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3D Printing of Metallic Implants

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***Abstract* - The fabrication of various elements, solid and open porous structures of stainless steel and Ti alloy is described. The process was started with the design of 3D models in CAD/CAM system. The 3D models were transformed into *.stl files and then the manufacturing process of the real structures by means of the selective laser melting with the SLM Realizer 100 3D printer was made. The paper shows the porous specimens made for possible application in medicine and the prosthetic bridges. The appropriate mechanical strength is the important property of porous structures for medical application and for curved prosthetic bridges it is necessary to take into account the thermal stresses, which appear during their SLM/DMLS manufacturing process.**

***Index Terms:* open porous structures, prosthetic foundations, selective laser melting, stainless steels, titanium alloys**

A. INTRODUCTION

The additive manufacturing technology with use of the metallic powders, also called the 3D printing, is widely used to obtain various details, also for medicine. The so far achievements and expectations relate to metallic implants include the hip joint implants, a knee implants, maxillofacial implants, personalized dental implants and prosthetic foundations and bridges. Among different methods, the selective laser melting (SLM) or direct metal laser sintering (DMLS) seems particularly suitable.

Among solid (non-porous) implants, Maji et al. [1] made the customized femoral prosthesis through computed tomography and CAD-RP-rapid tooling (RT)-investment casting (IC) route. Such prosthesis was also manufactured through conventional CT-CAD-CAM-CNC way. Joguet et al. [2] demonstrated that SLM could be successfully used for the Co-Cr-Mo part manufacturing. Chen et al. [3] developed the zig-zag laser path strategy for the SLM made Ti-6Al-4V solid parts. The SLM was used to make the dental implants [4], followed by laser-gas-nitriding to achieve better wear resistance. The patient fitted titanium complete denture base plate was fabricated by CAD/CAM and rapid laser forming [5]. Yang et al. [6] fabricated the customized brackets by SLM, using 316L stainless steel. In other work [7] the titanium alloy frameworks for a maxillary denture were manufactured by SLM. Rotta et al. [8] manufactured by SLM method the porous titanium structures with a different, precisely designed micro-architecture and estimated mechanical properties of proposed scaffolds in function of their porosity degree and pore shape.

The porous implants, suitable for better bonding of an implant to a human body by bone tissue in-growth, may be perfectly made with SLM technique. Recently, Chen et al. [9] developed the porous Ti-6Al-4V implants of human cortical bone and cancellous bone by SLM. The CAD designed structures possessed porosity levels ranged from 40% to 80%, and pore sizes from 600 to 1000 mm.

In this paper, the manufacturing of porous elements made of stainless steel, and prosthetic bridges made of the Ti-13Zr-13Nb alloy are presented. The assessment of dimensional precision, surface quality and mechanical strength of various structures, and encountered problems are discussed.

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B. EXPERIMENTAL

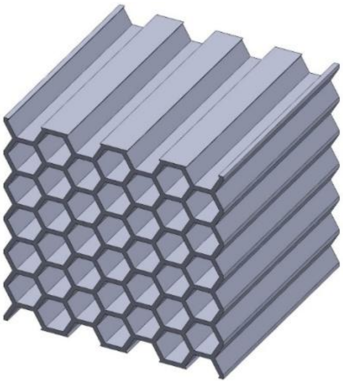
The used materials included the stainless steel 304 L and Ti-13Zr-13Nb alloy, both in powder form produced through plasma jet spraying. The whole procedure to make individually designed, personalised medical parts and implants by selective laser melting was composed of several stages: scan of patients` mouth (for prosthetic foundations), the design of elements in CAD/CAM software, the transformation of 3D models into *.stl files, the creation of supports with use of a CAMBridge (3Shape) or Magics (Materialise) software, slicing the model into layers suitable for the used SLM equipment, adjusting the parameters of the SLM process and manufacturing by SLM 3D printer. The obtained porous models specimens were cubes 13x13x13 mm, and printed-out prosthetic foundations corresponded to the dimensions of their virtual CAD models.

