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THE IMPORTANCE OF OPTIMIZATION OF LATTICE STRUCTURES FOR BIOMEDICAL APPLICATIONS

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ABSTRACT: The paper describes the importance of optimization of lattice structures intended to be used in medical applications. Additive manufacturing process gains an important place in the medical industry due to the ability to obtain complex geometries, lattice structures impossible to be achieved using conventional technologies. Developed as a new type of lightweight material, and inspired by natural cellular materials, lattice structures thanks to the possibility of obtaining characteristics as close as possible to bone characteristics, are successfully used in the medical field. In this paper, three types of lattice structures with two different porosity were designed and fabricated using selective laser melting and were investigated for optimization. Thus, the aim of this paper is to provide information on the optimization of lattice structures intended to be integrated into medical devices, in order to improve their use in the medical field.

KEYWORDS: optimization, lattice structures, medical application**,** additive manufacturing**,** strut size

1. INTRODUCTION

In the medical field, as compared to other conventional techniques, additive manufacturing techniques are favorable because of their capability to obtain an implant according to the patient's data [1].

Additive manufacturing, thanks to its free-form capability, enables the easy manufacture of the lattice structures [2].

Lattice structures are developed as a new type of lightweight, inspired by nature, material - such as the trabecular bone or the structure of wood. The subject has attracted significant attention due to its greatest benefits such as high strength and low mass property. These structures are a proper solution due to the lightweight and good mechanical properties, so they can be used to achieve excellent performance and multi-functionality while reducing weight [3].

Thanks to their porous architecture, lattice structures make possible tissue growth and implant fixation, providing suitable mechanical properties for the implantation, while remaining lightweight. So, in medical implantation, lattice structures are one promising approach, facilitate osseointegration and great support under loading conditions [3,4].

Lattice structures attracted significant interest in medical implantation because of their benefit of diminishing the stiffness of the metallic material used in implants, due to the fact that the bone can be resorbed, so the phenomenon of implant loss occurs if the stiffness of the implant is higher than that of the bone. Therefore, lattice structures help to prevent stress-shielding problems. Stress shielding can affect bone remodeling and normal healing processes since under-loaded bone will adapt to the low-stress environment and become more porous and weaker [5].

In implantation, the importance comes from the fact that the bone grows into lattice structures and enhances the fixation of the implant to the host bone, leading to better osseointegration [5].

This type of materials can be low density while having properties such as high mechanical strength and stiffness. For certain applications where a high surface area to volume ratio is important, only porous structures can satisfy the requirements.

Starting from the fact that for biomedical applications, porosity and pores size have a direct influence on their functionalities, our paper focuses on designing and manufacturing different lattice structures with different porosity.

Lattice structures provide a lot of benefits in the medical field: they mimic the bone properties in order to avoid stress-shielding, have excellent performance and multi-functionality while reducing weight, so this paper focuses on the method to design lattice structures in CAD tools and on manufacturing them using selective laser melting technologies, optimizing porosity for medical applications. [6].

The principal aim of this paper is to facilitate and improve the understanding and the importance of optimization of lattice structures for medical applications.

2. EXPERIMENTAL DETAILS

2.1 Materials

In order to optimize lattice structures intended to be used in medical application, three different types of lattice structures with three different unit cell sizes and two different porosities (different strut sizes) were designed, analyzed by the finite element method (FEA) and fabricated using selective laser melting process. [7] They were designed octet-truss, rhombic dodecahedron and diamond structures samples with unit cell sizes of 3x3x2; 3x3x3 and 3x3x4 and with two different strut sizes each structure namely: 0,36 mm and 0,5 mm. All these lattice structures have been processed from CoCr powder. For the manufacture of lattice structures was used the selective laser melting EOSINT M270 Machine.

2.2 Method

Initially, in order to achieve the optimization of the lattice structures, the paper presents a method to design the lattice structures, which consists of designing three different types of structures and modifying the unit cell and the strut size. Lattice structure design strategy helps understanding in what manner the structure's unit is duplicated, the effect the strut size has and the influence of unit cell sizes.

