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Comparison of mechanical properties of Ti-6Al-4V titanium alloy produced by the conventional method and the injection

P. Smolarczyk, A. Łukaszewicz*, M. Szota, M. Nabiałek, A. Bukowska
Faculty of Production Engineering and Materials Technology,
Czestochowa University of Technology, Al. Armii Krajowej 19, Częstochowa, Poland
* Corresponding e-mail address: alukaszewicz@wip.pcz.pl

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Properties

ABSTRACT

Purpose: In these paper was were characterized mechanical properties of titanium alloy Ti-6Al-4V, which were produced by two methods - conventional casting and injection casting. Studies were presented by comparing of samples which were produced by these methods.
Design/methodology/approach: Samples were produced by two methods – conventional and injection casting. To achieve the objective were performer the following steps: the microstructure was carried out, the analysis of mechanical properties was done (microhardness), study of surface roughness was made, research of abrasion was made and phase composition by X-ray diffraction was made. After then then a comparison of these studies between these samples was made.
Findings: The study of the microstructure was observed that the titanium alloy Ti-6Al-4V prepared by the conventional method, it has equiaxed and globular structure. In contrast, titanium alloy produced by the injection has strips structure, where phase α' is on phase β border. Further studies have shown that a sample of titanium alloy Ti-6Al-4V produced by injection it has a much greater tribological resistance because it has a higher microhardness and much greater roughness than the sample of the same alloy produced by the conventional method.
Originality/value: In this article conducted a comparative characteristics for the two production methods - conventional and injection - titanium alloy Ti-6Al-4V. The research indicated that much better mechanical properties are characterized alloys produced by injection.
Keywords: Comparative study; Injection method; Conventional method; Mechanical properties; Titanium alloy Ti-6Al-4V

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1. Introduction

The development of industry, has caused a need for novel materials that will meet a number of stringent requirements in terms of mechanical properties and physicochemical [1]. From the middle of the last century, in the context of industry on a large scale began to use titanium and its alloys. Titanium - due to its properties - started to be used in many industrial sectors: aviation (jet engine turbine), automotive (car parts Formula 1 - motors, valves), medical (dental implants and bone implants), the nuclear power industry, architecture, food industry (dye E171) and other industrie [2].

Taking into account the use of titanium and its alloys, it is worth to look at what its properties determine the suitability. For example, for aviation, through the use of vanadium-titanium alloys, the material is obtained with significant strength in relation to low density [3]. Topping airport, which is made mostly of titanium alloys is the SR-71 Blackbird. Production of this aircraft has opened the way for the use of titanium and its alloys in the construction of passenger flying units - Boeing 777, 747, 737 and Airbus A320, A330 [4,5].

Relevant properties of titanium and its alloys are obtained by a series of operations, or an appropriate selection of alloying elements, which have a significant effect on the production of the individual phases Ti_{α} and Ti_{β} [6]. Another way to obtain the desired properties can be atomic applying suitable coatings which enhance the properties of these alloys. The effect on the properties of titanium alloys can also be observed as a result of changes in technology, the production of these alloys.

Focusing on the latter element - production technology - among the currently used methods include: casting, plastic forming process and machining. In order to obtain components with complex geometry, the most commonly used casting. This method allows to obtain the appropriate shape, with a significantly lower cost - up to 30% relative to the metal forming processes [7]. This method is used when the performance of a given element is not possible by the turning of or welding, for example jet engine rotors, pump rotors, casings. For this purpose, it is recommended to use a casting in metal molds. This method was improved by construction of appropriate treatment for manufacturing the device itself, which was abandoned of gravity and push the material into the mold is done by the pressure. The advantages of that method against conventional casting are: possibility of obtaining fine grain metal structures through the use of rapid cooling, which allows for a much higher fatigue strength as compared to the elements obtained by conventional casting; additionally in injection casting (VDC) [8] is eliminated the process of waxing and shaping ceramic mold, which is necessary at the time of precision casting with using melted models.

The injection method is that the metallic material is in liquid form is injected into the mold copper. This process consists of the following steps [9]:

- placing a pre-melted ingot to the quartz capillary,
- induction melting ingot,
- injection into the copper mold under the influence of noble gas,
- cooling of the melt in the mold, which has radial.