The selective laser melting was performed at different process parameters, directly described at appropriate figures. The assessment of the effects of laser melting parameters on the shape, dimensions, quality, foundation's matching degree and the state of their surface was conducted with X-ray microtomography (µCT). The assessment of surface quality was performed with profile analysis. The tests for compression strength were made with the tensile machine in compression mode.

C. RESULTS AND DISCUSSION

Fig. 1-4 show the scaffolds obtained from stainless steel powder. The high dimension accuracy and pore shape precision can be obtained, but it needs a long time for stepwise adjustment of SLM process parameters. The results prove that any complex structure necessary, e.g., for porous or surface porous scaffolds for various implants can be obtained. Such possibility is important for all cases, in which the implant must be de design and custom made. The more complex structure, the longer time necessary to finish the manufacturing. The long fabrication time is the disadvantage, but making of even very complex structures – the greatest advantage of the SLM/DMLS methods.

(a)



(b)

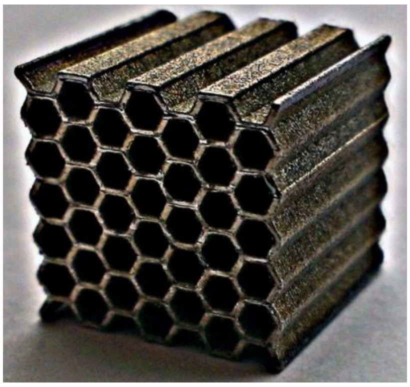


Fig. 1. Honeycomb structure: (a) CAD model, (b) real structure. The laser beam 0.18 mm, number of supports` layers 133, number of model layers 422, fabrication time 2 h.

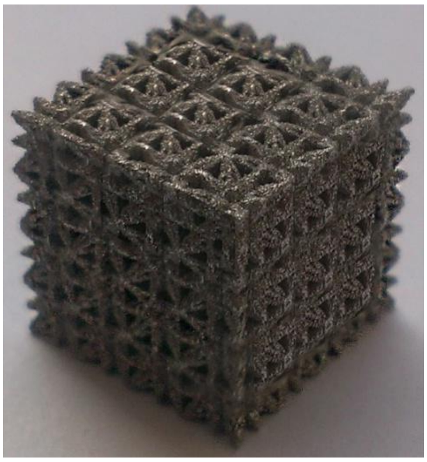
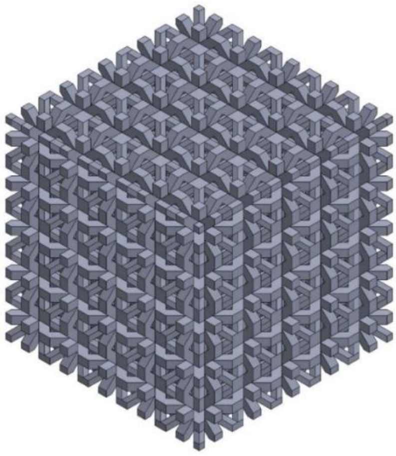


Fig. 3. Fractal structure. The laser beam 0.18 mm, number of supports` layers 133, number of model layers 425, fabrication time 3 h.

(a)



(b)

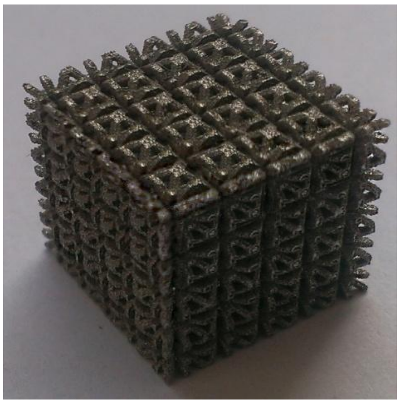


Fig. 2. Truss structure: (a) CAD model, (b) real structure. The laser beam 0.18 mm, number of supports` layers 132, number of model layers 426, fabrication time 2,5 h.

