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Finite Element Analysis of Cellular Structures Using Ansys

ABDON I.[1], ALKENTAR R.[2], BORTOLINI A.[3], GURBANOV O.[4], LIMA C.[5]

[1] University of Debrecen, Faculty of Engineering, Department of Mechanical Engineering, izabellaabdon@mailbox.unideb.hu
[2] University of Debrecen, Doctoral School of Informatics, rashwanken@gmail.com
[3] University of Debrecen, Faculty of Engineering, Department of Mechanical Engineering, bortoliniamm@mailbox.unideb.hu
[4] University of Debrecen, Faculty of Engineering, Department of Mechanical Engineering, oghuzg@mailbox.unideb.hu
[5] University of Debrecen, Faculty of Engineering, Department of Mechanical Engineering, caiolima@mailbox.unideb.hu

Abstract: Additive manufacturing (AM) is a process in which the product is composed of overlapping layers of a material that is added using devices such as 3D printers. Its process has been evolving for decades and nowadays it can be used for several applications and with different materials. One modern usage is for medical and dental purposes. Since it became possible to print metal, it has been a good solution for bone implants, once it must be done with biomaterials and can now replicate the bone structure, for that unit cells should compose the implant. Both conditions are now possible to be achieved by AM, and the current study will analyze, using finite element method, the possibilities to create specimens for tests which the final product would result in a 3D printed bone implant.

Keywords: Additive manufacturing (AM), 3D printer, implant, cellular structure, finite element method, Ansys.

Introduction

This study performed a finite element analysis of a cellular structure under compression using Ansys software. Its context is based on a collaboration project between physicians and engineers, whose objective is to develop prosthesis with additively manufactured biomaterials like titanium alloys [1].

Twenty percent of the human skeleton is composed of cancellous bones, whose structure is spongy; not compact. The bone matrix is set as a 3D latticework, and it provides structural support and flexibility being lighter than the compact structured bone [2,3].

Orthopedic implants have been used for many decades [4], and one of their challenges is to have an implant that suits the body well enough to be merged into the real bone. As mentioned above, some of those bones have a cellular structure.

Cellular structures are composed of small units that are uniformly distributed to form the whole body [5, 6]. These structures are used in various applications due to their special mechanical

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properties [5, 7, 8]. The relative density is the main property that characterizes this structure, where it is defined as the ratio of the latticed body density to the fully solid body. Good cellular structures are considered to have a relative density less than 0.3 g/cm^3 when compared with the original solid [5].

One of the solutions to mimic the bone structure on medical prosthesis is to use metal foams because its arrangement is also a porous structure that provides a high strength and low weight result [9, 10, 11]. However, due to its non-uniform porosity and properties, the 3D printed materials are strongly more reliable choice to fulfill this role.

There are various methods to generate a cellular structure like model Boolean operation, implicit surfaces, topology optimization and image-based methods [12,13]. For the purpose of the present study, the cellular structure was constructed using the predefined options available on Ansys.

With the innovation of metal additive manufacturing, e.g. 3D printing, it is possible now to 3D-print biomaterials, such as titanium alloys [1]. Some experiments are being conducted worldwide regarding 3D printing of cellular structures for different applications from aircraft and vehicle devices to medicine purposes, understanding its properties, behaviors, advantages, and disadvantages, as presented in articles [8, 12, 14, 15].

To evaluate the process of 3D printing for medical use [8, 16, 17], especially implants, the design should be tested. For that, as for any engineering product, a finite element analysis is advised to be conducted on the project to set the testing parameters [5, 8].

This paper investigates the analysis of compression test made on a cellular structure that would be used as a structure for the implants [8]. The software used was Ansys R2 version 2020, since it has the feature to create lattices in the studied structure. Various kinds of lattices can be selected with distinct types of unit cells, e.g: 3D lattice infill pattern, cube lattice with side cross support, double pyramid lattice with cross, double pyramid lattice and face diagonals and octahedral lattice two. However, porosity percentage, height, and bulk volume can be manipulated.