Apparatus for the preparation samples by injection method is composed of: vacuum work chamber, vacuum transformer coil position controller, induction furnace, gauge, pumping system, control panel injection process and cooling, control rotary and diffusion pump, vacuum gauges and cooling medium. The device was designed and build on Faculty of Manufacturing Engineering and Materials Technology - Częstochowa University of Technology.The sample was produced by using copper mold - Fig. 1.

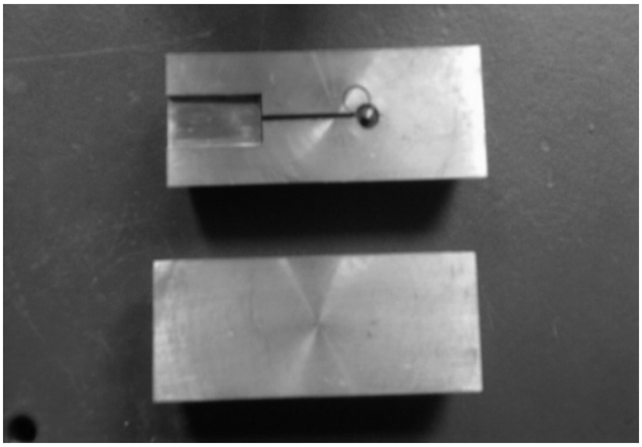

Fig. 1. Copper mold wich was used in injection method

2. Material and methodology

Test samples were titanium alloy Ti-6Al-4V, whose chemical composition is given in Table 1.

Table 1.
Chemical composition of Ti-6Al-4V [10]

Component of alloy	The percentage [%]
Al	6.00
V	4.00
C	0.03
Fe	0.1
O	0.15
N	0.01
H	0.003
Ti	rest

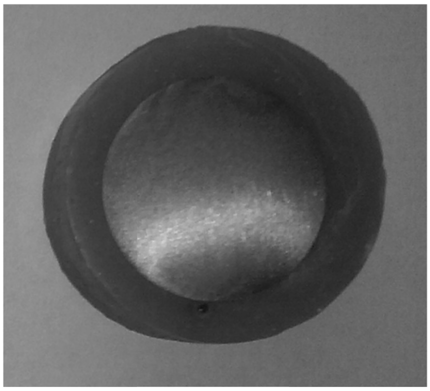

Fig.2. Macroscopic samples of Ti-6Al-4V alloy produced by conventional method

Test samples were made using two methods - by conventional casting and by injection. The cast parts were cut into pieces, which are then embedded in epoxy resin. This procedure allowed for a much easier keeping the sample in the time research, and secured it from direct contact with fingers. Macroscopic samples of titanium Ti-6Al-4V produced by these methods shows in in Fig. 2 the sample formed by casting, and Fig. 3 for a sample produced by the injection.

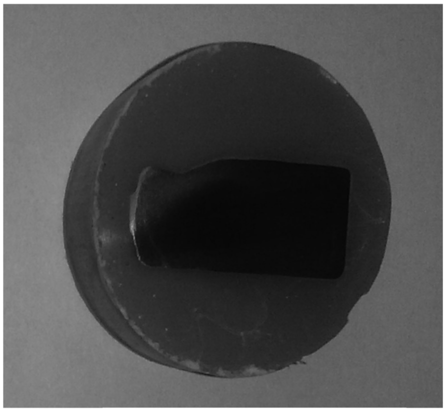

Fig. 3. Macroscopic samples of titanium Ti-6Al-4V obtained by injection

Subsequently, these samples were subjected to microstructural examination which was used Axiovert 25 microscope light produced by the Carl-Zeiss. The microscope is additionally equipped the camera, the images were taken of structures.

Subsequently, the samples were tested with the topography of the profilometer HOMMEL T1000. Measuring the length of this device is 80µm. This study consisted of a device's needle contact with the surface of the sample device. The needle was connected with differentiating system. On the basis of study were obtained information about surface roughness.

Samples were subjected to microhardness testing. The tests were performed at Vicker's method with load equal 980.7 mN - HV 0.1 with using the microhardness machine FM - 7 firmy FUTURE - TECH.

