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# Linear elastic finite element investigation of titanium specimen produced by Additive Manufacturing

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*Abstract: Nowadays orthopaedic implants are mainly fabricated from solid material (titanium alloy). The mechanical properties of these implants are much stronger than human bone tissue's properties, and this leads to fixation problems and a short lifetime, but today these problems can be eliminated with the usage of metal additive manufacturing. The mechanical properties of the implants can be influenced on demand with the variation of the material structure using different sizes and types of unit cells for building up its structure.*

## 1. Introduction, biomedical basics

The schematic of a modern hip implant used in today's world can be seen in Figure 1. The implant is fitted into a hole drilled into the femur, using a stem. The material of the implant (usually titanium alloy) has much stronger mechanical properties than the human bone tissue. The loads which occur during activity get transferred on a path represented by the arrows, therefore as it can be seen, the stronger material holds all the load on the upper part, and takes it off of the original bone tissue, up to the length of the fitting, where it finally transfers this load to the lower parts of the femur. This means, that the upper part of the femur is without load, and the so called "stress shielding" phenomenon occurs. The unloaded parts weaken during time, and in the weakened tissue, cracks start to spread due to repeating loads. With time, the cracks cause a fraction. This is not good, and has to be avoided. If a fraction occurs, a new surgery and implantation is required, which is stressful for the human body, especially for the elderly. [1]

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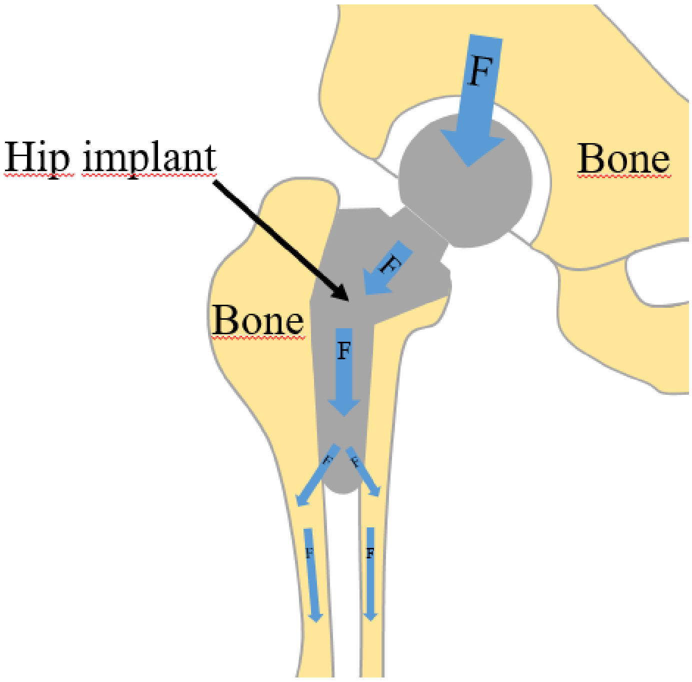


*Figure 1. Schematic of the fitting of a hip implant*

Metal Additive Manufacturing provides a promising solution for the phenomenon, as with its help, we can manufacture structures built up of pre – designed unit cells with 20 to 40 micrometers of accuracy, which can also be made porous this way. This means, that we can change the mechanical properties of the material of the implants according to our needs, depending on the type of unit cell and porosity used, therefore there could be a variation that resembles the properties of the human bone tissue. If we can develop and use such a structure for manufacturing orthopaedic implants, the penomenon of stress shielding could be eliminated, and the fixation and lifetime of implants could be improved.

## 2. Materials and methods

The point of the current research is to test and specify the mechanical properties in the elastic region (force – displacement curves) of open cell porous structures manufactured from various types of unit cells by Additive Manufacturing.

### 2.1 Production of titanium specimen by Additive Manufacturing

The Department of Mechanical Engineering has already continued research in this field, specifically in the testing and specification of the mechanical properties of metal foams, but the foaming is not a controllable process, therefore we can not manufacture two identical structures with metal foaming.