Three different lattice structures were designed in the CAD software SolidWorks, starting with the unit cell. Finite Element Analysis tool was used to observe in what way the elasticity is influenced by adjustments of the porosity, by variation of the strut size. [8]

All lattice structures were manufactured by SLM on EOSINT M270 Machine, with a layer thickness of 0.02 mm.

3. RESULTS AND DISCUSSION

3.1 Design and FEA analysis of lattice structures

This study started with the design strategy to multiply the unit cell to obtain lattice structures presented in the next figure (Figure 1).

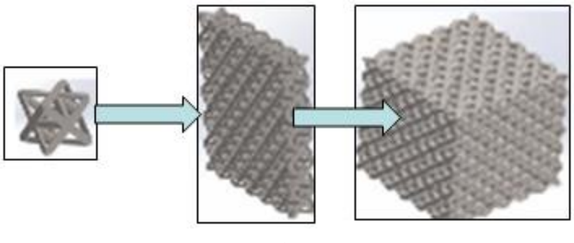


Figure 1. Thee strategy of multiplying the unit cell

Considering that for lattice structures included in medical devices, the porosity and the pore size have a direct influence on the functionality, three types of lattice units, with two different strut sizes of 0,36 and 0,5 mm, were designed, as shown in the next figures (Figure 2, Figure 3 and Figure 4).

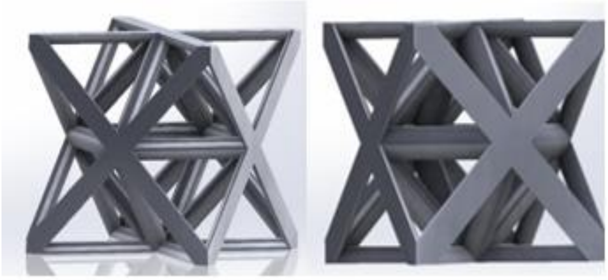


Figure 2. Octet-truss structure unit of 0,36 mm and 0,5 mm strut size

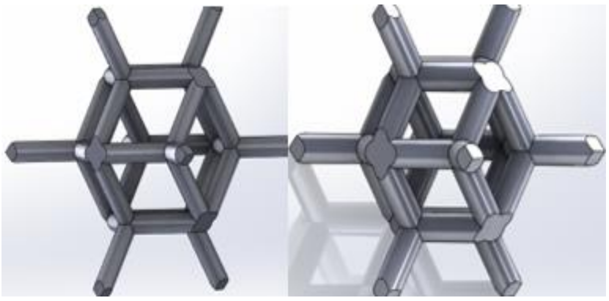


Figure 3. Diamond structure unit of 0,36mm and 0,5 mm

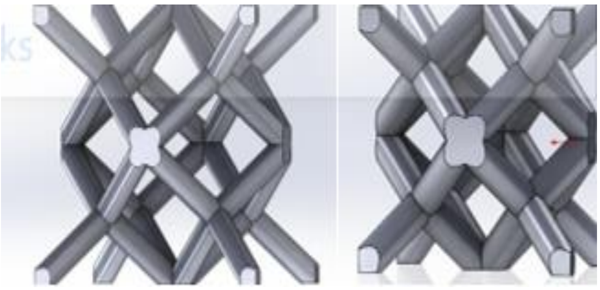


Figure 4. Rhombic Lattice structure unit of 0,36mm and 0,5 mm strut size

Starting from the unit cell and using the described strategy, there were designed samples with units of 3x3x2, 3x3x3 and 3x3x4 for all three structures type cases as shown in Figure 5, Figure 6 and Figure 7.