The next step was to study the abrasion made with using ball-tester, where abrasive material was zirconium ball. The resulting samples were subjected to X-ray qualitative analysis to determine the phase composition. X-ray diffraction was performed on the X-ray Seifert 3003 T - T, with using filtered radiation from a cobalt lamp, for which the X-ray wavelength is $\lambda = 0.179$ nm, filament current was 30 mA, and the voltage 40 kV.

3. Results

The obtained images of the microstructures of samples tested are shown in Fig. 4. Where Fig. 4a is a structure of titanium alloy Ti-6Al-4V produced by the conventional method, while Fig. 4b is the structure of titanium alloy Ti-6Al-4V produced by injection.

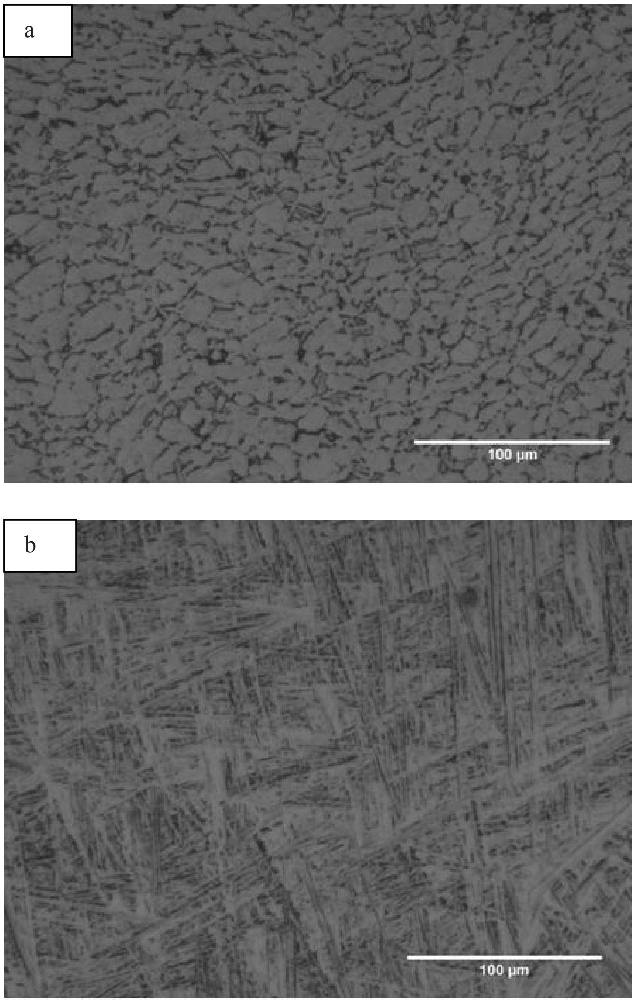

Fig. 4. Microstructure of titanium alloy Ti-6Al-4V produced by a) conventional method, b) injection method. Zoom x500

Microstructural observations of titanium alloy produced by two methods made it possible to determine the type of the resulting structure. The titanium alloy Ti-6Al-4V prepared by the conventional method, it has equiaxed and globular structure Fig. 4a. In contrast, titanium alloy produced by the injection has strips structure, where phase α' is on phase β border Fig. 4b. Proof of that observation of these phases are graphs of qualitative X-ray diffraction, which is shown in Fig. 5.

Roughness test were performed in three measurements for samples made with both methods. Then, the averaged results of all tests are presented in Table 4. These values are presented on column graph in Fig. 8; components of this graph are the data obtained during the test roughness profiles - Figs. 6 and 7.

a)

b)

