HİBRİT HÜCRELERE SAHİP KAFES YAPILARIN EKLEMELİ İMALAT İLE ÜRETİLEBİLİRLİĞİNİN ARAŞTIRILMASI

INVESTIGATION OF ADDITIVE MANUFACTURING OF LATTICE STRUCTURES WITH HYBRID UNIT CELL

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ÖZET

Eklemeli imalat 3 boyutlu (3B) modellerden nihai ürün elde edilmesinde kullanılan nispeten yeni bir teknoloji olarak karşımıza çıkmaktadır. Metal eklemeli imalat metodları bu tür karmaşık geometrilerden olan kafes yapıların üretimine de olanak sağlamaktadır. Bu yapılar dikmelerin veya plakaların biraraya gelmesiyle oluşan birim hücrelerin belli bir düzende bir araya gelmesiyle elde edilmektedir. Kafes yapılar morfolojisine göre dikme tabanlı ve yüzey tabanlı olarak ikiye ayrılmaktadır. Bu çalışma kapsamında dikme tabanlı olan hacim merkezli kübik (HMK), yüzey merkezli kübik (YMK) ve bu iki hücrenin birleşiminden meydana gelen hibrit hacim yüzey merkezli kübik (HYMK) birim hücre yapılarından meydana kafes yapılar kullanılmıştır. 3 farklı birim hücre ardından bu birim hücrelerin oluşturduğu kafes yapılar Solidworks yazılımı kullanılarak 3B olarak tasarlanmıştır. Tasarlanan modellerden elektron ışını ile ergitme yöntemiyle Ti6Al4V tozu kullanılarak numuneler üretilmiştir. Numunelerin üretim sonrası geometrilerinin tasarımla olan farklılıklarının ortaya konulması için Arşimet yöntemiyle numunelerin hacimsel boşluk oranları ölçülmüştür. Ayrıca tüm numuneler stereo mikroskopta incelenerek üretim sonrası kolonlardaki kalınlaşmalar ve ergimemiş tozların varlığı incelenmiştir. Arşimet yöntemiyle elde edilen sonuçlara göre tasarım ile üretim hacimsel boşluk oranlarındaki sapmanın en fazla HYMK hibrit birim hücre yapısında, sonrasında YMK ve en az ise HMK birim hücre yapısında meydana geldiği görülmüştür. Hücrelerin hacimsel doluluk oranı arttıkça tasarım ile üretim arasındaki hacimsel boşluk oranlarındaki sapmanın da arttığı görülmüştür. Stereo mikroskop incelemeleri sonucunda birim hücreleri oluşturan dikmelerde kalınlaşmalar oluştuğu ve numunelerin içerisinde sinterlenmiş fakat ergimemiş tozların mevcut olduğu görülmüştür. Bu durumun numunelerin üretim sonrası hacimsel boşluk oranının tasarıma oranla az olmasının temel sebepleri olduğu görülmüştür. Ayrıca numunelerdeki dikme sayısı arttıkça kolonlardaki kalınlaşma ve ergimemiş tozların varlıuğına bağlı olarak tasarım ile üretim sonrası hacimsel boşluk oranları arasındaki sapmanın daha da arttığı sonucuna varılmıştır. Bu çalışmanın, hibrit hücrelere sahip kafes yapıların tek tip hücre içeren kafes yapılara göre üretim sonrası geometrik davranış farklılıklarının inceleneceği çalışmalar için iyi bir kaynak oluşturacağı düşünülmektedir.

Anahtar Kelimeler: Eklemeli İmalat, Elektron Işını ile Ergitme, Kafes Yapı, Hibrit Birim Hücre, Ti6Al4V.

ABSTRACT

Additive manufacturing is a relatively new technology used to manufacture final products from 3 dimensional (3D) models. Metal additive manufacturing methods also allow the manufacturing of lattice structures from such complex geometries. Lattice structures are obtained by combining the unit cells, which are formed by the combination of struts or plates, in a certain pattern. These structures are divided into two as strut-based and surface-based according to their morphology. In the scope of this study,