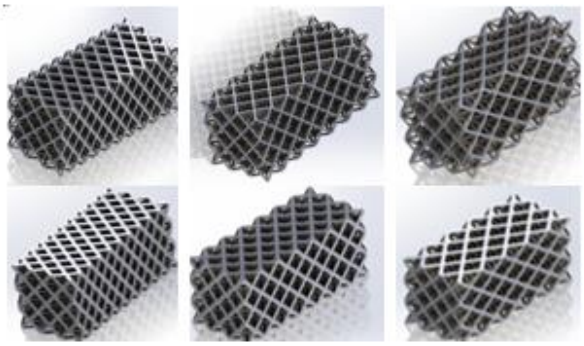


Figure 5. Octet-truss structure with unit of 3x3xx2, 3x3x3 and 3x3x4 and 0,36 (first line) and 0,5 mm strut size (second line)

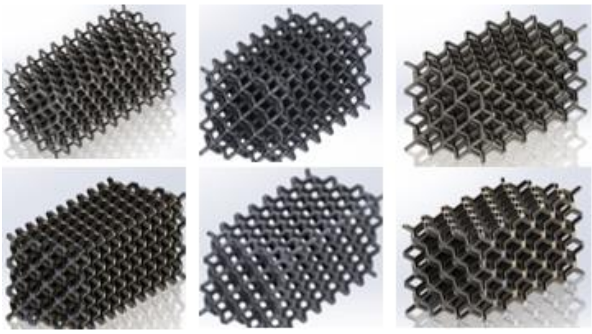


Figure 6. Diamond structure with unit of 3x3xx2, 3x3x3 and 3x3x4 and 0,36mm (first line) and 0,5 mm strut size (second line)

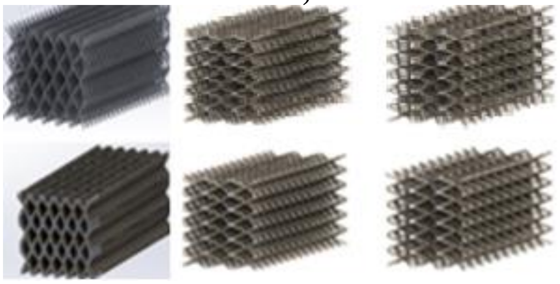


Figure 7. Rhombic Lattice structure unit of 3x3xx2, 3x3x3 and 3x3x4 and 0,36 mm and 0,5 mm strut size

All lattices structures were investigated using Finite Element Analysis (FEA). By using this analyzing method can be achieved the purpose of the paper: investigating how porosity and design influence the compression results. The results of the compression test in Solidworks will be presented below (Table 1, Table 2, Table 3).

Table 1. Octet-truss structure with the unit of 3x3x2, 3x3x3 and 3x3x4, the strut size of 0,36 mm and 0,5 mm

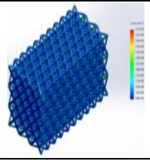
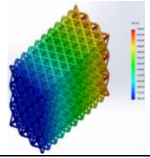
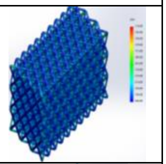
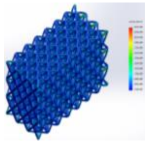
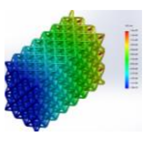
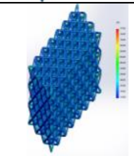
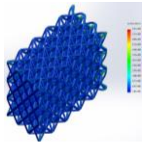
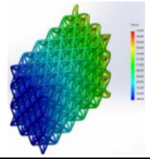
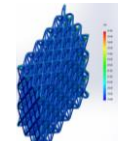
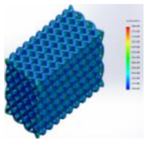
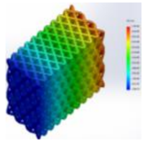
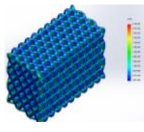
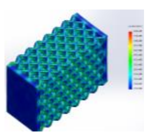
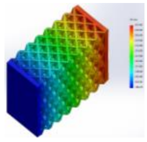
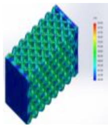
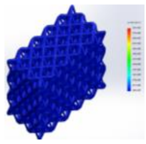
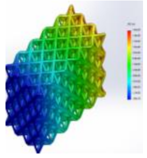
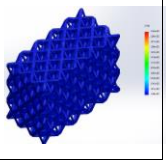
Structure characteristic		**Compression results**		
Strut size	Unit dimension	**von Mises Stress**	**Displacement**	**Strain-Strain1**
0,36	3x3x2			
	3x3x3			
	3x3x4			
0,5	3x3x2			
	3x3x3			
	3x3x4			

