FINITE ELEMENT ANALYSES (FEA) OF A MINI HIP ENDOPROSTHESES WITH MESH STRUCTURE

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Abstract— Currently, most of the endoprosthesis fixed by pressure (press fit) have porous surfaces. These surfaces are produced by different coating processes and are designed to improve fixation of the endoprosthesis. This study aims to determine the optimum geometry of the volume mesh structure to withstand the demands arising in human joints. The structures studied were designed to be manufactured by rapid prototyping technology of electron beam melting (EBM). The structures are built by repetition of a cell in 3 directions, included in the volume of a hip stem.The analyse of the structure was carried out in Ansys Workbench, in order to determine the distribution of stress and strain in the mesh structure.

I. INTRODUCTION

In the construction and use of a metal hip implant there is a great difference between the elastic behavior of the metal part and the bone. This often results in concentration of forces in certain areas and bone remodeling. Remodeling process may cause delay in healing of surrounding bone tissue which means loss of the implant, often leading to revision surgery. The best solution to avoid mechanical contact problems at the bone/implant interface is to have the same elastic modulus for the two elements, a very serious demand for a metal part. Another objective of the design optimization of a hip joint implant is to reduce the concentration of transfer forces between metal and bone, based on the reality that a high contact pressure at the metal/bone interface is destroying the new bone cells although the pressure is stimulating in general the growth of the bone [1]. In [2] the optimal elastic deformation to stimulate the growth of the bone tissue is declared between 0.0015-0.004 strains [mm/mm].

The implants must also stimulate the growth of the bone and provide good resistance to forces that appear in the joint [1]. All these demands are difficult to combine in a solid metal structure. Therefore the implant designer must look for solutions in the area of structuring the material and building of non continuous parts.

The latest research in the endoprosthesis field refers to mesh structures. The manufacturing of this kind of structures is possible due to the Rapid Prototyping technology, especially EBM (Electron Beam Melting) [3].

Such structures can be integrated into the implant thus making them lighter and decreasing their modulus of elasticity. Also, these structures can offer a much better osseointegration than the surface treatments that are being used nowadays [4].

In [2] [5] [6] [7] mesh and lattice structures have been studied for tissue engineering applications. Lattice structures were used in [1] to manufacture knee and craniofacial implants. Only in [8] is analyzed the mechanical comportment of some simple mesh structures which are incorporated in a small portion of the hip implant.

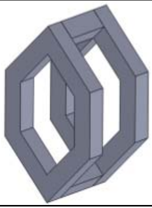
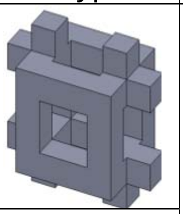
In the research work presented in this paper, different mesh structures are designed and analyzed with finite element method (FEA) in order to determine the best type of structure suitable to be integrated into a short stem endoprosthesis.

II. EXPERIMENTAL PROCEDURE

A. Designing the Structures

The recommendations from the Arcam AB User's Manual were taken into account in what concerns the dimensions of the unit cells in the mesh structure. Table 1 shows the most important dimensions of the 3D unit cels.

TABLE I
DIFFERENT TYPES OF MESH CELLS

	hight	width	depth	beam
 cell type 1	2 [mm]	2 [mm]	2 [mm]	0.4x0.4 [mm]
 cell type 2	3.5 [mm]	1.4 [mm]	2.2 [mm]	0.4x0.4 [mm]
 cell type 3	2.4 [mm]	1.4 [mm]	2.4[mm]	0.4x0.4 [mm]

Mesh structures were designed using SolidWorks software by repetition of a unit cell on the three directions x, y and z, resulting the structure presented in figure 1.a. In order to avoid the errors related to the geometry of the part in the analysis of the endoprosthesis with structure, the structure was formatted into a negative matrix (Figure 1. b), which was substracted from the body of the solid stem in the design process.

The mesh structure is placed in the central region of the stem, traversing it completely as shown in figure 1.d.

