Selective Laser Melting of Ti Alloy for Manufacturing The Prosthetic Elements

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***Abstract* – The selective laser melting (SLM) is the additive manufacturing method of custom-designed parts. The used materials and the applications are various, including medicine. The titanium and its alloys are materials for which the dimensional quality, surface smoothness and no or extremely low porosity are difficult to reach. In this paper, the successful attempt to obtain by SLM the individually designed prosthetic bridges is described. The desired elements were obtained by the proper design, the adjustment of laser equipment parameters and necessary surface post-treatment.**

Index Terms: **selective laser melting, prosthetic bridges, titanium alloys**

1. INTRODUCTION

The additive manufacturing technology based on the melting of metallic powders has recently become important to obtain different parts of medicine of titanium and its alloys. It is widely used to obtain various details, also for medicine [1]. Among different methods, the selective laser melting (SLM) seems particularly suitable as it may result in very complex parts and structures in short time and as low-expense. However, the proper CAD/CAM design, development of an appropriate stl. file and an adjustment of proper laser treatment parameters are much more difficult for titanium alloys than for stainless steels or Cr-Mo alloys based on own experiences of authors.

The two dominant research and application directions are: (i) development of laser treatment procedures for different Ti alloys and (ii) development of custom-design and made (personalized) medical parts. For both directions, the most important is obtaining the model specimens, or CAD/CAM prepared medical parts of the proper dimensional quality, smooth surface, and very low porosity. Suitable examples have been presented in new research reports as shown below.

Chen et al. [2] applied the SLM to make various medical parts of the Ti-6Al-4V solid parts. Chen et al. [3] manufactured by SLM the Ti-6Al-4V porous implants of human cortical bone and cancellous bone by SLM. The parts of biomedical titanium alloy (Ti–24Nb–4Zr–8Sn) scaffolds were also fabricated by SLM [4]. Zhou et al. [5] demonstrated a novel titanium alloy (Ti–5.5Al–3.4Sn) melted by 140 W laser power at 400 mm/s scan rate. Fischer [6] manufactured the Ti-26Nb alloy by SLM. Ishimoto et al. [7] produced Ti–15Mo–5Zr–3Al alloy products by SLM. Wei et al. [8] made by SLM another Ti-5Al-2.5Sn - Ti alloy. As the last example, Yan et al. [9] developed new biocompatible Ti-15Ta-xZr (1.5, 5.5, 10.5 and 15.5 wt%) alloys fabricated by selective laser melting.

The titanium implants made by SLM include the hip joint implants, knee implants, maxillofacial implants, dental implants, and prosthetic foundations and bridges. The SLM was used to make the dental implants [10]. The patient fitted titanium denture base plates [11] were fabricated by integrating the technologies of computer-aided design and computer aided manufacture (CAD/CAM) and rapid laser forming (LRF). In other work [12] the thin titanium alloy frameworks for a complete maxillary denture were made with SLM.

Here the SLM was used to fabricate the prosthetic foundations and bridges for dental crowns made of not yet investigated for such purpose titanium alloy. So far such foundations are produced by precision milling of Co-Cr alloy or by the 3D printing using the corundum ceramics. The first solution is time-consuming and leaves a lot of metallic wastes; the second brings out the foundations of nice quality, but very expensive and brittle. This paper is aimed to show our results in the manufacturing of dental prosthetic bridges and to demonstrate the appropriate process determinants.

II. EXPERIMENTAL

The Ti-13Nb-13Zr alloy was investigated at it possess acceptable biocompatibility, is corrosion-resistant, has desired tensile and fatigue strength, has an elastic modulus approaching that of a bone and contains neither Al nor V, elements claimed to be toxic for humans and animals.

The alloy powder was manufactured from the Ti-13Zr-13Nb wire. The powder was produced by plasma jet spraying. The obtained spherical powder was sieved and separated into different fractions. The melting was performed with the Realizer100 equipment.

The prosthetic foundations and bridges were made based on real scans of patients` mouths followed by the development of specific stl. files for laser work.

The selective laser melting process was carried out at various values of laser power 50-75W, 0.19 mm of the laser beam spot size, the single layer thickness of 25 μm and base plate temperature of a 150ºC.

The finishing treatment of ready prosthetic parts included the sand and glass bead blasting and their oxidation. The assessment of the final shape, CAD/CAM, and melted parts

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accordance, and surface quality dimensions were investigated with the naked eye, light microscopy, scanning electron microscopy, profilometry and computer microtomography (µCT).

III. RESULTS AND DISCUSSION

Fig. 1 demonstrate the examples of prosthetic foundations made by SLM method. Such results were obtained after many trials and attempts as the characteristics of final part are very sensitive to the proper change in basic machine stl. file. The laser equipment manufacturers are not obliged to deliver these machine manufacturing files, and all producers of personalized implants of any specific alloy must step-by-step reach the best file contents. Our original solution is under patent. What may be discovered, there are some adjustment parameters: laser power in the range of 45-85 W, the spot size of the laser 0.19 mm, layer thickness 25 µm, oxygen level inside the chamber 0.2%, argon as technical atmosphere, the temperature of base plate 150°C. The base plate was made of technical titanium. The dimensional quality was at the acceptable level.