This research takes metal printing under the scope. With metal printing, we can manufacture structures according to our needs, that could be reproduced in great numbers, which is the precondition of biomedical use. The University of Debrecen has an EOS M290 type 3D printer in the Biomechanical Laboratory of the Orthopaedic Clinics, which uses titanium alloy powder as a raw material. [2-6]

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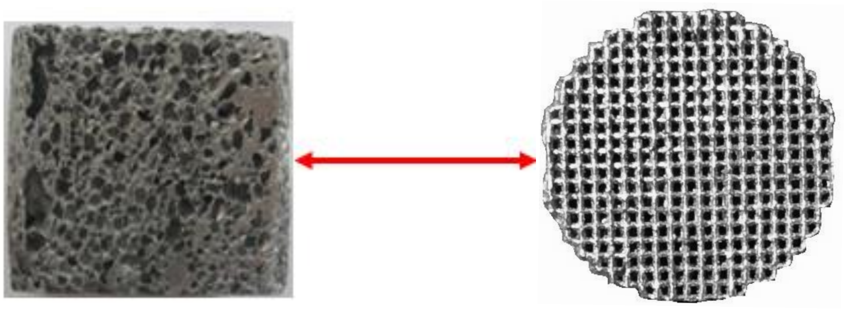

*Figure 2. Metal foaming (left) [7] and metal printing (right)*

Mechanical properties of the **Ti-6Al-4V** alloy

| | |
|---|---|
| Ultimate Strength (MPa) | 1075 |
| Yield Strength (MPa) | 965 |
| Elastic modulus (GPa) | 114,5 |
| Poisson's ratio | 0,34 |

*Figure 3. Mechanical properties of the Ti-6Al-4V alloy [3]*

## 2.2 CAD modelling of specimens

4 types of specimens were modelled with CAD software according to the ISO 13314 standard. It takes many steps to arrive to the simulation of full geometries, therefore standard compression test specimens were tested first. (Figure 4) The specification of their mechanical properties was done with simulated compression tests. Finite element analyses were done, and the results of these analyses will be compared to the results of the compression tests of the manufactured specimens. Refinements to the simulation parameters will be made according to these results, if necessary.

The specimens were created with the following sizes from 4 different types of unit cells:

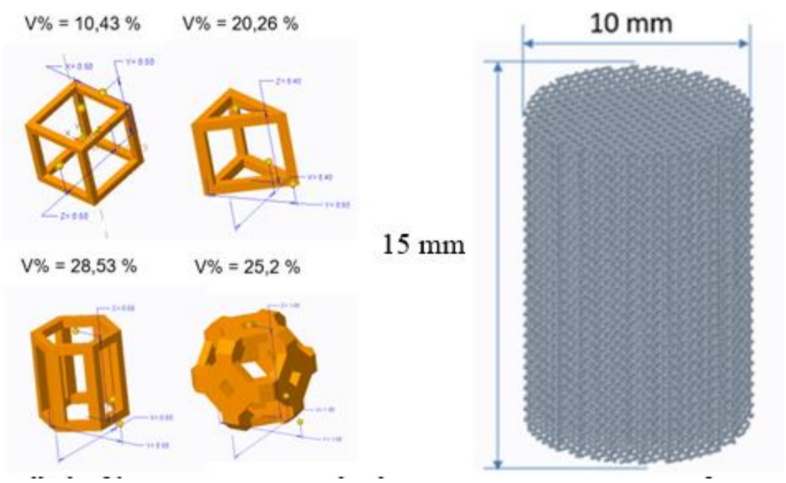


*Figure 4. Unit cells (Left) & ISO 13314 standard compression test specimen from cubic unit cell. (Right)*

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# 3. Linear elastic Finite Element Modelling calculations

I have taken the specimen which can be seen in Figure 3 under a numerical compression test with the help of FEMAP programme. [8-9] The investigated specimen were subjected to prescribed displacement at the top surface while normal contact were applied at the bottom and top surfaces. [10-14] Due to the size and complexity of the model, the numerical analysis is very costly, therefore with acces provided by the University of Nyíregyháza, High Performance Computing was used. Even this way, the simulation of the full model did not succeed, due to insufficient amount of RAM.