Table 2. Diamond structure with the unit of 3x3x2, 3x3x3, 3x3x4 and 0,36mm and 0,5 mm strut size

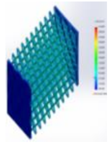
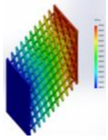
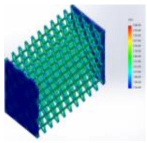
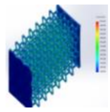
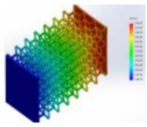
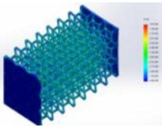
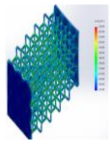
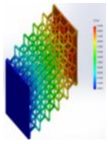
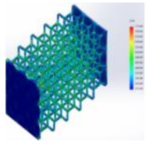
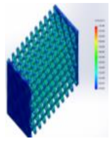
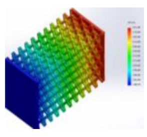
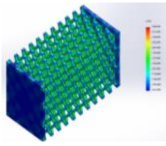
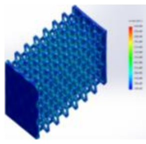
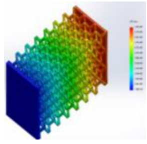
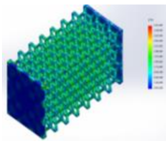
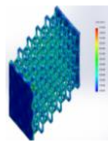
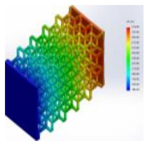
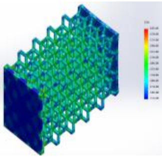
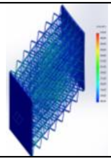
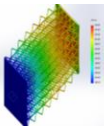
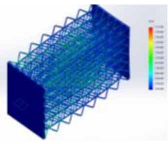
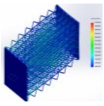
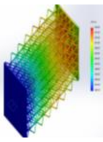
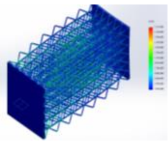
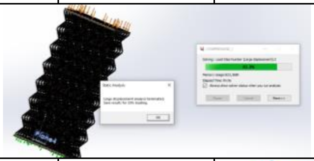
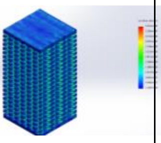
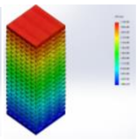
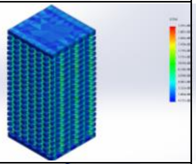
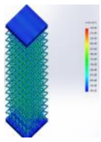
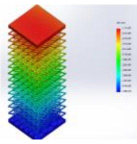
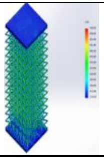
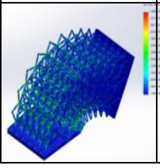
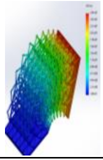
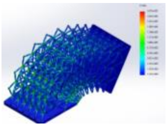
Structure characteristic		**Compression results**		
Strut size	Unit dimension	**von Mises Stress**	**Displacement**	**Strain-Strain1**
0,36	3x3x2			
	3x3x3			
	3x3x4			
0,5	3x3x2			
	3x3x3			
	3x3x4			

Table 3. Rhombic structure with the unit of 3x3x2, 3x3x3 and 3x3x4 and 0,36 mm and 0,5 mm strut size

Structure characteristic		**Compression results**		
Strut size	Unit dimension	**von Mises Stress**	**Displacement**	**Strain-Strain1**

Structure characteristic		Compression results		
0,36	3x3x2			
	3x3x3			
	3x3x4			
0,5	3x3x2			
	3x3x3			
	3x3x4			

The simulation of compression was used to observe the lattice structures properties and to analyze how modification in strut size and porosity influences the elasticity. In FEA, the same loading condition was maintained with a 2400N load value.

