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Analysis of the Physicochemical Properties of The Ti6Al4V Titanium Alloy Produced by the Plastic Working Method and the SLS Method

KIERAT Oliwia[1,a], DUDEK Agata[1,b *] and MOSKAL Grzegorz[2,c]

[1]Czestochowa University of Technology, Faculty of Production Engineering and Materials Technology, Department of Material Engineering, Czestochowa, Poland, EU

[2]Silesian University of Technology, Faculty of Materials Science and Engineering, Department of Material Technologies, Katowice, Poland, EU

[a]oliwia.kierat@pcz.pl, [b]agata.dudek@pcz.pl, [c]grzegorz.moskal@polsl.pl

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Abstract. This work compared the physicochemical properties of the Ti6Al4V titanium alloy produced by plastic working and selective laser sintering. The corrosion behavior of materials was analyzed in terms of their application in medicine, particularly in implantology. For this purpose, corrosion resistance tests were carried out in Ringer's fluid. The microstructural analysis of these materials was performed – before and after corrosion tests using the KEYENCE VHX-7000 digital microscope. Phase analysis of these materials was performed using a SEIFERT T-T X-ray diffractometer.

Introduction

Ti6Al4V titanium alloy is successfully used in the automotive and aviation industries, as well as in medicine [1-3]. Taking into account biomedical applications, the use of titanium alloy in implantology deserves special attention due to a number of advantages such as corrosion resistance, high biocompatibility, low weight, and fatigue strength [4]. However, the excessively high Young's modulus of the Ti6Al4V titanium alloy compared to bone entails limitations in implantological applications, negatively affecting, among others, the connection of the implant surface with the bone tissue [1, 5]. An alternative solution to this problem is the use of 3D printing for the production of Ti6Al4V titanium alloy [6]. The following technologies are mainly used for 3D printing of powdered metals: (i) selective laser sintering (SLS), (ii) selective laser melting (SLM), and laser surfacing (LMD) [1]. Selective laser sintering uses a laser beam to sinter powdered materials, resulting in the formation of three-dimensional objects [7]. The process of selective laser melting is analogous, but in this case, the laser beam is used to melt powdered materials [1]. In the laser surfacing process (LMD), the laser creates a pool of liquid metal into which the melting powder is fed. As a result of this process, sediment is created that connects to the substrate - thus, layer by layer, a 3D object is created.

In this study, the properties of Ti6Al4V titanium alloy produced by plastic working and 3D printed by selective laser sintering were compared. In particular, the research focused on the corrosion resistance of titanium alloys produced by plastic working and selective laser sintering, their microstructural analysis, and phase composition analysis.

The presented results may be engaging in many industries due to the desired corrosion resistance, e.g. when applying special surface layers [8-10] obtained by coating deposition [11-14], their subsequent modification with laser treatment [15-18], but also in the production of devices exposed to corrosion in hydraulic heavy-duty machines [19, 20], to biocorrosion in biotechnology industry [21-23], agriculture [24-26] and surgery implants [27-29]. They can also inspire the development of classic data analysis methods [30-32], their non-parametric variants [33], and failure analysis methods [34-37]. A significant improvement in corrosion resistance will also have a large impact on the current quality management due to the extension of the service time of equipment and infrastructure [38-42].

Materials and Methods

Titanium alloy Ti6Al4V was obtained by two methods: the plastic working method and the selective laser sintering (SLS) method was used for the tests. To visualize the microstructure, the specimens were etched with a reagent containing: 2.5 ml of nitric acid, 2.5 ml of hydrofluoric acid, and 95 ml of water.

The corrosion resistance of the tested materials was tested. For this purpose, samples of titanium alloy were mounted in polymethyl methacrylate frames with epoxy resin and mechanically polished using sandpaper with a grain size of up to 2000. The corrosion resistance tests were carried out using the CH Instruments 440A (USA) measuring station in a three-electrode system, where a platinum electrode was used as the auxiliary electrode, and the reference electrode was a saturated calomel electrode, and the working electrode was the tested titanium alloy sample. In order to test the corrosion resistance, potentiodynamic polarization curves were recorded in the potential range from -1.5 to +3.0 V (measured against a saturated calomel electrode - NEK). Ringer's fluid was used as the corrosive medium. The composition of Ringer's fluid is shown in Table 1.