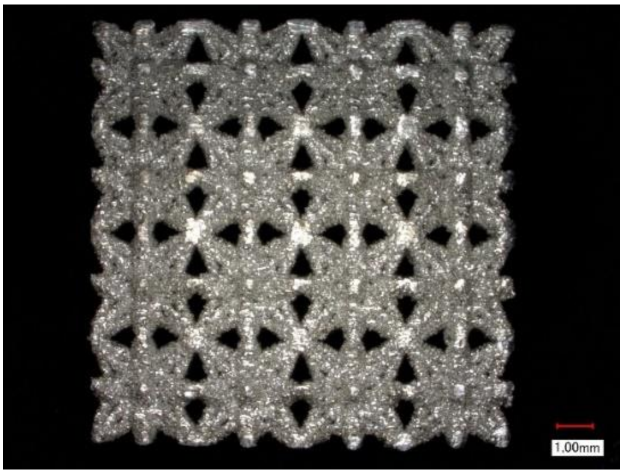


Fig. 4. Magnification of vertical side of the fractal structure shown in Fig. 3.

The compression tests demonstrated that the mechanical strength depends on the structure type, i.e., pore shape (Fig. 5). This relation is complex as it also is determined by the laser power, likely influencing the quality of joining of neighboring layers. The compression strength is quite high for truss and fractal structure and sufficient for medical purposes.

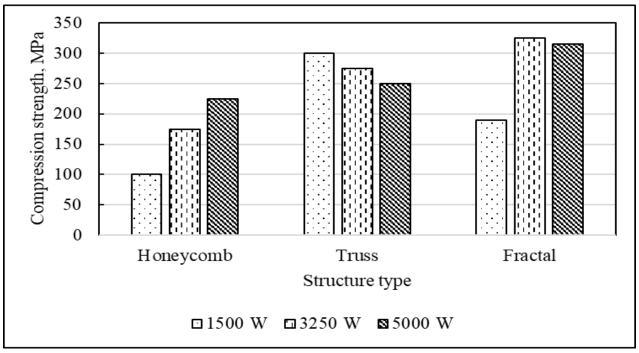
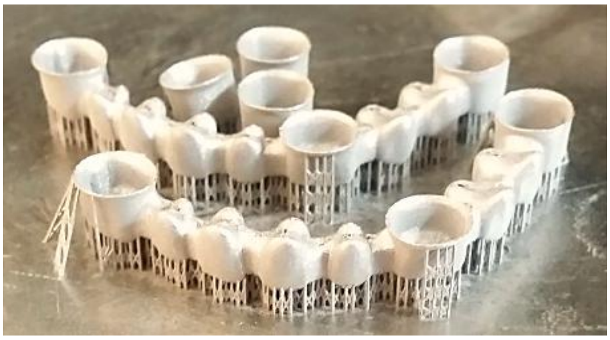


Fig. 5. Compression strength in function of structure type and laser power.

(a)



(b)

Fig. 6. The prosthetic bridges after selective laser melting before (a) and after (b) sand-blasting. The applied parameters: laser power at building the contour 50 W, laser power at filling the contour 75 W, the spot size of the laser 0.13 mm, layer thickness 25 µm, oxygen level inside the chamber 0.2%, argon as technical atmosphere, the temperature of base plate 200°. The base plate was made of technical titanium.

Fig. 6 a and b show the non-porous prosthetic bridges made of the titanium alloy, which so far has been never attempted to be used for such a purpose. The curved shapes of dental foundations need to introduce the necessary change in file with the SLM process parameters to take into account the high thermal stresses resulting to distortion of these elements. The optimization of process parameters should be done to minimize the number of pores in printed objects structure; the too high number may lead to cracking of a porcelain covering the titanium bridges during firing process, due to air bubbles liberating from too porous, laser melted Ti alloy. Another problem, which needs to be considered during SLM process parameter`s modification, is surface roughness of the manufactured objects. Due to the fact that objects are printed from powdered metals and their alloys, it is not possible to obtain a smooth surface of a ready object. The printed-out objects are generally subjected to final treatment by different methods (sandblasting, polishing, painting, etc.). In order to ensure good adhesion of the ceramic cover to the titanium foundations, the crowns and bridges obtained by SLM were sandblasted with aluminia and glass beads.

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