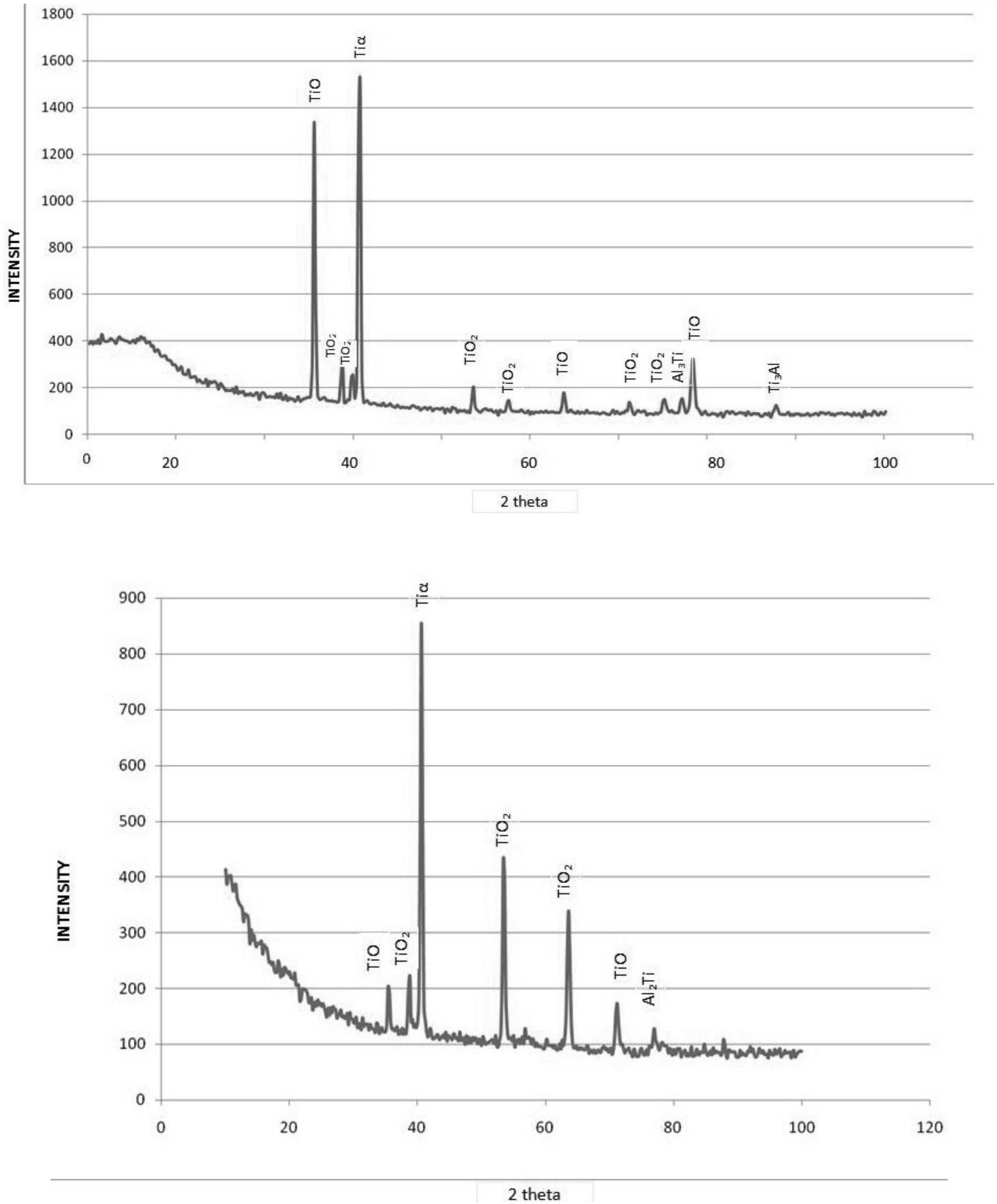

Fig. 5. Diffraction patterns for alloy Ti-6Al-4V produced by a) conventional method, b) injection method

Tabulation of microhardness measurement results shown in Table 5, then the averaged results shown in Fig. 9. These studies were performed in a 10 hardness tests for each sample.

Microhardness tests was showed that in the case of a titanium alloy sample Ti-6Al-4V produced by the conventional method is much lower hardness than that of the same sample prpduced by injection. It is worth mentioning here the fact that the sample produced by the injection is characterized by a much greater hardness throughout its cross - both: core and surface. Arithmetic averages for the individual samples equal:

- sample produced by the conventional method: 342.61 HV0.1,
- the sample produced by the injection method: 451.04 HV0.1 (core),
- the sample produced by the injection method: 474.67 HV0.1 (surface).