The ISO 13314 standard, Mechanical testing of metals — Ductility testing — Compression test for porous and cellular metals was used as a reference for the model dimensions [18]. Then the simulations for the finite element analysis was conducted on many unit-cell options. The goal of this paper is to compare the results of those types selected.

1. Materials and Methods

This paper shows the design of the cellular structure to be printed later using the EOS M 290 3D printer available in the University of Debrecen.

1.1. Applied Material and its Properties

To comply with biomedical purposes, biocompatible materials must be used. Hence, the material chosen for the research was the Titanium Alloy Ti6Al4V. The composition content of the alloy is shown in table 1. In addition to the composition content, the important physical and mechanical properties for the simulation are described in table 2.

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Element	Content
C	<0.08%
Fe	<0.25%
N	<0.05%
O	<0.2%
AL	5.5-6.76%
V	3.5-4.5%
H	0.015%
Ti	Balanced

Table 1. The composition of the Ti6Al4V alloy. [19]

Property	Typical Value
Density	4.41 g/cm3
Yield Strength	910 MPa
Elastic Modulus	114 GPa
Poisson's Ratio	0.34

Table 2. Mechanical and Physical properties of the Ti6Al4V alloy. [19]

1.2. Compression Test in Ansys

Following the International Standard of mechanical testing of metals, the ISO 13314, a simple parallelepiped model with dimensions of 20x20x20 mm was created using the Ansys R2 version software.

Four lattice models were created: simple cube lattice pattern model, 3D infill lattice pattern model, face supported cubic model and center supported cubic model. For the purpose of simulation, a compression test was performed on the model by the software. In order to reduce the processing time, one quarter of the model was used.

As shown in figure 1, a displacement of 0.1 mm was applied on the top surface of samples. Fixed support constraint was set on the bottom face. The presentation of each model and the simulation results are available in the next chapters.