3.2 Selective Laser Melting (SLM) of lattice structures

After design and FEA analyses, the lattices structures were manufactured by SLM on EOSINT M270 machine, with a layer hatching thickness of 0.02 mm.

The selective laser melting Machine and cobalt-chrome powder are presented below (Figure 8).

Figure 8 - EOSINT M270 Dual Mode Machine owned by INCDMTM

The lattice structures are manufactured separately in two successful jobs.

In the first job, there were manufactured octet, rhombic and diamond (as in build plate) all with the unit cell of 3x3x2 and the strut size of 0,5 mm.

For SLM medical devices, the most important process steps are design, data preparation & software workflow for additive manufacturing, building, post-processing and final testing considerations. The process for producing lattice structures is detailed in the next figure (figure 9).

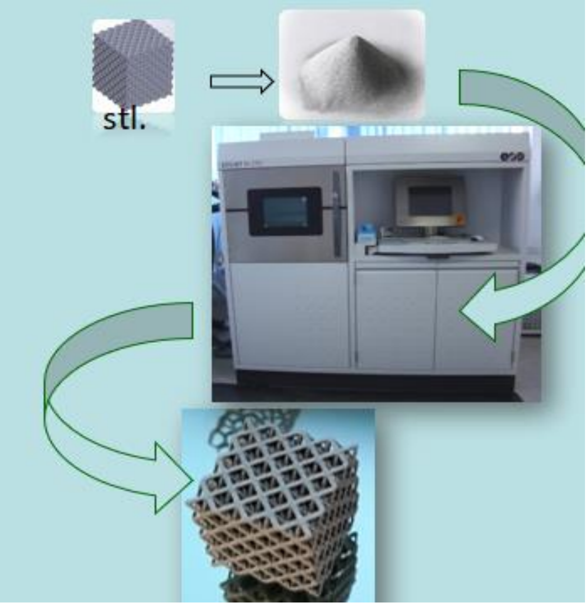


Figure 9. The additive manufacturing process to obtain lattice structures

In the next figures (Figure 10-12) are presented the lattice structures after the process is finished and the process of removing the powder.

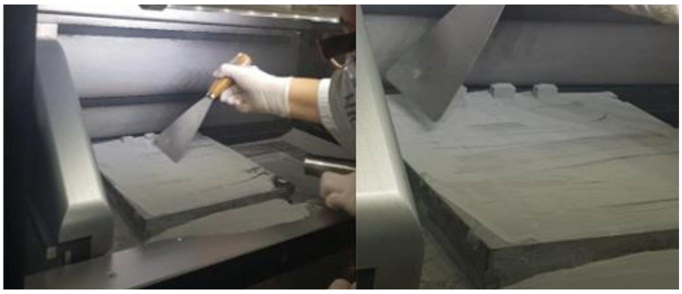


Figure 10. The build plate after job finished

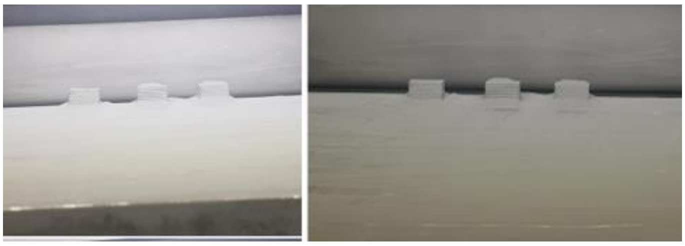


Figure 11. The lattice structures on building plate

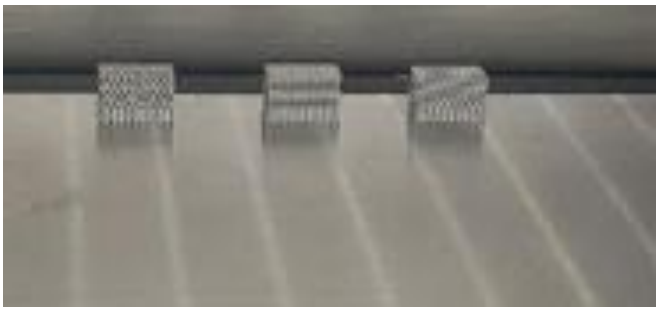


Figure 12. The lattice structures (1st job) on the building plate after removing the powder