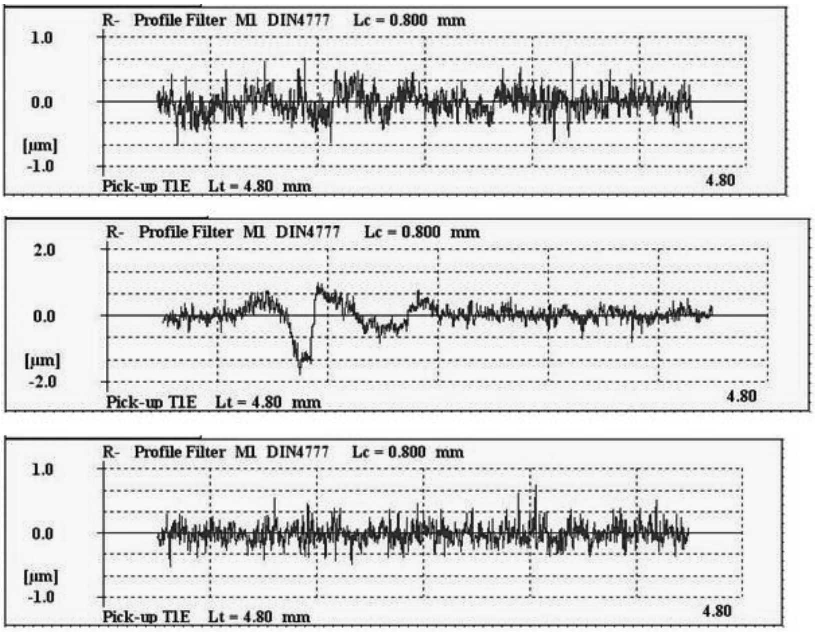

Fig. 6. The results of three different measurements of the roughness profile of a sample Ti-6Al-4V produced by the conventional method

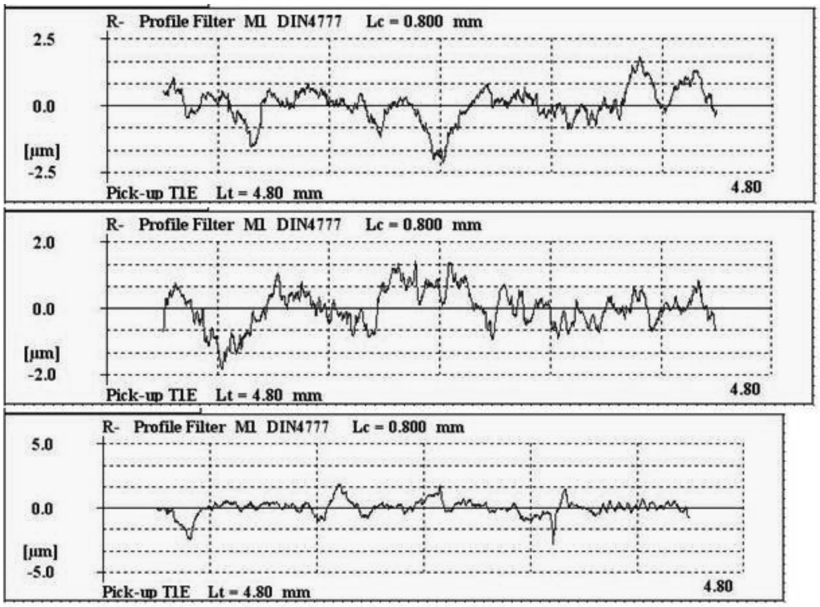

Fig. 7. The results of three different measurements of the roughness profile of a sample Ti-6Al-4V produced by the conventional method

Table 2.
Tabulated results roughness measurements alloy Ti-6Al-4V produced by the conventional method

Roughness parametr	Measurement result 1	Measurement result 2	Measurement result 3
Ra [µm]	0.14	0.23	0.1
Rz [µm]	1.13	1.62	0.95
Rmax [µm]	1.32	2.82	1.11

Table 3.
Tabulated results roughness measurements alloy Ti-6Al-4V produced by the injection method

Roughness parametr	Measurement result 1	Measurement result 2	Measurement result 3
Ra [µm]	0.48	0.46	0.43
Rz [µm]	2.3	2.04	2.97
Rmax [µm]	2.92	2.61	4.36

