Analysis of the Surface Quality of Test Samples Made of Biocompatible Titanium Alloys by Sintering

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The aim of this paper is to analyse the surface quality of test samples made of biocompatible titanium alloys that are obtained by the rapid prototyping process called Direct Metal Laser Sintering (DMLS) and used for making medical prostheses. The employed analysis methods (optical microscopic and scanning electron microscopy - SEM) revealed the different quality of the parts obtained by sintering. Following the analysis of the samples it was discovered that there is an incomplete melting area of the titanium powder at the surface of the samples. The thickness of the incompletely molten layer and the shape of the part surface influence the quality of the obtained sample.

Keywords: titanium, biocompatibility, prosthetic, DMLS

In general, primary processes of metals include the processing ingot to mill products in the case of wrought alloys, and casting process in the case of cast alloy. In addition, the primary products of metals can also be produced by powder metallurgy. Processing of implant alloys is thought to be a very expensive process, which involves a complex process of production, especially for the case of biocompatible Ti alloys. The main reason for this condition is due to the high reactivity of the alloys, therefore special handlings are required to perform their process of production. Another near net shape process is direct metal laser sintering (DMLS), also known as Selective Laser Melting, which is an additive metal fabrication process. DMLS machines use a high powered 200 watt Yb-fiber optic laser to fuse metal powder into a solid part. Aluminium, Stainless Steel, Titanium and Co-Cr alloys are DMLS materials used for rapid manufacturing projects [1,2].

Utilizing the material mixture of alloys, the metal parts built with DMLS technology will not only provide you parts with great appearance, but will create versatile designs with powerful mechanical properties [3]. The main disadvantages of the additive manufacturing technologies consist of the limitation of the dimensions of the obtained parts as well as of the occurrence of stresses in the body of the parts during the manufacturing process. The high level of stresses may lead to part deformation, their separation from the manufacturing support leading in the end to parts with improper geometrical dimensions or, in worst case scenario, to the blocking of the manufacturing system.

New technologies used to manufacture high-quality components, such as direct laser sintering, require spherical powders of a narrow particle size distribution as this affects the packing density and sintering mechanism. The powder also has to be chemically pure as impurities such as H, O, C, N, and S cause brittleness, influence metal properties such as tensile strength, hardness, and ductility, and also increase surface tension during processing [4].

Titanium alloys have an extended use as dental and orthopaedic implant materials, due to their biocompatibility, corrosion resistance and high specific strength. As alloying base, titanium is considered to be totally inert and immune in the human body, and thus wholly biocompatible. Good mechanical properties, as strength, ductility and hardness, can be achieved by controlling the chemical composition and microstructure [5-8].

Experimental part

The main objective of the experimental procedure was to analyse the quality of the surfaces of Ti-6Al-4V test samples (biocompatible alloy) obtained by sintering with the help of DMLS.

The EOS Titanium Ti64 powder was used - it is a titanium alloy powder which has been optimized especially for processing on EOSINT M systems (EOSINT M270). Parts built in EOS Titanium Ti-6Al-4V have a chemical composition corresponding to ISO 5832-3, ASTM F1472 and ASTM B348. This well-known light alloy is characterized by excellent mechanical properties and corrosion resistance combined with low specific weight and biocompatibility [9-13].

This material is ideal for many high-performance engineering applications, for example in aerospace and motor racing, and also for the production of biomedical implants. Due to the layerwise building method, the parts have a certain anisotropy, which can be reduced or removed by appropriate heat treatment [13].

The parameters used for sintering metallic powders mainly include the laser power, the scanning speed and the beam offset. Each layer structure (surface and contours) is exposed to a laser power and a scanning speed. As the diameter of the melted (sintered) zone is usually larger than the effective laser diameter, it is necessary to compensate the dimensional error and the laser beam must be shifted by half the curing width from the contour to the inside, to make sure that the contour of

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Table 1
WORKING PARAMETERS OF THE MACHINE

Parameters	Value	
	Hatching	Contouring
Laser power (W)	170	150
Scan speed (mm/s)	1250.0	
Hatching spacing (mm)	0.10	NA
Stripe width (mm)	5.0	NA
Beam offset (μm)	0.015	0.020
Scanning pattern	Rotated	