Table 1. *Ringer's fluid composition*

Ingredient	NaCl	KCl	$CaCl_2$
Amount [g/l]	8,6	0,3	0,333

The KEYENCE VHX-7000 digital microscope was used for microstructural analysis of the tested materials, both before and after the corrosion tests. Phase analysis was performed using a SEIFERT T-T X-ray diffractometer.

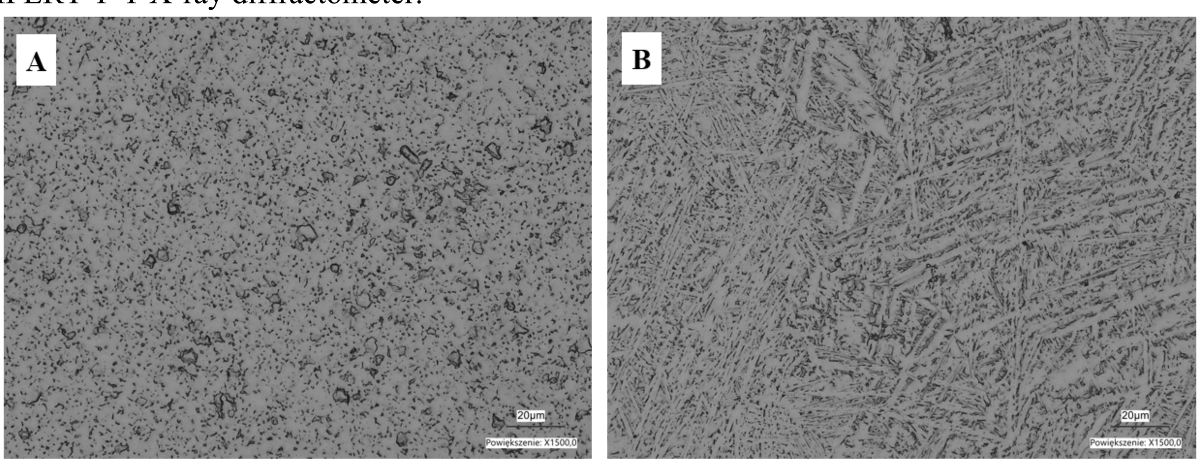

Fig. 1. *Microstructure of (A) Ti6Al4V titanium alloy produced by plastic working method and (B) Ti6Al4V titanium alloy 3D printed by SLS method.*

Results

Fig. 1 shows the microstructure of the Ti6Al4V titanium alloy (A) produced by plastic working and (B) 3D printed using the SLS method. Ti6Al4V titanium alloy is an $\alpha + \beta$ two-phase alloy.

Based on the obtained microstructures, it was found that the method of producing the Ti6Al4V titanium alloy significantly affects its structure. The structure of both samples shows a different morphology. The microstructure of Ti6Al4V titanium alloy produced by plastic working is visible, equiaxed grains, while the microstructure of Ti6Al4V 3D SLS alloy is acicular.

Phase analysis of the Ti6Al4V alloy produced by various methods was performed. Fig. 2 shows the diffractogram recorded for the Ti6Al4V titanium alloy produced by the plastic working method, and in Fig. 3 for the Ti6Al4V alloy produced by the SLS method. Phase analysis revealed the presence of α and β phases for both materials. Peak positions were read from recorded diffractograms and fitted to individual α and β phases.