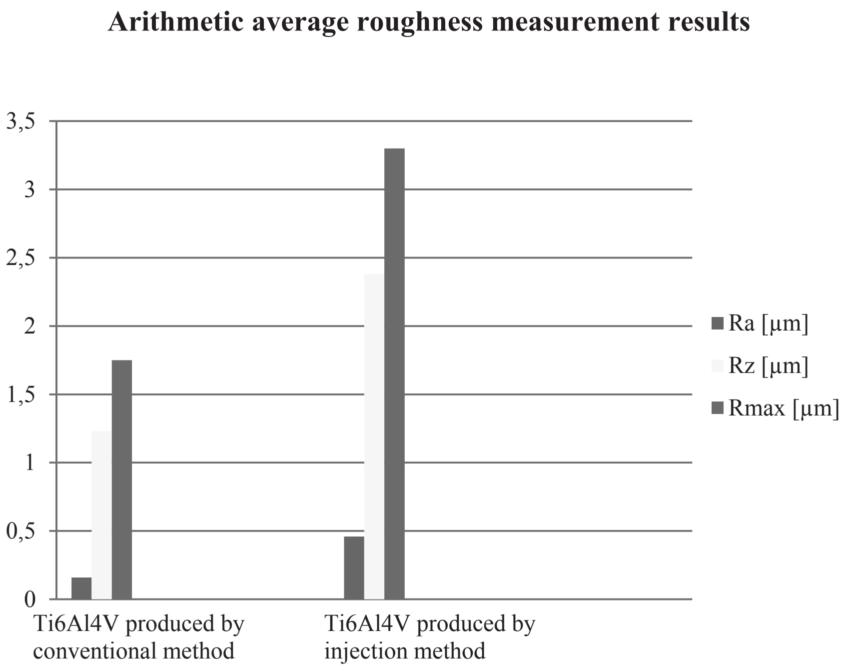

Fig. 8. Arithmetic average of the roughness profile measurement results for the alloy Ti-6Al-4V produced by the conventional method and the injection

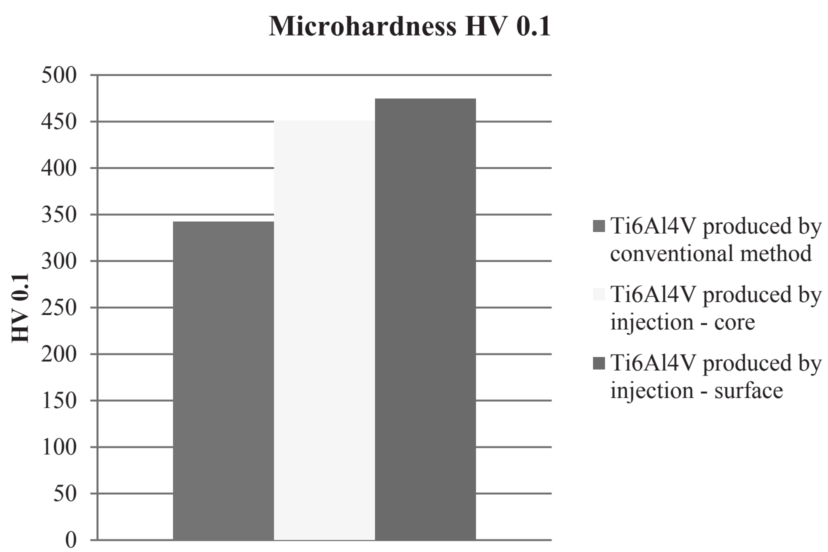

Fig. 9. Average results of microhardness of titanium alloy Ti-6Al-4V produced by conventional and injection method. For injection were obtained results for core and surface

The next step was to conduct studies relating to the resistance to abrasion - which was carried out using ball-tester. These tests were performed for each of the methods (conventional and injection) in triplicate - 0.5 h, 1h and 2 h (Figs. 10-12).

Tests of resistance to abrasion showed for each of the times that the sample alloy Ti-6Al-4V prepared by injection characterized by a much greater strength than those produced by the conventional method.