To succesfully run the simulations, various simplifications have been used. The analyses were ran on the 1/8 slice of the full height model, and the cylinders with 1,5 mm and 3 mm height of the full diameter model, which can be seen in figure 5.

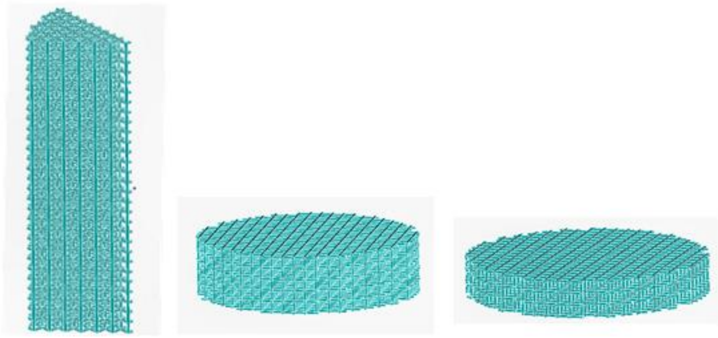

*Figure 5. Slice (left) and cylinders (middle & right)*

The results of the simulations have been displayed in diagrams. (Figure 6 & 7) For comparability reasons, the analyses have been run on solid models also.

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$$\sigma_{max} = 482{,}5\ MPa$$

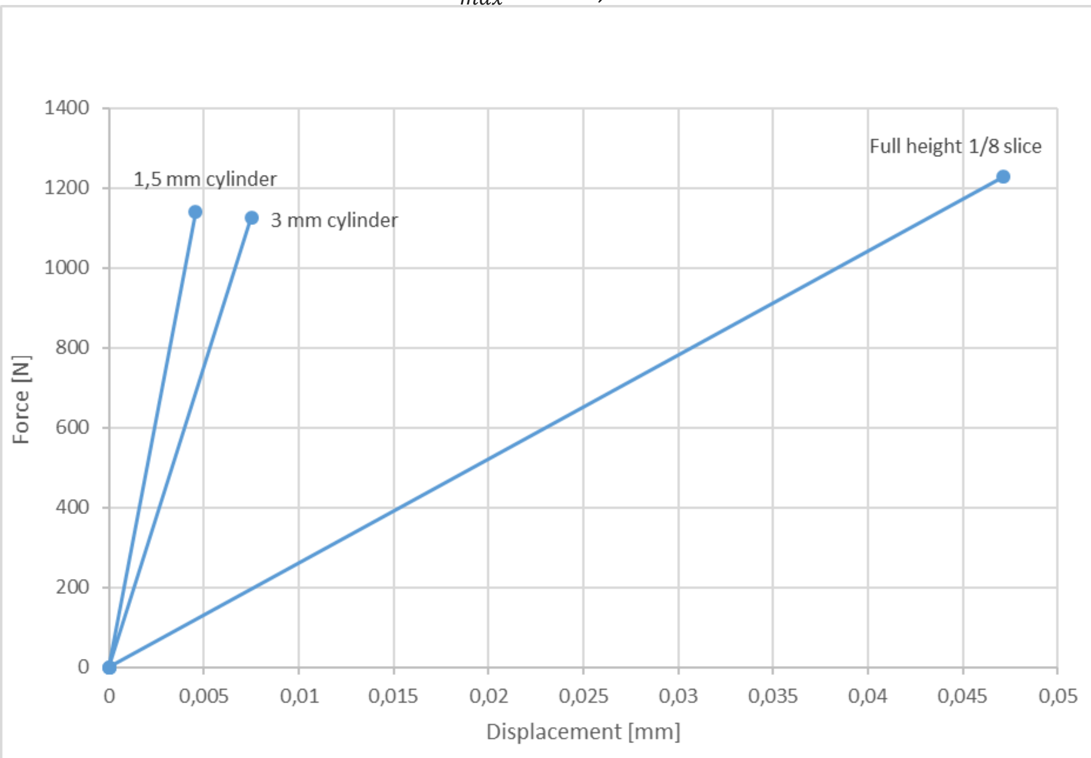


*Figure 6. Force – displacement curves of the* ***porous*** *model in the elastic region.*