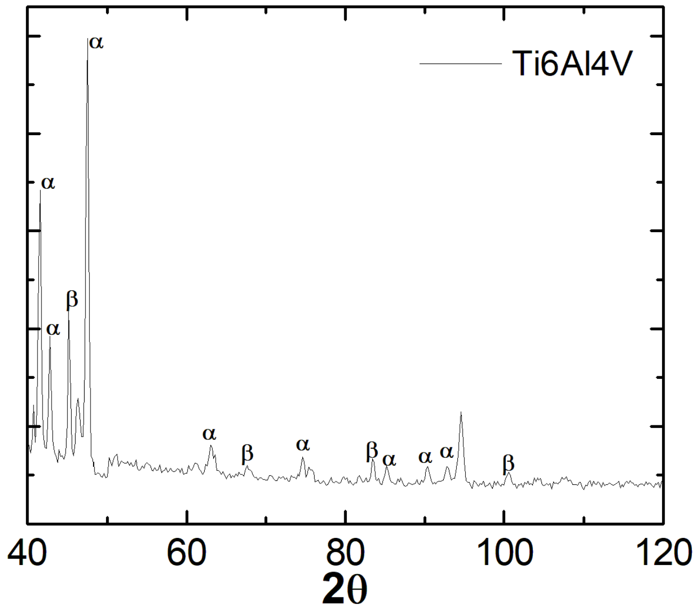

Fig. 2. *The diffractogram registered for the Ti6Al4V titanium alloy produced by the plastic working method.*

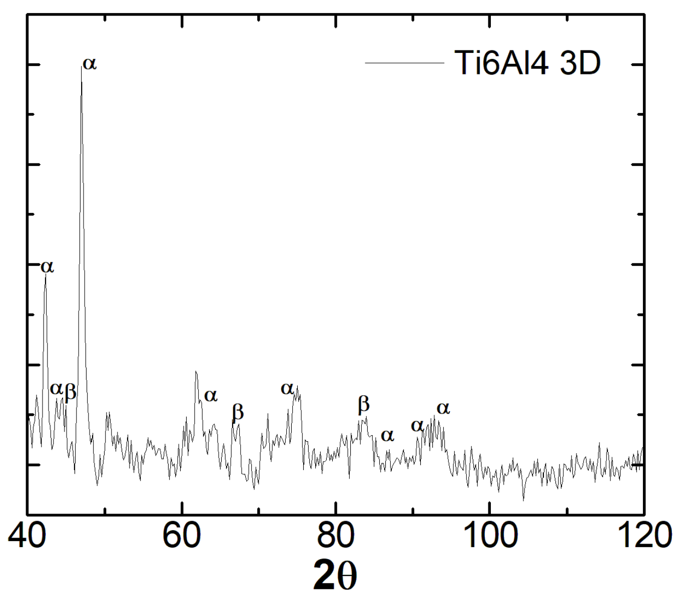

Fig. 3. *Diffractogram registered for Ti6Al4V titanium alloy 3D printed by SLS method.*

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The corrosion resistance of the Ti6Al4V titanium alloy was tested. Fig. 4 shows the potentiodynamic polarization curves for the Ti6Al4V titanium alloy produced by plastic working and by selective laser sintering. The corrosive potential of the Ti6Al4V alloy was -0.7 V, while the Ti6Al4V 3D SLS alloy was - 0.63 V. The cathode current densities for both materials were the same. For the Ti6Al4V 3D SLS alloy, a sharp increase in the anode currents density was observed for the potential above +1.9 V.