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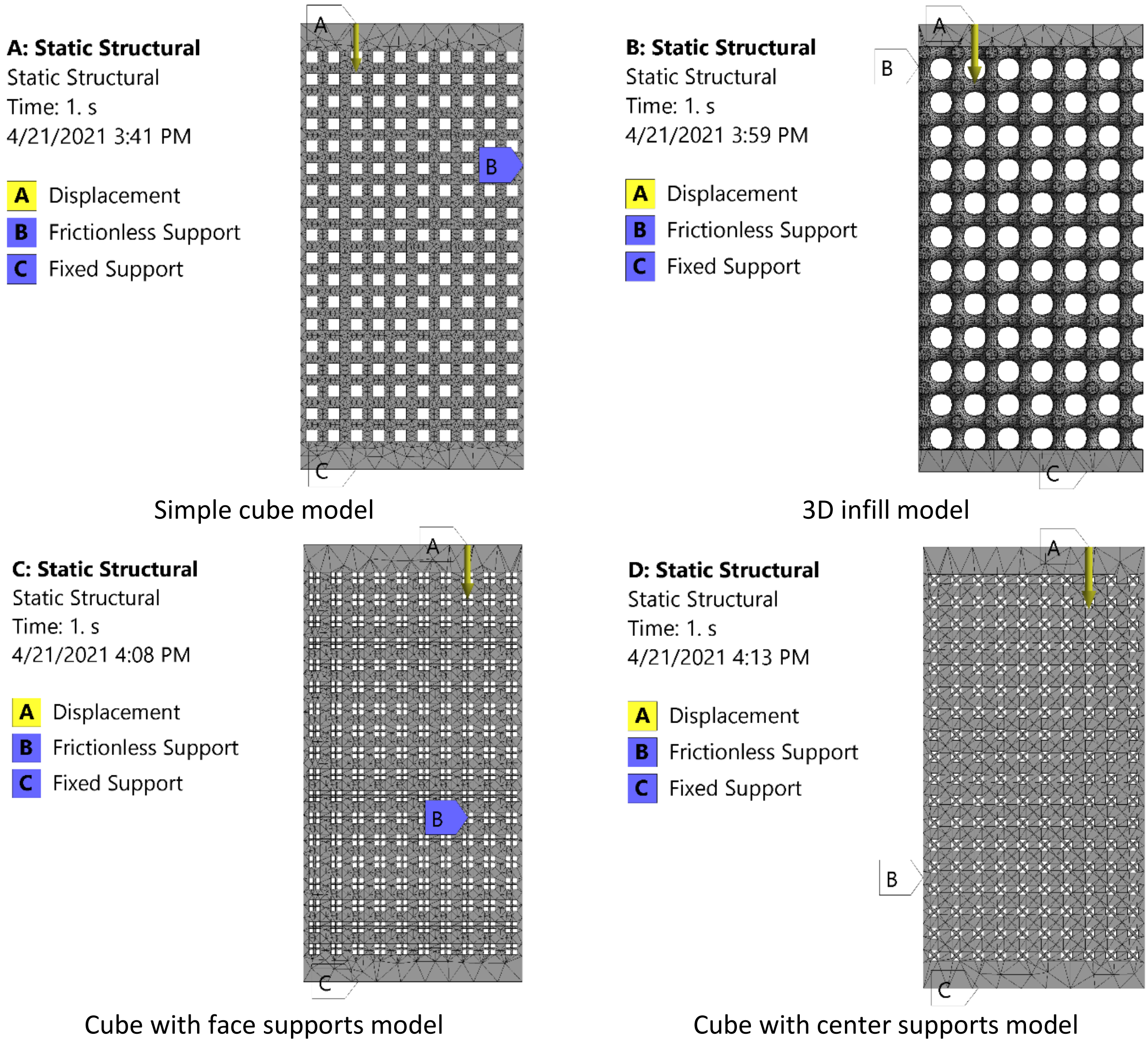
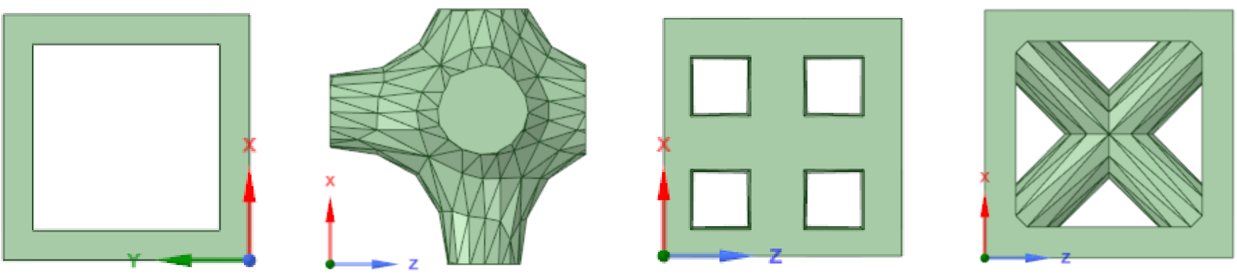


Figure 1. Simulation parameters of the samples

1.3. CAD Models

Figure 2 shows the details of each unit cell of the four CAD models developed on Ansys:



Simple cube lattice pattern model | 3D infill lattice pattern model | Cube with face supports model | Cube with center supports model

