# RESEARCH ON THE MECHANICAL PROPERTIES OF TITANIUM BIOCOMPATIBLE ALLOYS OBTAINED BY SINTERING

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*This paper presents a study on the microstructural and mechanical characteristics of a biocompatible Ti-6Al-4V alloy used for orthopedic implants. The Ti-6Al-4V test pieces were obtained by the Direct Melting Laser Sintering (DMLS) process. The test pieces obtained by sintering were properly processed and subjected to the tensile test. Following the analysis of the obtained results it was concluded that the values of the mechanical properties of the sintered test samples are within the limits as prescribed by the producer of the titanium biocompatible alloy powder. The products obtained by DMLS offer excellent combination of tensile strength, ductility and coefficient of elasticity, which proves the high mechanical biocompatibility of the Ti-6Al-4V alloy and its suitability for biomedical applications involving static or dynamic loading conditions, as for example orthopedic implants.*

**Keywords**: orthopedic implant, titanium alloy, biocompatible, laser sintering

## 1. Introduction

Contemporary product design processes have been affected by new technologies that assist the manufacturing sector to meet the specifications of specialized components used in the aerospace and medical industries [1,2]. Direct selective laser sintering (SLS) or, more specifically when considering the processing of metal, direct metal laser sintering (DMLS), are some of these technologies. Implants used in the medical industry to repair or replace bone structure must be strong, ductile and biocompatible [3,4].

The basic principle of the Direct Metal Laser Sintering (DMLS) Technology is to melt down thin layers (20 ÷ 60 μm) of Metal Powder with an

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electronically driven LASER beam (200W). The DMLS technology was developed, like other Rapid Prototyping technologies, to provide a prototyping technique to decrease the time and cost of the product cycle design. It consists of building a three dimensional object layer by partial melting a powder bed by laser radiation [5, 6].

Most metallic materials currently used in the manufacture of prostheses and medical devices are, at best, inert to human bone tissue. These may become bioactive by controlling the morphology and chemical composition at the surface level. The material type, the process and product standards, the chemical composition, the processing conditions and mechanical properties significantly affect the interaction between the material and the bone tissue. The long-term stability of the implant is closely linked to its ability to integrate into adjacent bone tissue [7-9].

At this moment orthopedic prostheses can be made of metallic materials as stainless steel, Co-Cr alloys, nickel-titanium alloys, beta-titanium alloys [10].

Titanium and its alloys are intensively used as biomaterials in bone surgery, thanks to good biocompatibility. In addition, titanium and titanium alloys have high mechanical properties (resistance to abrasion, torque and pressure), has small specific weight (half of the specific weight of steel), it is not toxic (stainless steel can cause a series of allergies) and is not ferromagnetic (allows persons with prostheses to make investigations using magnetic resonance imaging -MRI-method) [11].

## 2. Experimental procedure

The main objective of the experimental procedure was to analyze in terms of mechanical properties the test samples made of the biocompatible alloy Ti-6Al-4V and manufactured using the Direct Metal Laser Sintering process (DMLS).

The test samples used for the experimental trials were made by using the DMLS process on EOS Titanium Ti64, a titanium alloy powder which has been optimized especially for processing on EOSINT M systems (EOSINT M270). Parts built in EOS Titanium Ti64 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 [12-16].

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 (note: subject to the fulfilment of statutory validation requirements where appropriate). Because they were built in layers, the parts have a certain anisotropy, which can be reduced or removed by appropriate heat treatment [16].

The properties of EOS Titanium Ti64 powder are presented in table 1 and the chemical composition is presented in table 2 [16].

