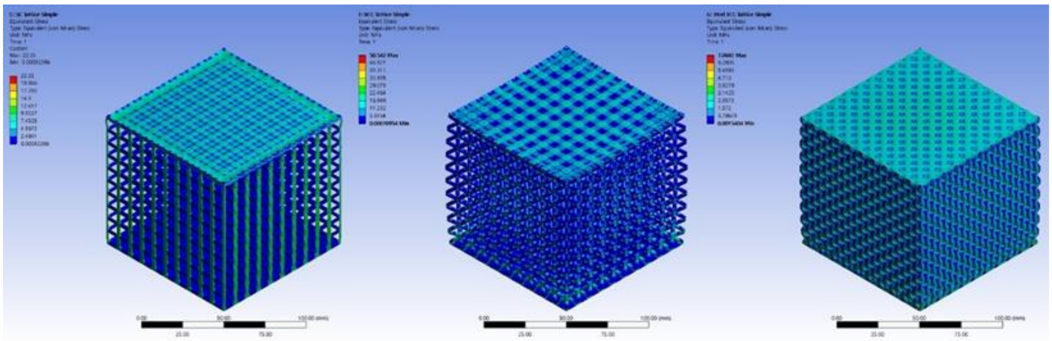

Figure 8. Stress distribution of a 1,000 units lattice.

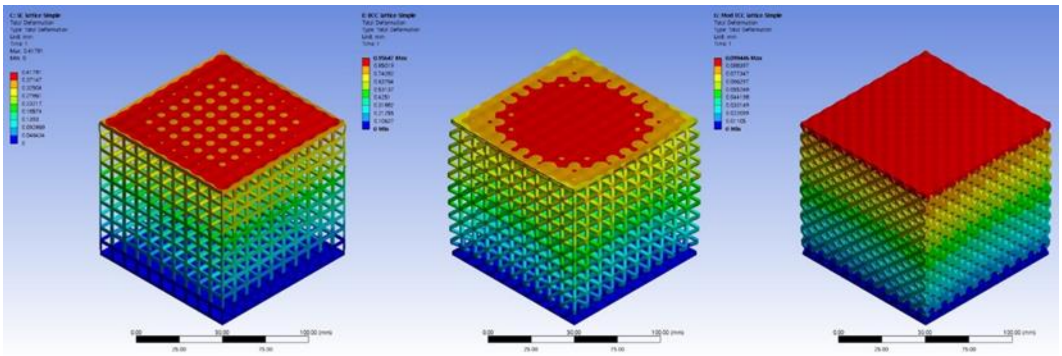

Figure 9. Deformation of 1,000 units lattice.

March - April 2020
ISSN: 0193-4120 Page No. 4195 - 4201

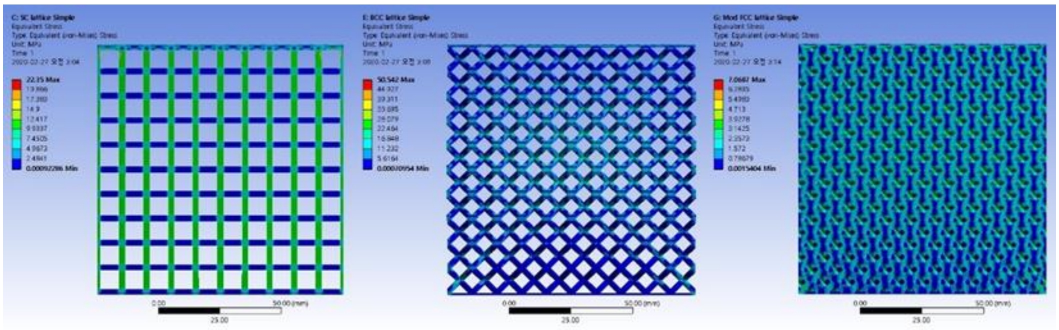

Figure 10. Stress distribution of a 1,000 units lattice in the middle plane.

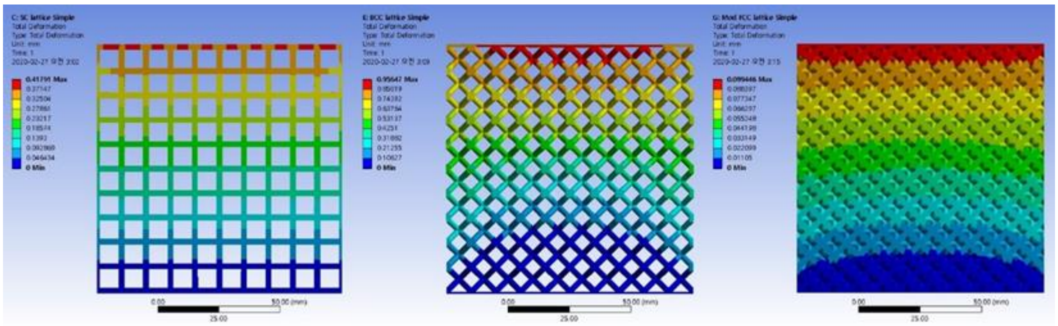

Figure 11. Deformation of 1,000 units lattice in the middle plane.

Table 4 summarizes the results from Figure 4 to 11.

Table 4. Maximum stresses and maximum strains depending on the lattice structure.

Item		Maximum Equivalent Stress [MPa]	Maximum Deformation [mm]
Single Unit Lattice	SC	25.667	0.13798
	BCC	37.353	0.13511
	Mod FCC	8.742	0.01826
1,000 Units Lattice	SC	22.350	0.41791
	BCC	50.542	0.95647
	Mod FCC	7.068	0.09945

For single unit lattice, the lattice with the highest stress concentrations in Figure 4 and 6. In addition, it can be seen that the face-centered cubic lattice having the highest filling rate disperses the stress well.

For shapes consisting of 1,000 units lattice, the highest stress concentrations occurred in the body-centered cubic lattice, as shown in Figures 8 and 10, as in the single unit lattice. It was also confirmed that the body-centered cubic lattice distributed the stress most efficiently.

4. Conclusion

As a result of FEM analysis of simple compressive stress considering self-weight, it was confirmed that the lattice structure showing the best results in stress distribution and strain was the modified face-centered cubic lattice. In the case of body-centered cubic lattice, the stress concentration caused higher stress than other lattice, and also showed high value in the amount of deformation. This showed similar stress distributions and strains in the shape of 1,000

March - April 2020
ISSN: 0193-4120 Page No. 4195 - 4201

units lattice However, when comparing the stress distributions between the simple cubic lattice and the body-centered cubic lattice, only the struts in the direction consistent with the stress applied in the simple cubic lattice were loaded. For the body-centered cubic lattice, it showed a uniform deformation in the vertical and horizontal direction with respect to the applied stress. This resulted in the better mechanical performance of the simple cubic lattice than the body-centered cubic lattice, contrary to the expectation that higher fill rates would result in even stress distribution and low strain. In contrast, the modified face-centered cubic lattice showed much better mechanical performance than the other lattice, and the stress distribution and strain were relatively even.

Based on the results of this study, compression and other tests will be performed by printing each lattice using a 3D printer. Based on this, we will study the change and regularity of maximum allowable stress and modulus of elasticity in the same volume according to parameter and lattice structure. In addition, only the PLA properties were used in this study, but other materials will be tested.

Since this study generated the geometry by the parameter modeling, it can be applied to the analysis by modifying the lattice shape conveniently in the optimization study for the products produced by filling the inside with the lattice structure.

5. Acknowledgment

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