In the second job, there were manufactured the diamond, rhomb and octet lattice structures with the unit cell of 3x3x4 and the strut size of 0,5mm. These are presented in Figures 13-15.

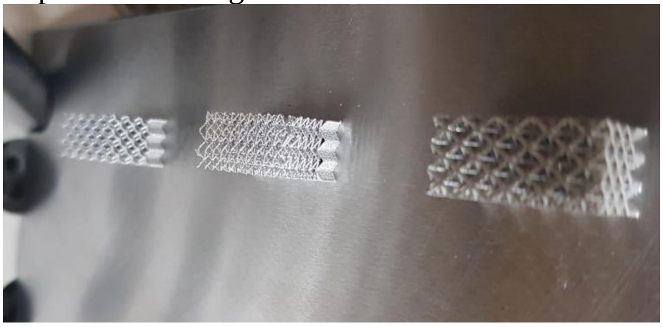


Figure 13. The lattice structures (2nd job) on the building plate after removing the powder

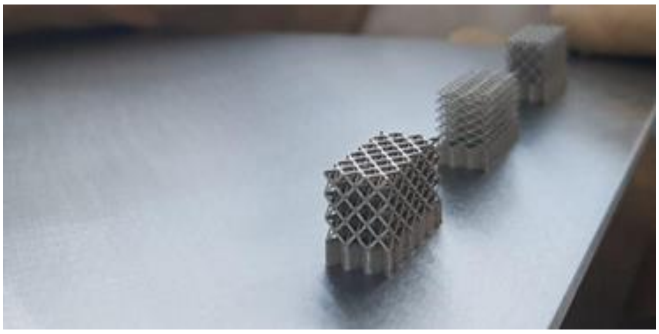


Figure 14. The lattice structures (2nd job) on the building plate

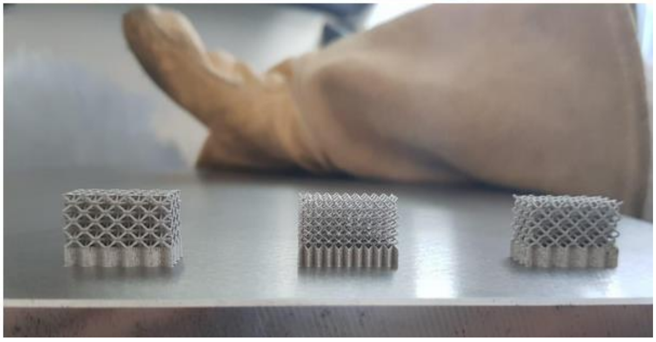


Figure 15. The diamond, rhomb and octet lattice structures (2nd job) on the building plate

After the additive manufacturing process, the lattice structures are post-processed in order to remove the powder from inside the cells (Figure 16).

Figure 16. Post-processing

The integration of lattice structures in the design is very important, starting from the fact that the implants' characteristics should be as close as possible as the bone's.

In the next figure are shown the integration of lattice structures in the zygomatic bone (Figure 17).