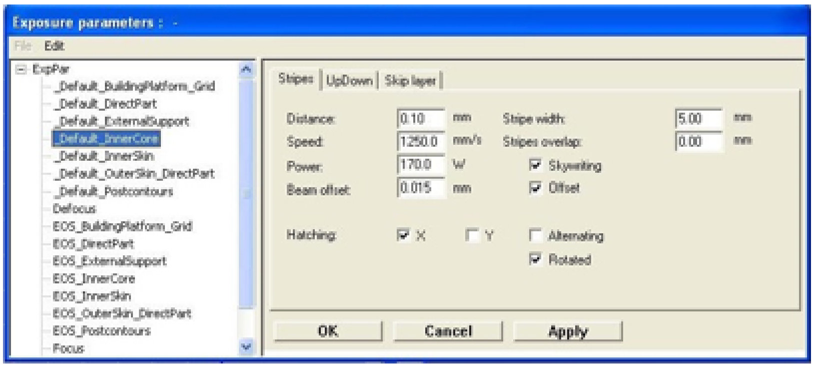


Fig. 1. The settings for the inner core of the part

a

b

Fig. 2. Configuration of the test samples obtained by sintering: a – test sample with circular cross section, b – test sample with square cross section

the latter part will correspond exactly to the original CAD data. This correction of the position is called beam offset [14].

The samples were made with the additive manufacturing EOS M270 machine, which features an Ytterbium fibre laser 200W, the scanning speed is max. 7.0 m/s and the effective laser beam diameter ranges between 100 and 500μm. For the parts described in the article the default parameters of the machine were used, which are presented in the table 1.

The settings for the inner core of the part are illustrated in the figure 1.

Two types of test samples with different geometrical configurations were used to analyse the surface quality of the samples obtained by sintering: the first test sample was made with a circular cross section with a diameter of ∅2.5 mm (fig. 2.a) and the second was made with a square cross section of ∈2mm (fig. 2.b) [15].

In order to perform the metallographic analysis the samples were cut using a special cutting system at low cutting speeds with continuous cooling so as to prevent the analysed zone from being affected by the heat. After the cutting process, the samples were cleaned from impurities and subject to a polishing process using metallographic paper with different granulations; finally, the samples were subject to polishing with abrasive diamond paste.

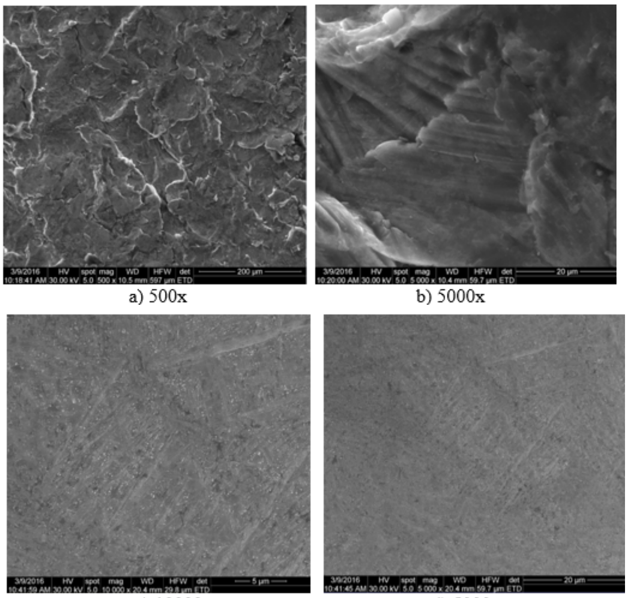
Results and discussions

Figure 3 presents the micrographic images obtained by using SEM for the two types of analysed samples. It is can be seen that at the surface of the analysed samples there is an un-melted area or a partially molten area of the titanium alloy powder. Furthermore, it can be seen that there are differences with respect to the quality of the molten surface of the two types of analysed samples.

The surface of the test samples with circular cross section had high roughness and can be considered as a porous surface because the powder was not wholly sintered, which can be observed by continuous spheroidal or plate agglomerates of metallic powder (fig. 3.a. and 3.b) [16].

The surface of the test samples with square cross section had lower roughness compared to the samples with circular cross section (fig. 3.c. and 3.d). Furthermore, in this case a columnar structure can be seen, which is partially martensitic and specific to Ti-6Al-4V alloy.

The influence of Ti6-Al4-V on the corrosion of NiCr and CoCr alloys was studied in [17].



a) 500x b) 5000x

c) 10000x d) 5000x

Fig. 3. SEM image showing the quality of the test samples obtained by DMLS process: a, b - test samples with circular cross section; c, d - test samples with square cross section

Conclusions

The microstructural analysis of the surface quality of Ti-6Al-4V DMLS samples led to the following conclusions:

- the surface quality of the samples obtained by sintering with the help of DMLS rapid prototyping process depends on the shape of their cross section and is influenced by the discretization possibility of the model surface;

- when using the DMLS process, the test samples with square cross section have a columnar grain with partial martensitic structure;

- when using the DMLS process, the surface of test samples with circular cross section contains un-melted or partially melted powder particles with high roughness.

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