lattice structures consisting of strut-based body-centered cubic (BCC), face-centered cubic (FCC) and hybrid body face-centered cubic (BFCC) unit cell structures formed by the combination of these two cells were used. 3 different type of unit cells and lattice structures were designed as 3D models using Solidworks software. The samples were manufactured by electron beam melting method using Ti6Al4V powder from designed models. In order to reveal the differences between the manufactured sample geometries and design, the porosity of the samples were measured by the Archimedes method. In addition, all samples were examined under a stereo microscope and the thickenings in the columns were examined after manufacturing. According to the results obtained by the Archimedes method, it was observed that the deviation in the design and manufacturing highest porosity occurred in the BFCC hybrid unit cell structure, followed by the FCC unit cell structure and the least in the BCC unit cell structure. It was observed that as the occupancy rate of the unit cells increased, the deviation in the porosity between design and production also increased. As a result of stereo microscope examinations, it was observed that thickenings occurred in the struts forming the unit cells. Also, it has been observed that this is the reason why the porosities of the samples after manufacturing is less than design. In addition, it was concluded that as the number of struts in the samples increased, the thickening in the struts further increased the deviation in the porosities between design and manufactured samples. This study will be a good source for studies that will examine the post-production geometric behaviour differences of lattice structures with hybrid unit cells compared to containing single-type cells.

Keywords: Additive Manufacturing, Electron Beam Melting, Lattice Structure, Hybrid Unit Cell, Ti6Al4V.

1. INTRODUCTION

Additive manufacturing is a production method in which a large number of final products are manufactured using less material and energy to achieve the desired mechanical properties. This method is preferred in the manufacturing of many geometries and structures that are limited in manufacturing with traditional manufacturing methods. Additive manufacturing is based on the principle of manufacturing of the designed 3D model by creating layer by layer. In addition, additive manufacturing allows the manufacturing of parts without the need for any molds and tools unlike traditional manufacturing methods. This new generation manufacturing technology is used in many sectors such as space, aviation, automotive and biomedical. Additive manufacturing technology, which allows complex geometries to be produced with good precision and significantly reduces material consumption, can be adapted to a large number of materials. The additive manufacturing method in which metal alloys such as aluminum, titanium, stainless steel and nickel alloys are used is defined as metal additive manufacturing. One of the complex structures that can be manufactured by utilizing the geometric adaptability of metal additive manufacturing is lattice structures. Lattice structures are morphologically divided into strut-based and surface-based [1-3]. These struts and surfaces come together in a certain pattern to form unit cells and unit cells come together to form lattice structures. Also, lattice structures are distinguished from other geometries with their excellent strength, energy absorption, thermal insulation and light weight properties [5]. These structures are divided into two as strut-based and surface-based according to their morphology. When the studies in the literature were examined, it was seen that the hybrid cell structure of BCC, FCC and BFCC was studied by selective laser melting method and using AlSi10Mg powder. However, no study has been found in the literature to compare these geometries, using the Electron Beam Melting method and Ti6Al4V alloy powder, which is widely used in additive manufacturing, and comparing the porosities [6]. In the scope of this study, lattice structures consisting of strut-based body-centered cubic (BCC), face-centered cubic (FCC) and hybrid body face-centered cubic (BFCC) unit cell structures formed by the combination of these two cells were used in order to reveal the differences between the manufactured sample geometries and designed models [3-4].Besides, porosity of the samples were measured in order to reveal porosity differences between hybrid unit cells and 2 type of cells that form the hybrid unit cell. These 3 different type of unit cells and lattice structures were designed as 3D models using Solidworks software. The samples were manufactured by electron beam melting method using Ti6Al4V powder from designed models. The

porosity of the samples were measured by the Archimedes method. In addition, all samples were examined under a stereo microscope and the thickenings in the columns after manufacturing were examined.

2. MATERIAL AND METHOD

2.1. Design of Unit Cells and Lattice Structures

In the scope of this study, lattice structures consisting of strut-based body-centered cubic (BCC), face-centered cubic (FCC) and hybrid body face-centered cubic (BFCC) unit cell structures formed by the combination of these two cells were used [3-4]. 3 different type of unit cells and lattice structures were designed as 3D models using Solidworks software.