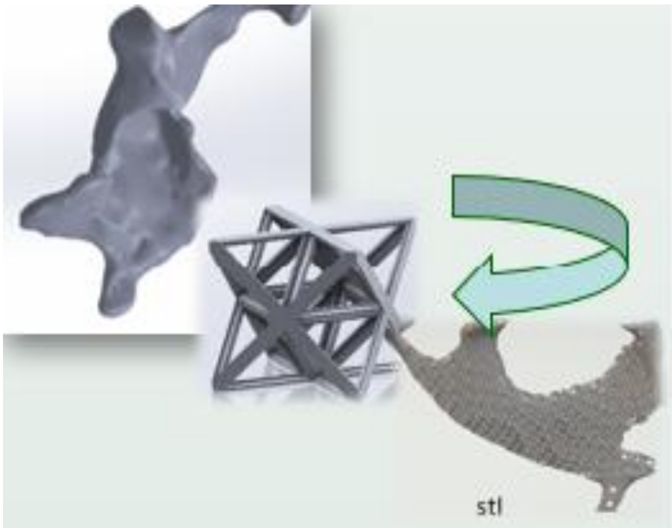


Figure 17. The integration of lattice structures in zygomatic bone implant

3.3 Interpretation of the results

The lattice structures are very important. The FEA results show that, from the lattice structures, the octet-truss design exceeds the performance of the other two types of lattice structures.

In the case of a rhombic structure with the unit of 3x3x4 and 0,36 mm and 0,5 mm strut size the compression test shows that, as a result of the large displacement, the compression test failed under the same load conditions.

4. CONCLUSIONS

In this paper, a methodology to optimize lattice structures is exposed. On the basis of the analysis carried out in this paper, it was found that:

Three types of lattice structures with two different porosity were successfully designed and obtained using additive manufacturing technology.

Additive manufacturing has a lot of benefits such as freedom of design, productivity and cost advantages for complex implants. And lattice structures are an emerging solution to weight, energy and advanced manufacturing time reduction.

They are used to create rough surfaces, to stimulate bone ingrowth (osseointegration), to mimic bone properties in order to avoid stress-shielding, to achieve excellent performance and multi-functionality while reducing weight.

Lattice structures consume less material while still distributing the necessary strength.

The FEA results show that, from the lattice structures, the octet-truss design exceeds the performance of the other two types of lattice structures.

We can conclude that the optimization is very important because of the elastic modulus and yield limit under the same lightweight condition, which emphasizes the prominent advantage in mechanical properties; for the same deformation, the indicating in a better ability to resist at impact.

It can be concluded also that FEA method reduces a great deal of time and money for the study of the lattice structure.

The importance of optimization of lattice structures in the case of structures intended to be used in implantation it comes from the possibility to obtain ultra-low weight and favorable mechanical properties, and also to obtain characteristics as close as possible to bone characteristics.

5. ACKNOWLEDGMENTS

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6. REFERENCES

1. Qian Yan, Hanhua Dong, Jin Su, Jianhua Han Bo Song Qingsong Wei Yusheng Shi, A review of 3d printing technology for medical applications, https://doi.org/10.1016/j.eng.2018.07.021;
2. Abdul Hadi AZMAN, Design Configurations and Creation of Lattice Structures for Metallic Additive Manufacturing, March, 2015, https://www.researchgate.net/publication/290107997;
3. Abdul Hadi AZMAN, Method for integration of lattice structures in design for additive manufacturing.Material, Universite Greonoble Alpes, 2017;
4. Pacurar Razvan, Pacurar Ancuta, Applications of the Selective Laser Melting Technology in the Industrial and Medical Fields, *New Trends in 3D Printing*, 1st edition, Igor Shishkovsky ed., pp. 175- 183, Rijeka, Croatia, 2016, doi: 10.5772/63038;
5. Dalia Mahmoud * and Mohamed A. Elbestawi, Lattice Structures and Functionally Graded Materials Applications in Additive Manufacturing of Orthopedic Implants: A Review
J. Manuf. Mater. Process., Vol. 1, nr.2, p.13, 2017; https://doi.org/10.3390/jmmp1020013;
6. Davy Orye, Benefits of 3D printed lattice structures for the medical industry,
7. IgY. Tang, Y. F. Zhao, Lattice-skin Structures Design with Orientation Optimization, 2015, https://www.semanticscholar.org;
8. Sarah Sauders, Finite Element Modeling Used to Study How Defects Can Effect Porosity in 3D Printed Lattice Structure, 2018, https://3dprint.com/225835/artificial-defects-lattice-structures.