A hip stem with this kind of structure can be effectively prototyped on the Arcam EBM S12 machine [9].

a b c d

Figure 1. ***Design of the hip stems implant with mesh structure: a) the mesh structure, b) the mesh structure mould, c) the hip endoprostheses, d) the hip stem with mesh structure***

B. The Simulation

The analyses were carried out using Ansys Workbench software.

The biomaterial that was considered in the FEA is CoCr, with main properties presented in table 2. This material can be used with the Arcam EBM S12 machine for the stem fabrication.

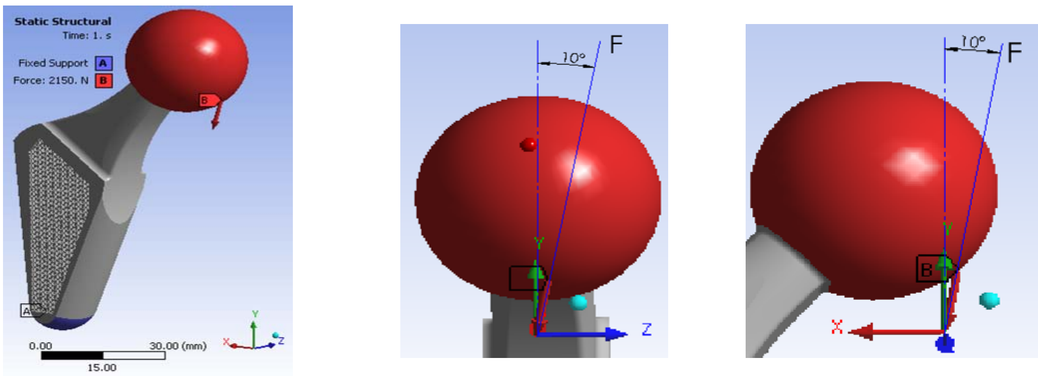
Regarding the boundary conditions, the distal end of the hip stem was considered fixed. A load force of 2150 N was applied in the middle plane of the ball of the endoprosthesis and the lower-back-lateral direction, with an angle of 10° in the frontal plane and 10° in the sagittal plane, as specified in ISO7206-4. These conditions are presented in figure 2. [11]

In order to obtain accurate results, a high quality mesh was generated for all the structures.

The presented results are equivalent stress (Figure. 3 a, c, e) and equivalent elastic strain (Figure. 3 b, d, f) for the three mesh structures used in the design of the hip stem.

TABLE II
MECHANICAL PROPERTIES OF COCR. [10]

	CoCr
Tensile Strength, Yield	560 Mpa
Tensile Strength, Ultimate	960 Mpa
Young's modulus	230 GPa
Poisson's ratio	0,33



a b c

Figure 2. The FEM analysis conditions. a) general view of the fix points and the loading force, b) the direction of the load in the frontal plane, c) the direction of the load in the sagittal plane.