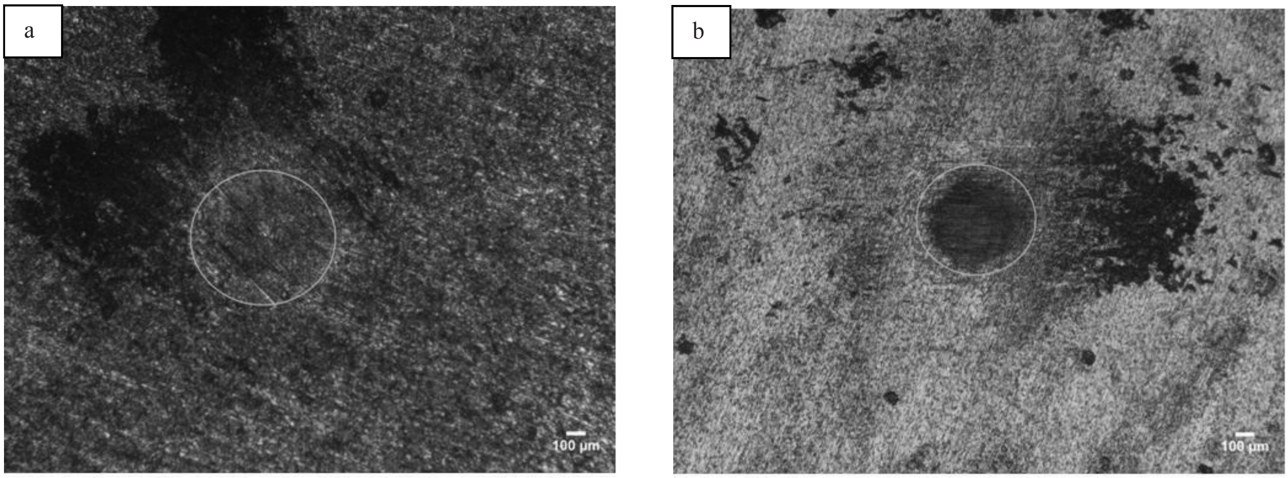

Fig. 10. Microscope figures were obtained after 0.5h of testing on ball-tester, a)conventional method, b) injection method

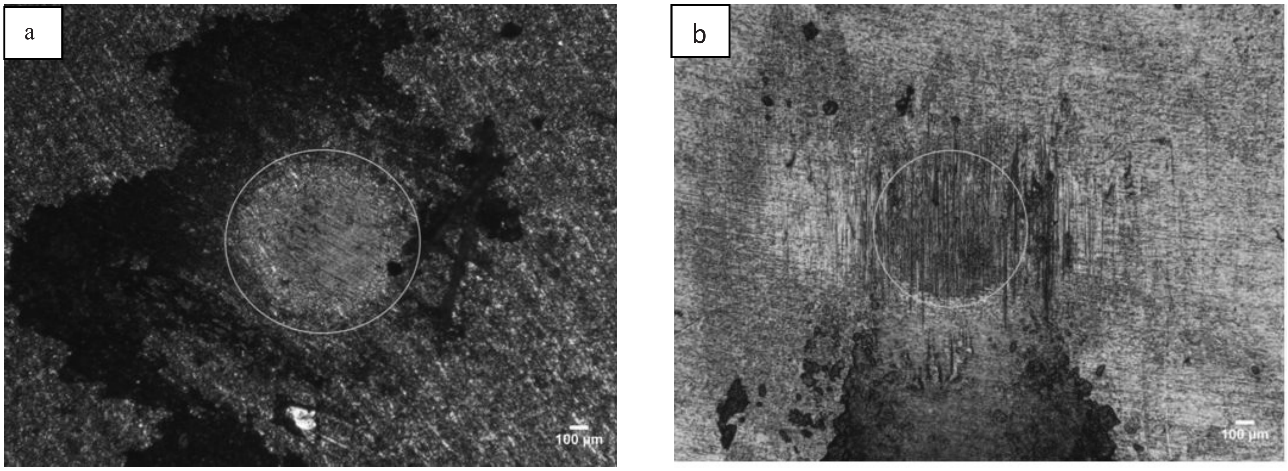

Fig. 11. Microscope figures were obtained after 1h of testing on ball-tester, a) conventional method, b) injection method