2.1.1. Design of unit cells

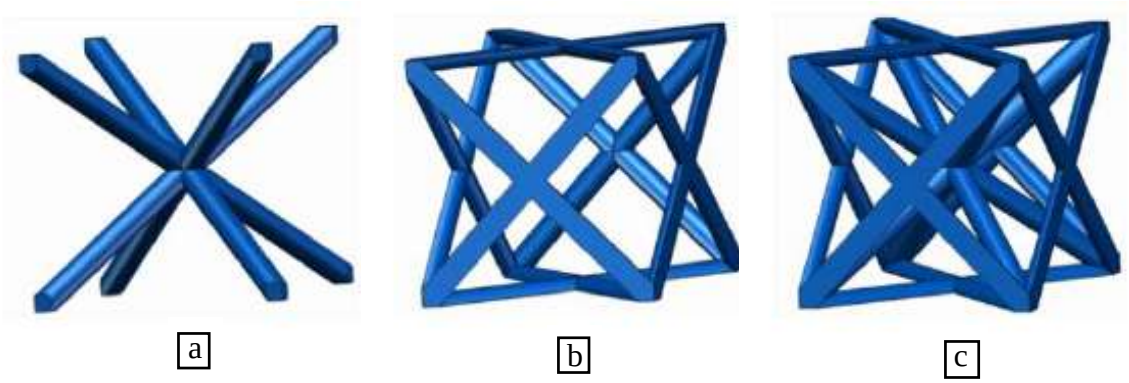


Figure 2.1. Image of lattice structures that designed in Solidworks software
a) BCC, b) FCC and c) BFCC unit cell [6]

2.1.2. Design of lattice structures

After the cells were designed, the cells were brought together in a certain order and lattice structures were designed.

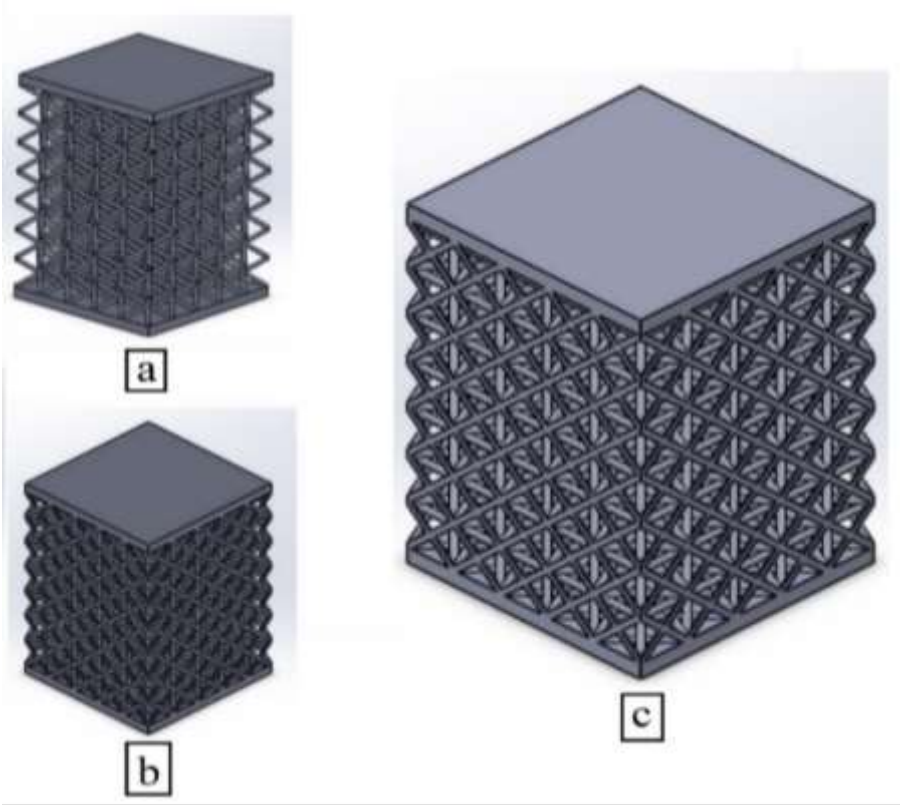


Figure 2.2. Image of lattice structures that designed in Solidworks software a) BCC, b) FCC and c) BFCC lattice structure

2.2. Production of Samples

2.2.1. Pre-production preparations

After the designs of the samples were completed in Solidworks software, the designs were saved in STL format. The designs in this format were transferred to the Materialise Magics software. Support structures have been added to the bottom of the designs so that the produced samples can be easily separated from the table.

2.2.2. Production of samples by additive manufacturing

The designed samples were produced by using Ti6Al4V alloy powder with electron beam melting in Additive Manufacturing Technologies Application and Research Center of Gazi University (EKTAM).