Fig. 2 and Fig. 3 show bridges after SLM and after heat treatment (Fig. 2) and after sand-blasting (Fig. 3).

The results obtained after SEM (Fig. 4) and after CT (Fig. 5) examinations prove that applied surface treatment parameters are suitable for these elements. The whole process manufacturing of prosthetic foundations and bridges, and oxidation procedure are currently under patent.

Fig. 1. View of the various prosthetic foundations with supports on the base plate directly after sintering process

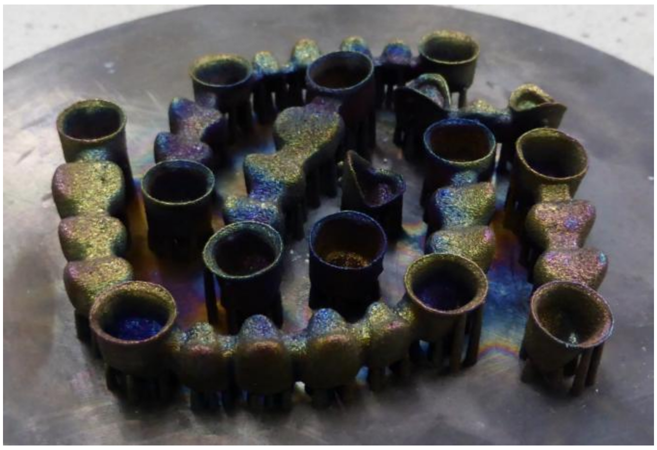

Fig. 2. View of base plate with prosthetic foundations after heat treatment in argon atmosphere

Fig. 3. View of prosthetic foundation after sand-blasting

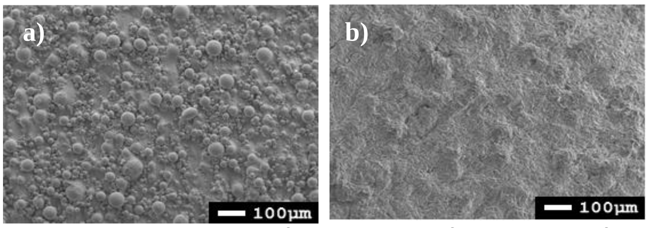

Fig. 4. The SEM images of the prosthetic foundation surface: before sand and glass bead blasting (a) and after sand and glass bead blasting (b)

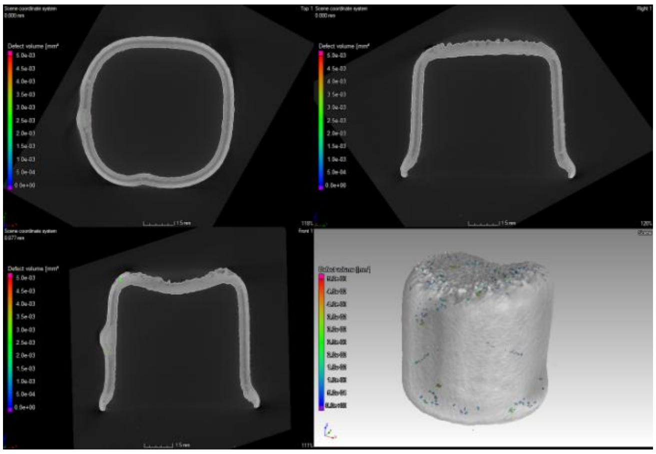

Fig. 5. The results of investigation of internal structure of the prosthetic crown by µCT

The selective laser melting of the single foundations made of titanium alloy has encountered a single problem, the proper adjustment of many laser treatment parameters, as shown above. For example, too high scan rate resulted in no melting of some grains, too great grains demonstrated low cohesion of adjacent grains, etc. Another problem was the correspondence of dimensions of CAD/CAM and melted specimens, difficult to reach because of an application of an alloy composed of three elements of different melting temperature and diffusivity, demonstrating the high shrink and no homogeneity.

For bridges, another problem became important. The bridges possessed the curvature different that of CAD/CAM model because of thermal stresses. Therefore, this problem was taken into account at the design stage.

Finally, the melted specimens were rough and possessed low corrosion resistance. The sand-blasting with low grain SiO_2 suspension eliminated the roughness problem, and prosthesis oxidation (parameters currently under patent process) resulted in an excellent corrosion protection.

In Fig. 6 an example of the ready-to-use prosthetic foundation is presented.

Fig. 6. View of the ready-to-use prosthetic bridge made of Ti-13Zr-Nb with ceramic coating

IV. CONCLUSIONS

The selective laser melting can be used to obtain the prosthetic foundations and bridges of the Ti-13Zr-13Nb alloy very precisely.

The achievement of dimensional accuracy needs the adjustment of laser treatment parameters and proper design.

Sand-blasting can achieve the smooth surface and proper oxidation – the corrosion resistant surface.

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