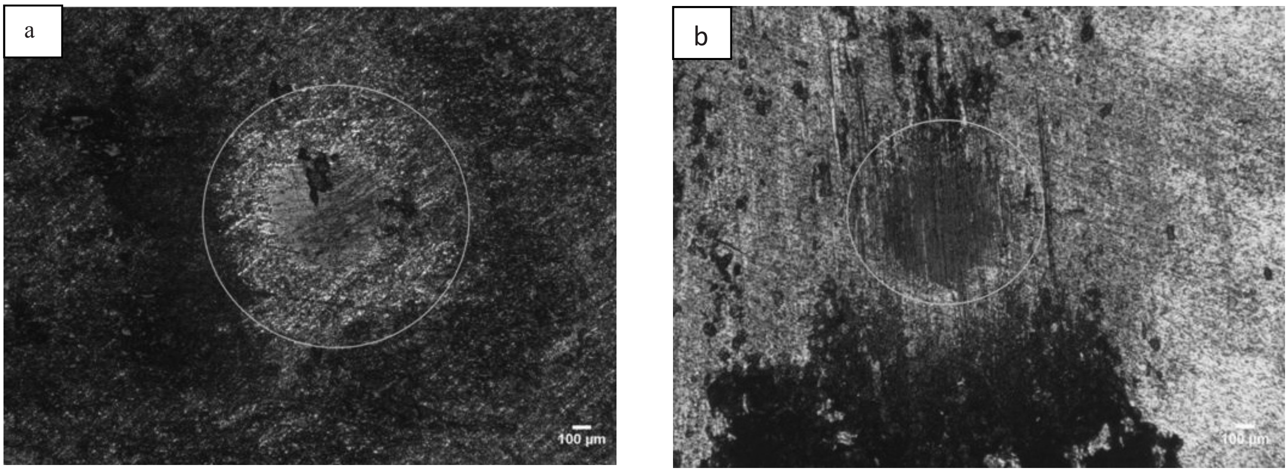

Fig. 12. Microscope figures were obtained after 2h of testing on ball-tester, a) conventional method, b) injection method

Table 4.
A tabular summary of the averages of the measurements of the roughness profile alloy Ti-6Al-4V made by the conventional method and the injection

Roughness parametr	Averages of roughness measurements	
	Alloy Ti-6Al-4V produced by conventional method	Alloy Ti-6Al-4V produced by injection method
Ra [µm]	0.16	0.46
Rz [µm]	1.23	2.38
Rmax [µm]	1.75	3.3

Table 5.
Results of microhardnerss HV 0.1 measurement, were carried out for titanium alloy Ti-6Al-4V for samples produced by conventional and injection methods

Number of measurement	Microhardness HV 0.1		
	Ti6Al4V conventional method	Ti6Al4V injection method	
		Core	Surface
1	332.1	445.2	467.68
2	363.2	446	448
3	330.1	442.1	471.8
4	334.4	441.5	476.6
5	339.4	448.2	493.5
6	343.9	470.4	515.9
7	357.8	477.6	522.2
8	337.1	446.7	449.1
9	339.7	444.7	450
10	348.4	448	451.8
Average results	342.61	451.04	474.67

Table 6.
Tabulation of the diameter and depth of the abrasion of titanium alloy Ti-6Al-4V produced by the conventional method and the injection of the individual time

Sample	Time / diameter abrasion of [µm]			Time /depth of abrasion [µm]		
	0.5 h	1 h	2 h	0.5 h	1 h	2 h
Ti6Al4V Produced by conventional method	741.6	991.6	1375	360.7	485.7	677.4
Ti6Al4V Produced by injection method	600	783.3	1008.3	289.8	381.6	494.1

4. Conclusions

Structural studies were showed a significant difference in structures of titanium alloy Ti-6Al-4V -between conventional method and injection method. This indicates that the process has been affected by the structure.

On the basis of further research can make the following conclusions: by studying on a Hommel T1000 profilometer can be concluded that the titanium alloy Ti-6Al-4V samples prepared by injection have more roughness than the titanium alloy sample produced conventionally, the difference is about 53.5%. Further studies indicated lower by more than 40% microhardness of titanium alloy produced by conventional method, than produced by injection method. Average results of conventional sample microhardness is equal 342,61 HV0,1. and for injection casting is equal 451.04 HV0.1 for core, 474.67 HV0,1 for surface. Samples of the titanium alloy were produced by the injection have much better tribological resistance, as indicated by the depth and diameter of abrasion, which was higher in the samples of titanium alloy Ti-6Al-4V produced by conventional method.

To summarize the information gathered, it is clear that mechanical properties of alloys are depending upon the method of production. In order to visible improvements in these properties should be applied technological procedure consists on injection casting.

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