Figure 2.3. Arcam A2X Electron Beam Melting Machine

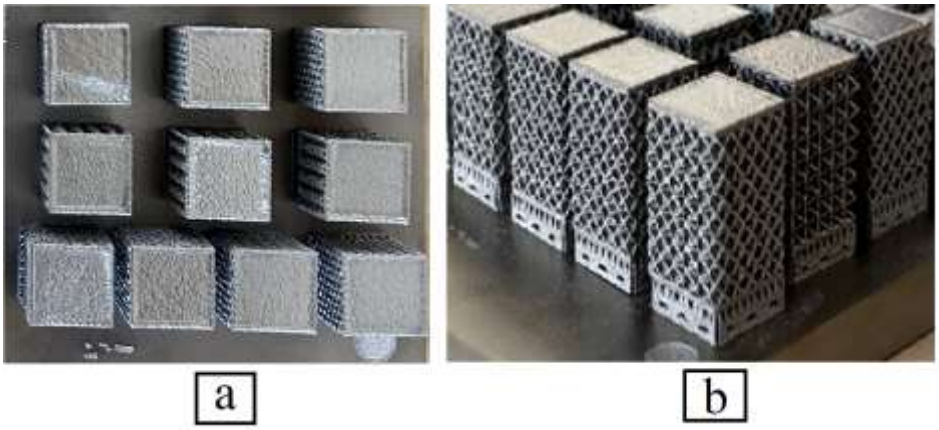


Figure 2.4. Manufactured Samples, a) top view, b) side view of samples

2.3. Determination of Porosity with Archimedes Method

Archimedes' principle is a method used to measure the density of particles. While the reference fluid used in this method is air, the second fluid can be selected as pure water, acetone and ethanol [7]. In this study pure water was used for density measurement. The weights of the samples in air and water were measured for Archimedes method with a Shimadzu brand and AUW320 model device located in the Powder Metallurgy Laboratory of Faculty of Engineering of Gazi University.



Fig. 2.5. Measurements of weight of the samples in air and water

After these measurements, densities of the samples were calculated using the equation 1.

$$\rho = \frac{W_a}{W_a - W_l}\rho_l \qquad (1)$$

W_a in the equation is the weight of the samples in air, W_l in water; ρ is the density of the samples and ρ_l is the density of the pure water. After calculation of densities, the porosity of the specimens were calculated by subtracting the manufactured volume of the specimen from the total volume of the specimen including the porosities. Then these porosity values were compared with the design porosity values obtained from Materialise Magics software.

2.4. Microstructure Examination of Samples in Stereo Microscope

Microstructure of the samples were examined with Nikon brand and SMZ745T model stereo microscope in order to see the thickenings in the columns after production.



Figure 2.6. Nikon SMZ745T stereo microscope

3. RESULTS AND DISCUSSION

According to the results that seen in Table 3.1 obtained by the Archimedes method. It was observed that the deviation in the design and manufactured samples porosity occurred mostly in the BFCC hybrid unit cell structure, followed by the FCC unit cell structure and the least in the BCC unit cell structure. It was observed that as the porosity of the cells increased, the deviation in the porosity between design and manufactured samples also increased.

Table 3.1. Porosities and deviations between samples according to Archimedes method and the design

Sample Name	Porosity(%)		Design-Archimedes Deviation (%)
	Design	Archimedes	
BCC 1	83,554087	77,238155561	-7,56
BCC 2	83,554087	76,481219948	-8,47
BCC 3	83,554087	76,976460570	-7,87
FCC 1	81,992502	70,743516764	-13,72
FCC 2	81,992502	68,353913982	-16,63
FCC 3	81,992502	68,711286653	-16,20
BFCC 1	75,353043	59,504849155	-21,03
BFCC 2	75,353043	59,498715701	-21,04
BFCC 3	75,353043	59,565024480	-20,95

It is seen that there is a similarity between the data obtained by the design and Archimedes method in terms of geometries as seen in Figure 3.1. In other words, in the datas obtained by both design and Archimedes method, it was seen that lattice structures with BCC unit cell structure had the highest porosity, while lattice structures with BFCC hybrid unit cell structure had the least porosity.