Figure 2. Unit cells of each CAD model

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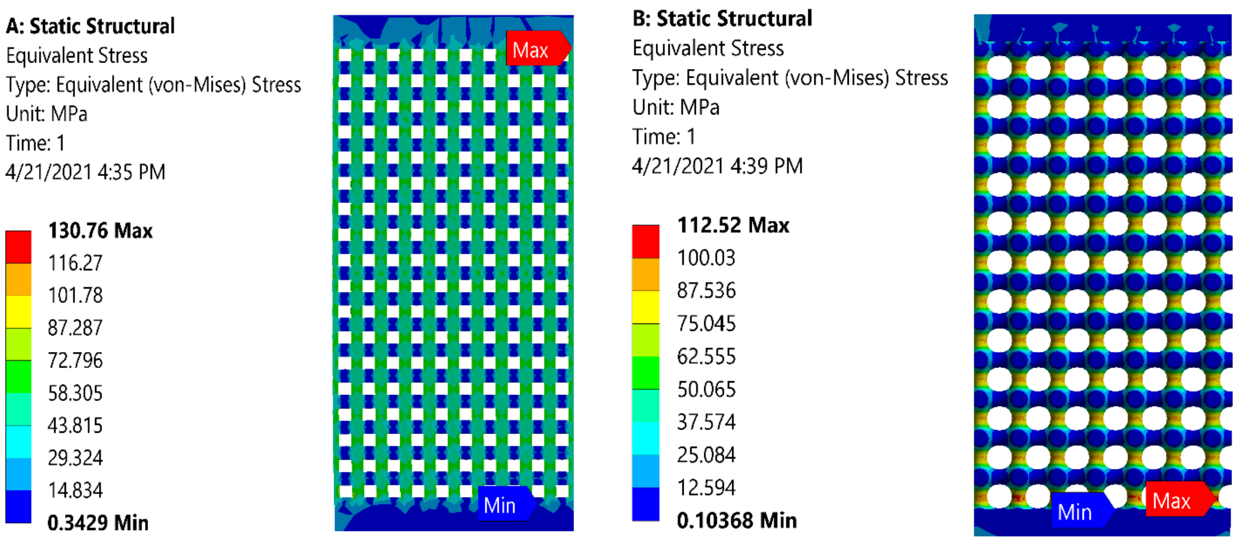
The following table 3 shows the parameters of the unit cells chosen for the test.

Cell type	Porosity percentage (%)	Beam (strut) thickness (mm)	Beam (strut) length (mm)
Simple cube lattice pattern	58.5	0.2	1
3D lattice infill pattern	58	0.35	1
Cube with face supports model	60	0.3	1
Cube with center supports model	59	0.25	1

Table 3. Unit cells parameters

2. Simulation Results

Figures 3 and 4 present the stress results for each model:



Simple cube model 3D infill model

Figure 3. Stress of the simple cube model and the 3D infill model

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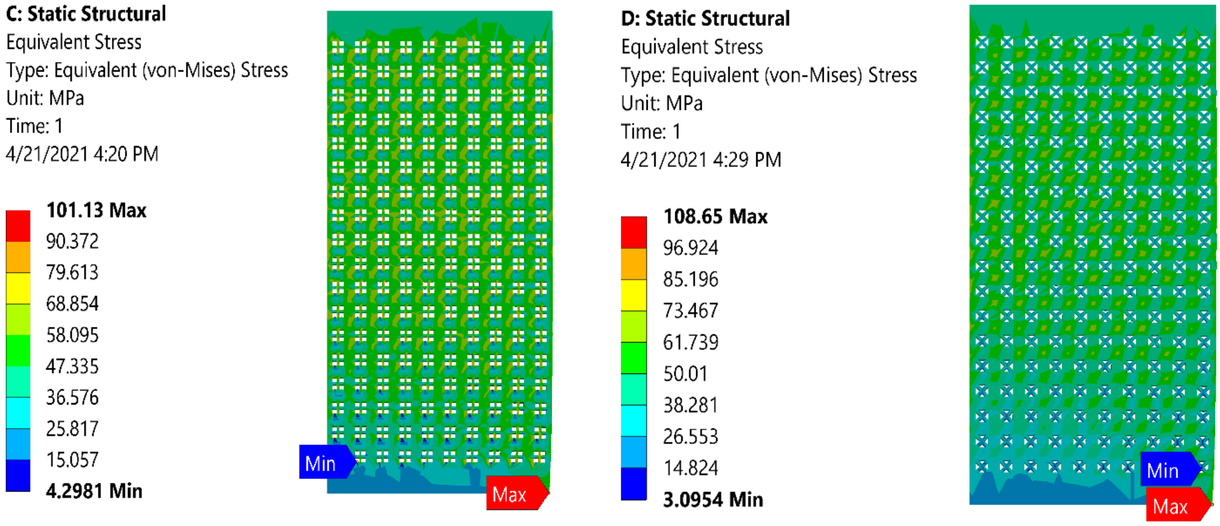

Cube with face supports model Cube with center supports model

Figure 4. Stress of the cube with face supports model and cube with center supports model

Figure 5 shows the Force-Displacement curves for each model: The bigger the line slope, i.e., the more inclined the line is, the bigger was the model resistance to the displacement.