*Table 1*

**Properties of EOS Titanium Ti64 powder [16]**

| Material (DMLS) | Tensile strength $R_m$ [MPa] | Yield strength $Rp_{0.2}$ [MPa] | Elongation [%] | Modulus of elasticity [GPa] | Hardness [HRC] |
|---|---|---|---|---|---|
| Ti-6Al-4V | 1150 ± 60 | 1030 ± 70 | 11 ± 2 | 110 ± 15 | 31-35 |

*Table 2*

**Chemical composition of EOS Titanium Ti64 powder [16]**

| Material | Al [%] | V [%] | Ti [%] |
|---|---|---|---|
| Ti64 powder | 5.5-6.75 | 3.5-4.5 | balance |

In order to conduct the tensile test and the experimental measurements of the mechanical properties of the sintered titanium alloy Ti-6Al-4V obtained using the EOSINT M270 machine, four test samples were manufactured from this material. Their shape was designed in accordance with EN ISO 6892-1: 2010, with the dimensions shown in Fig. 1, these test samples having two areas for fixing in the clamping devices of the static testing equipment and an active area with a length of 60 mm, on which an extensometer was mounted [17].

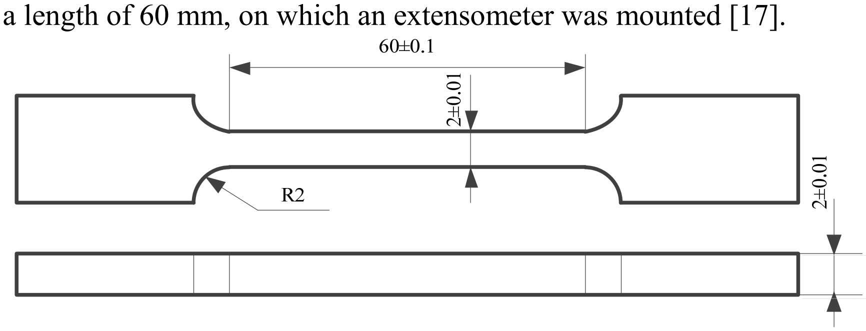



Fig. 1. The form of the manufactured test samples for tensile test

Since the loading capacity of the static testing equipment was 1 kN, from the design stage the test samples were provided with a square section in the active area with a 2 mm side, meaning a cross sectional area A = 4 mm$^2$, thereby limiting maximum tensile force to an approximate value of 5000 N.

In accordance with the testing standard, the transition from the active area to the clamping area was performed using the maximum possible connecting radius (R = 2 mm), so that in this zone there are no effort concentrators.

The test samples were numbered from 1 to 4 (see Fig. 4) with a permanent marker, at both ends on the clamping area in order to ensure the traceability of the test. The method of attachment (clamping) of the test samples on the static testing equipment is shown in Fig. 2.

Fig. 2. Clamping the tests on the H10KT tensile tester

A dedicated subroutine was designed for the testing in which the test speed was established to 2 mm/min (corresponding to a loading rate of $23N/mm^2 \cdot s$), and the breaking of the test sample was the ending condition for the test [18,19,20].

After completing the tensile test, the tests samples were tested in order to determine their hardness using the HRC method. The testing was conducted in accordance with the requirements of EN ISO 6508: 2015 [21].

Following the completion of the experimental tests we obtained information on:

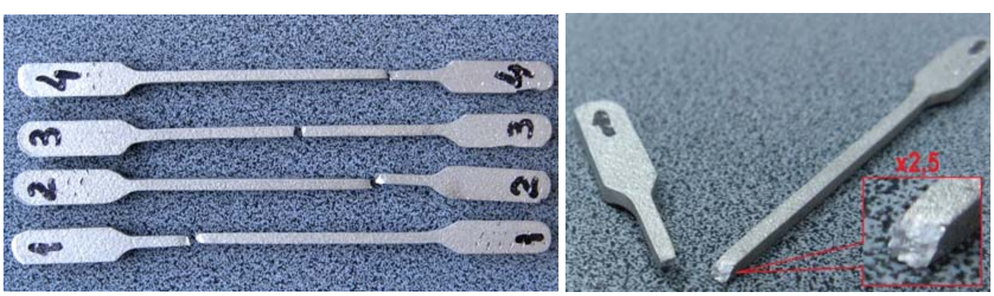
- Stress-strain curve;
- Tensile strength [MPa];
- Yield strength [MPa];
- Elongation to break;
- Elastic modulus [MPa];
- Hardness [HRC].