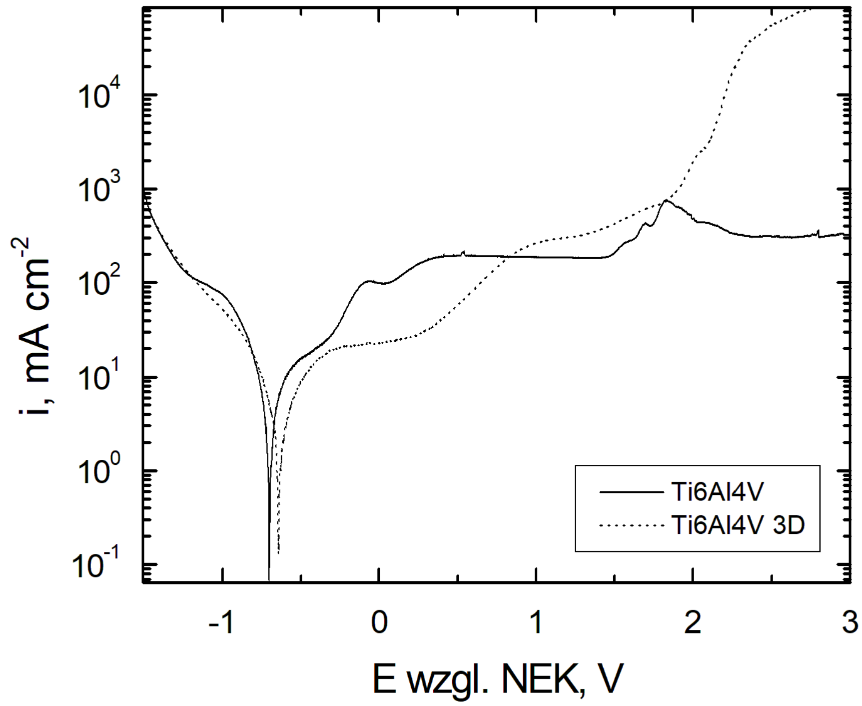

Fig. 4. *Potentiodynamic polarization curves recorded for the Ti6Al4V titanium alloy produced by plastic working and 3D printed with the SLS method in Ringer's fluid.*

Fig. 5 shows the microstructures of the Ti6Al4V titanium alloy produced by various methods after corrosion tests in Ringer's fluid. No signs of pitting corrosion were observed on the surface of these materials, which proves the good corrosion resistance of both the Ti6Al4V titanium alloy produced by plastic working and 3D printed by SLS.

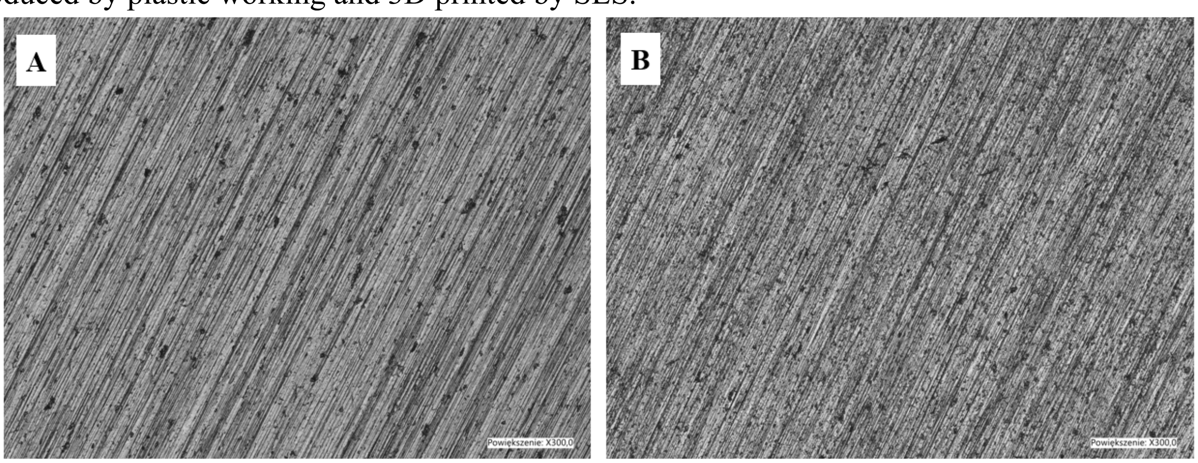

Fig. 5. *Microstructure of (A) Ti6Al4V titanium alloy produced by plastic working and (B) Ti6Al4V titanium alloy produced by SLS method after corrosion tests.*

Conclusions

In this study, an analysis of the physicochemical properties of the Ti6Al4V titanium alloy depending on the production method was carried out. It was revealed that the structure of the tested materials had a different morphology. The Ti6Al4V alloy produced due to plastic working had equiaxial grains, while the Ti6Al4V alloy, 3D printed using the SLS method, had a coniferous structure. The X-ray analysis confirmed the presence of α and β phases in both materials. The corrosion resistance of both materials was analyzed in Ringer's fluid. The conducted analysis revealed slight differences in the corrosion potential values - the corrosion potential of the Ti6Al4V alloy produced by the SLS method was shifted by 0.07 V towards positive values in relation to the corrosion potential of the Ti6Al4V alloy made as a result of plastic working. The cathode current densities were equal in both cases. For the Ti6Al4V 3D SLS alloy, a rapid increase in the anode currents density for the potential above +1.9 V was observed. The microstructural analysis performed after the corrosion tests did not reveal any signs of pitting corrosion.

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