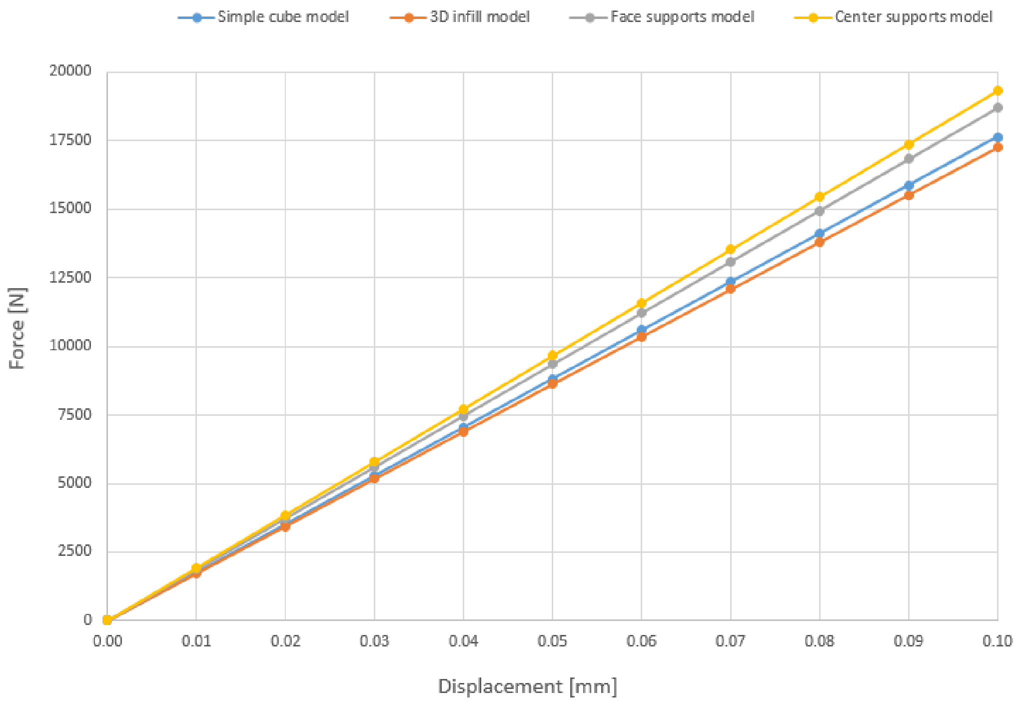

Figure 5. Force-Displacement curve for each model

3. Discussion & Conclusion

In this work, four parallelepiped models (Simple cube, 3D infill, Face supported cubic and center supported cubic models) with dimensions of 20x20x20 mm were designed using ANSYS software. Compression tests were conducted on the models, also using ANSYS software where the respective

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displacements were applied to each model. The models were compared considering their resistance to the applied displacement, as shown in Figure 5.

Besides, biocompatible material was chosen in order to ensure the model is suitable to be used for biomedical purposes. Since the structural model for additive manufacturing (3D printing) is being studied, the materials have to be compatible, i.e., printable with the equipment that performs such manufacturing.

In Figure 5, it is obvious that the 3D infill model was the one which required the least force 17258 N to reach a displacement of about 0.1 mm. It makes this model the least resistant to the compression force.

The simple cube and the face supported models obtained close results: They required 17628 N and 18697 N respectively to reach a displacement of 0.1mm. This classifies them above the 3D infill model in terms of resistance against the displacement imposed.

The center supported model, in its turn, obtained the best results in terms of resistance to the displacement: it required 19320 N to reach the 0.1mm displacement, putting it in the first place in terms of resistance against the imposed displacement.

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