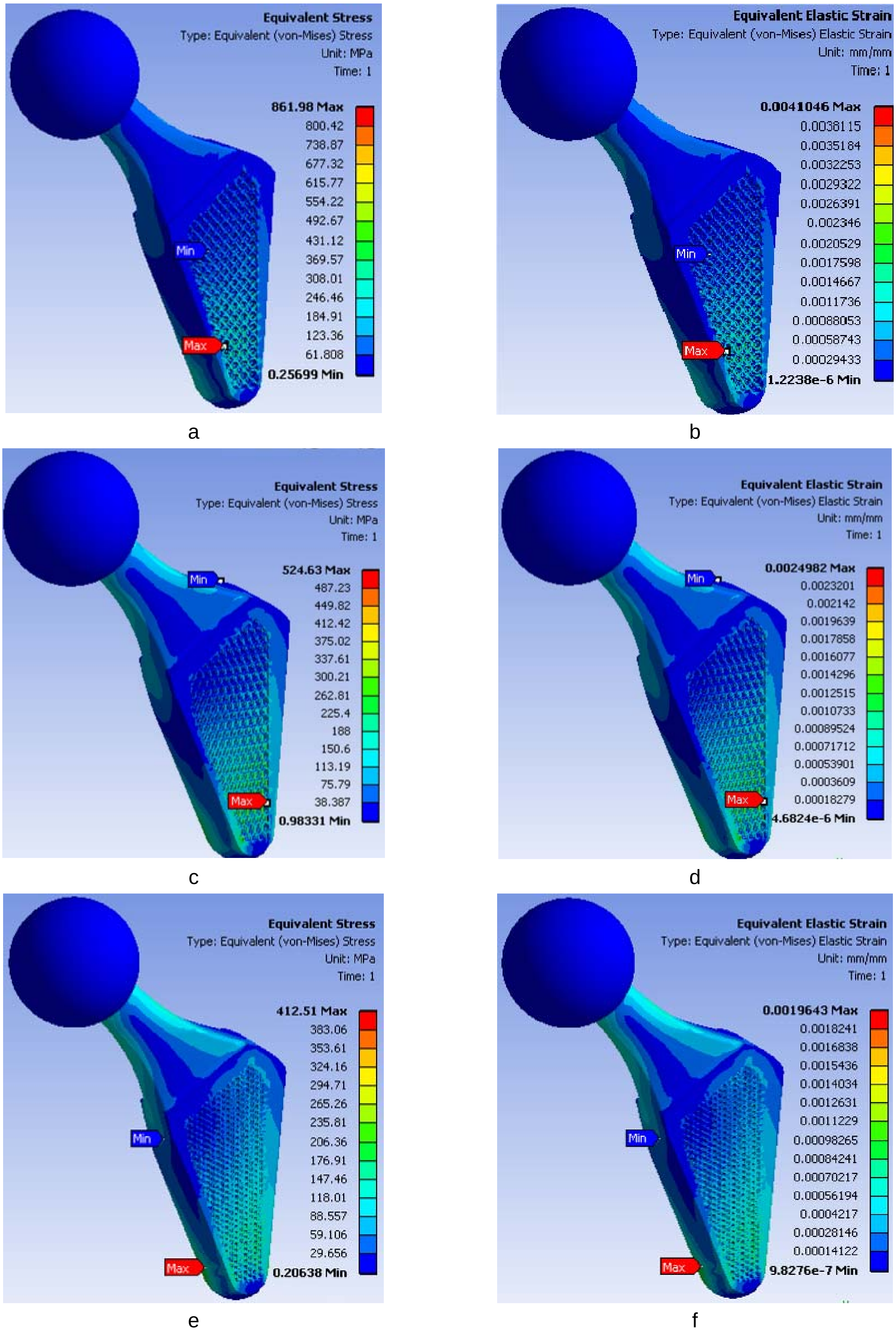


Figure 3. ***Simulation results: a) equivalent stress cell 1, b) equivalent elastic strain cell 1, c) equivalent stress cell 2, d) equivalent elastic strain cell 2, e) equivalent stress cell 3, f) equivalent elastic strain cell 3.***

III. RESULTS

A more rapid fixation of the stem will occur if the surrounding bone tissue is stimulated with low pressure [2]. If the forces that stimulate the surrounding bone tissue are too high the fixation may not appear because the new grown tissue might break.

As it is shown in figure 3 the shape of the cell has great influence upon the results of the FEA.

The hip stem with cell type 3 (see Table 1) has the lowest equivalent stress and equivalent elastic strain unlike the hip stem with cell type 1. Between the two structures, the hip stem with cell type 2 is the most suitable, in this case having optimal values for maximal stress and strain. The hip stem with cell type 1 could lead to bone resorption and the hip stem with cell type 3 to homeostasis. [2]

IV. CONCLUSIONS

The hip stem endoprosthesis with mesh structures can offer a better osseointegration than the conventional coated hip stem endoprosthesis. The quantity of material used for building a structured stem is smaller, but the manufacturing conditions by prototyping are more difficult than the classical solutions based on forging or machining.

This paper present solution regarding the design and integration of a lattice structure into a hip implant.

For the future of this research, in [12] we have determinate the modulus of elasticity of the structure made from cell 2.

The Arcam EBM S12 machine will be used to build the stems, and mechanical tests will be run on the parts in order to validate the results of the simulations.

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