### 3. Results and discussions

After subjecting the test samples to tensile testing the characteristic curve was obtained, the curve being traced out automatically by the software of the testing equipment. Since the curve shape for the other samples is similar and the drawing of all four curves in a single figure would have charged too much the image, in Fig. 2 is presented only the resulting curve for sample number 1.


Fig. 2. Stress-strain curve of Ti-6Al-4V test sample no. 1

Based on the analysis of the characteristic curve shown in Fig. 2 it was noted that the material has no plateau region in the yielding zone, while in the strain hardening zone the stress is increasing due to the cold hardening of the material just before fracture. Corresponding to the tensile strength of 1120.33MPa and to the sample area which was $1.99 \times 2.08 = 4.14\text{mm}^2$, the breaking load can be calculated, the result being 4637.6N. The aspect of the test samples after the tensile test is illustrated in Fig. 3. and the appearance of the fracture area in sample 1 is shown in Fig. 3.b.




a) b)

Fig. 3. Results of the tensile test: a – the samples resulted following the tensile test, b – appearance of the fracture area for sample no. 1.

By analyzing the fracture area of the samples in Fig. 3.b., a slight fragile breaking aspect of the sample can be noticed, with reduced plastic deformation and reduced necking, cross-sectional area configuration being crystalline, shiny and rough [22].

The mechanical property values resulting from the tests carried on the four samples are presented in table 3.

*Table 3*

**Mechanical properties measured on the test samples**

| Material (DMLS) Ti-6Al-4V | Tensile strength $R_m$ [MPa] | Yield strength $Rp_{0.2}$ [MPa] | Elongation [%] | Modulus of elasticity [GPa] | Hardness [HRC} |
|---|---|---|---|---|---|
| EOS | 1150 ± 60 | 1030 ± 70 | 10 ± 2 | 110 ± 15 | 31-35 |
| Sample 1 | 1120.33 | 1040.99 | 8.98 | 99.41 | 31 |
| Sample 2 | 1132.69 | 1018.14 | 8.57 | 101.72 | 36 |
| Sample 3 | 1091.25 | 998.50 | 8.34 | 102.66 | 38 |
| Sample 4 | 1106.95 | 1006.46 | 9.01 | 107.86 | 34 |
| Average value | 1112.80 | 1016.02 | 8.72 | 102.91 | 34.75 |

Analyzing the results presented in table 1 it is noted that the samples obtained through rapid prototyping DMLS process have mechanical properties that are within the limits recommended by the producer of the titanium powder. Considering these values and comparing them to the mechanical properties of Ti-6Al-4V alloy, it results that products obtained using DMLS process can successfully replace products manufactured using primary methods of processing.

Regarding the differences in hardness value, these may be due to the fact that the testing was performed on samples already used in tensile testing and it is possible that this may have influenced the final result even if the measuring site was located in the clamping area of the sample - area that theoretically should not have suffered deformations.

## 4. Conclusions

A biocompatible test sample Ti-6Al-4V alloy was obtained by Direct Melting Laser Sintering and then examined in order to evaluate mechanical characteristics.

After analyzing the results obtained by subjecting the samples obtained by DMLS process to tensile testing we can draw the following conclusions:

- the values for the mechanical properties of the samples obtained through rapid prototyping DMLS process are within the range of values recommended by the manufacturer of Ti-6Al-4V alloy powder;
- the values from the examined samples indicate that the products obtained by DMLS process offer an excellent combination of tensile strength, ductility and modulus of elasticity, which demonstrates the high mechanical biocompatibility of the Ti-6Al-4V alloy and its suitability for biomedical applications involving static or dynamic loading conditions, as for example orthopedic implants.

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