$$\sigma_{max} = 482{,}5\ MPa$$

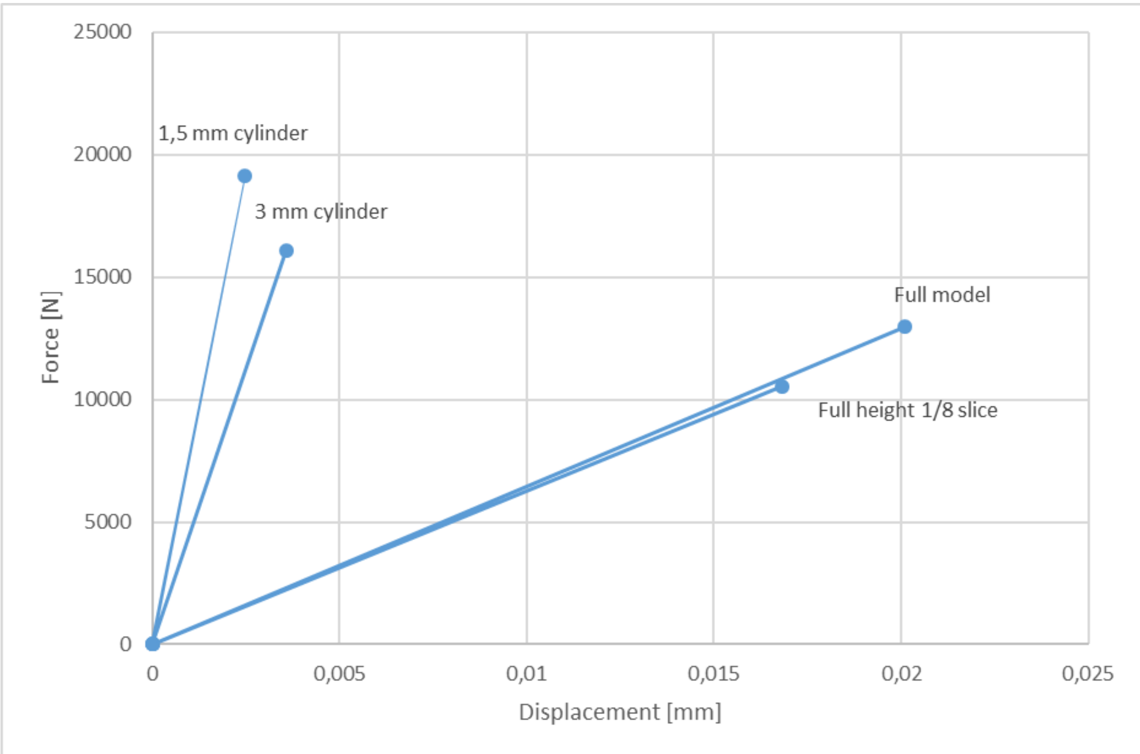


*Figure 7. Force – displacement curves of the* ***solid*** *model in the elastic region.*

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# Conclusion

As it can be seen in Figure 6 & 7, the simplifications which reduce the specimen's height cause a change in the test results, therefore a simplification like this can not be used to make the simulation less hardware demanding. However, with the slice type simplificaton, I've come to a different conclusion. The results show a similiarity in the curves of the full solid model, and the 1/8 slice of the solid model, which means, this might be an option for simplification. I couldn't achieve results in simulating the full porous model yet, due to insufficient amount of RAM in the supercomputer (488 Gb).

Another interesting point to note is that the behaviour of the solid model shows to withstand less force with the increase of displacement and the increase of height simultanously, whilst the porous model can withstand the same amount force with the increase of displacement and height simultanously.

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