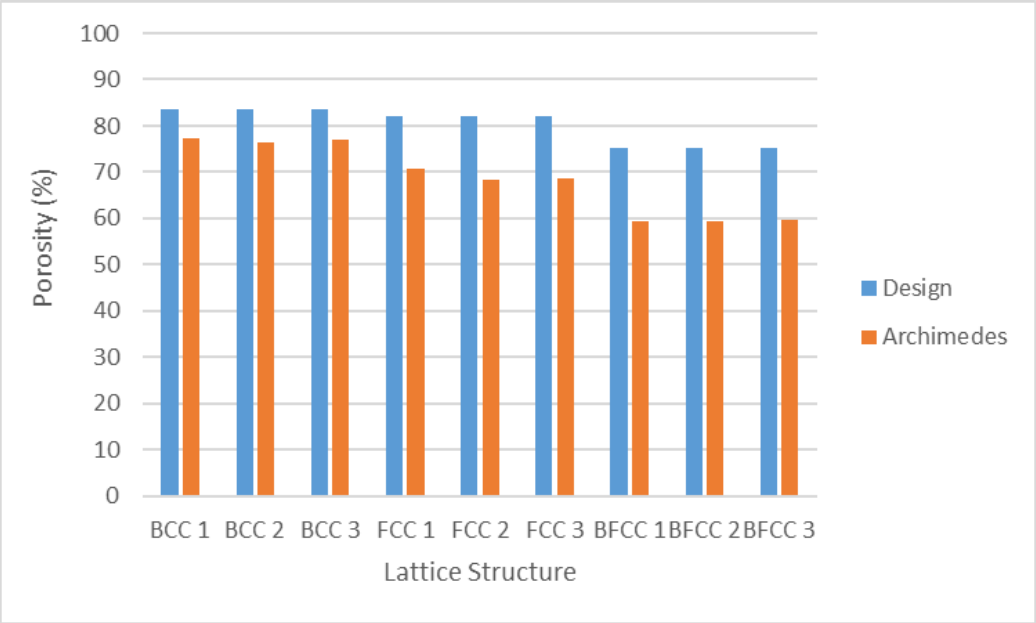


Figure 3.1. Graphical representation of porosity percentage obtained by design and archimedes method

As seen in Figure 3.2, thickenings can be observed in the struts forming the unit cells. It has been also observed that this is the main reason for the porosity of the samples after production to be less than the design porosity. In addition, it was concluded that as the number of strut in the samples increased, the deviation between the design and porosity of the samples after production increased due to the thickening in the columns.



Figure 3.2. Microstructure examination image taken from stereo microscope

4. CONCLUSION

Within the scope of the study, the lattice structures formed by the combination of BCC, FCC and hybrid BFCC cell structures were produced using Ti6Al4V powder by Electron Beam Melting method. First of all, the design porosities was obtained from the software in order to determine the changes that occurred after the production. Then it was compared and evaluated with the porosities by measuring porosities with Archimedes method. It has been observed that the formation of thickenings in the struts forming the unit cells during the production caused the porosity of the samples after production to be less than the porosity of design. In addition, it was concluded that as the number of struts in the samples increased, the deviation between the porosity of design and the porosity after production increased.

5. RECOMMENDATION

The lattice structures with hybrid cells produced by Electron Beam Melting method and Ti6Al4V alloy can be used on structural parts to examine their mechanical behavior. In addition, the lattice type with hybrid cells can be produced using different additive manufacturing methods and materials.

6. ACKNOWLEDGEMENT

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7. REFERENCES

[1] Wu, Y., Fang, J., Wu, C., Li, C., Sun, G., Li, Q. (2023). Additively Manufactured Materials and Structures: A State-of-the-Art Review on Their Mechanical Characteristics and Energy Absorption. International Journal of Mechanical Sciences. 246, 108102.

[2] Murugan, P. D., Vijayananth, S., Natarajan, M. P., Jayabalakrishnan, D., Arul, K., Jayaseelan, V., Elanchezhian, J. (2022). A Current State of Metal Additive Manufacturing Methods: A Review. Materials Today: Proceedings. 59, 1277-1283.

[3] Tyagi, S. A., M, M. (2023). Additive Manufacturing of Titanium-Based Lattice Strcutures for Medical Applications – A Review. Bioprinting. 30, e00267.

[4] Sos, M., Meyer, G., Durst, K., Mittelstedt, C., Bruder, E. (2023). Microstructure and Mechanical Properties of Additively Manufactured AlSi10Mg Lattice Structures from Single Contour Exposure. Materials & Design. 227, 111796.

[5] Yin, H., Zhang W., Zhu, L., Meng, F., Liu, J., Wen, G. (2023), Review on Lattice Structures for Energy Absorption Properties. Composite Structures. 304, 116397.

[6] Lei, H., Li, C., Zhang, X.,Wang, P., Zhou, H., Zhao, Z., Fang, D. (2020). Deformation Behavior of Heterogeneous Multi-Morphology Lattice Core Hybrid Structures. Additive Manufacturing.

[7] Arvieu, C., Galy, C., Guen, E. L., Lacoste, E. (2020). Relative Density of SLM-Produced Aluminum Alloy Parts: Interpretation of Results. Journal of Manufacturing and Materials Processing. 19.