Mechanical tests for Ti-based alloys as new medical materials

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Abstract. Medical implants of titanium alloys are frequently used in medicine being in attention for the researchers to develop alloys with properties close to the human bone. The most important thing in development of alloys for medical applications is to be composed from biocompatible elements to avoid to affect the health of patients. The paper contains some mechanical properties of three alloys of Ti-Mo-Zr-Ta. Results revealed that it possesses very good mechanical properties for use in medical applications.

1. Introduction
The use of materials for the reconstruction of tissues in the human body comprises several fields: orthopedics, cardiovascular surgery, ophthalmology, dentistry, urology, aesthetic surgery, neurology, etc. They began to be used a few thousand years ago, but clinically important advances have been achieved in the last century [1-3]. Great concern raises to use of non-toxic biomaterials with mechanical properties close to human tissue in medical fields.

Applications of biomaterials in the field of medicine are primarily due to the requirements of medical practice, but also to the continuous evolution of the sciences. A permanent correlation of research in the fields of chemistry, biology, engineering, and medicine drives the science of biomaterials to obtain new materials that can solve the many existing medical problems under current requirements [4-6].

The first metallic alloys used to make implants for orthopedics were alloy steels with vanadium and cobalt-chromium alloys. After 1940 titanium alloys (pure commercial titanium) were introduced. Among the first to make titanium dental implants were Linkow (1968), Branemark (1969) and Hofmann (1985), which, however, also investigated a titanium alloy: Ti6Al4V [7-11].

The study of titanium alloys has been and is an intense concern of researchers with the aim of improving them, of the mechanical, chemical and biological characteristics imposed on implant materials. Titanium alloys were developed by alloying with non-toxic elements to the human body, replacing aluminum and vanadium with other biocompatible elements with human tissue such as molybdenum, zirconium, tantalum, niobium and silicon. Thus, beta alloys and α + β alloys resulted in superior biocompatibility and improved mechanical properties [12-16].
The characteristics of titanium alloys depend on alloying elements, primarily by altering mechanical properties and also at biocompatibility [17-24].

Current paper contain some mechanical characteristics determined by tensile strength, which allow the assessment of the behavior of the alloys undergoing, during their application. The appearance of the breakage surfaces of TMZT alloys was analyzed by metallographic study using electron microscopy.

2. Experimental procedure
The raw materials used in this research are: titanium, molybdenum, zirconium and tantalum (Figure 1). The experimental alloys were fabricated in arc melting method using elements pure. Were elaborated two alloys: Ti15Mo7Zr5Ta and Ti20Mo7Zr5Ta. The samples were remelted at least seven times, to ensure homogeneity. After elaboration, they were cut without being thermally influenced. The chemical analyses (EDX) of the alloys studied are shown in Table 1.

![Figure 1. Stages of TMZT obtaining process: a) weighing of raw materials and gravimetric dosing; b) loading of the raw material; c) TMZT semi-products obtained after solidification.](image)

| Element | Mo   | Zr   | Ta   | Ti    | Named in paper   |
|---------|------|------|------|-------|------------------|
| wt. (%) | 13.56| 6.34 | 4.64 | balance| Ti15Mo7Zr5Ta     |
|         | 17.49| 6.45 | 5.17 | balance| Ti20Mo7Zr5Ta     |

The tensile test was carried out in concordance with the ISO 6892-1, using standardized size samples by applying a progressive traction load in the longitudinal axis direction. For each test, rectangular cross-sectional samples of flat shape and specific dimensions were made. Samples (Figure 2) were obtained by cutting on a wire electroerosion machine.
Figure 2. Illustrative specimen for the traction test.

The equipment used for tensile strength was INSTRON 8801 Servo Mechanical Testing System from Figure 3. This equipment provides complete static and dynamic test solutions for both metallic and non-metallic materials for both standard materials and advanced materials with testing on both samples and components. The INSTRON 8801 has a loading capacity of up to 100 kN, a working space between large sleepers, high stiffness and good alignment accuracy.

Figure 3. Equipment used - INSTRON 8801.

The appearance of the breakage surfaces of TMZT alloys was analyzed by metallographic study using scanning electron microscopy (Inspect S, SEM).

3. Results and discussions
The traction test is the basic test of a material for the purpose of determining its main mechanical properties. The test involves stretching samples of different sections by progressive and continuous application of a load and without shocks in the direction of the longitudinal axis, generally to breakage, while measuring the deformations corresponding to the various tensile forces values. During the trial, the trial is stretched, snapped, ecstatic, and finally breaks.

Samples subjected to traction test are of standardized shape and size and must meet certain conditions:
- the dimensions of the sample are large enough so that the results are not influenced by the particularities of the behavior of some crystalline formations of the material and that the elongation can be measured with sufficient precision;
- there should be a homogeneous voltage state in a certain area of the sample, the local stresses appearing in the specimen gripping portions (gripping jaws) to be minimal and not to affect the stress state of the main sample area.

The samples were tested by elongation along its main axis at a constant speed until breakage. Characteristic curves obtained from the traction test of TMZT alloys are shown in Figure 4.
Figure 4. Characteristic curves and results obtained from the traction test of samples from the investigated TMZT alloys: a) Ti15Mo7Zr5Ta, b) Ti20Mo7Zr5Ta.

The results of the experimental determinations obtained by the traction test of the elaborated TMZT alloys obtained are presented in Table 2.

Table 2. Determined mechanical properties of the TMZT samples.

| Alloy                 | Tensile Strength (MPa) | Flow Limit (MPa) | Elongation at break (mm) | Modulus of Elasticity (MPa) | Energy to Break (J) | Elongation (%) | Strangled (%) |
|-----------------------|------------------------|-----------------|--------------------------|-----------------------------|---------------------|----------------|--------------|
| Ti15Mo7Zr5Ta          | 712.29                 | 636.10          | 0.07                     | 36390.63                    | 2.35                | 4.75           | 22.22        |
| Ti20Mo7Zr5Ta          | 1410.38                | 1272.63         | 0.10                     | 51311.36                    | 6.76                | 4.75           | 30.55        |

From the characteristic curves recorded by the TMZT alloys, the behavior of the alloys can be observed at the traction request. TMZT alloys has presented a different behavior until breakage.

Tensile strength values for TMZT alloys are 712.29 MPa (Ti15Mo7Zr5Ta) and 1410.38 MPa (Ti20Mo7Zr5Ta). It can be seen that as the percentage of molybdenum increases, the tensile strength increases. Compared to Co-Cr alloys (900-1000 MPa) and stainless steels (500-1350 MPa) [1-3], TMZT alloys investigated, show superior values, which proves that the alloys have mechanical properties very good especially Ti20Mo7Zr5Ta.

Biomaterials should have a modulus of elasticity as close as possible to that of the structure of the system into which they are introduced, respectively to the human bone.

The values of the elasticity modulus of TMZT alloys measured by the traction test were 36390.63 (Ti15Mo7Zr5Ta) and 51311.36 MPa (Ti20Mo7Zr5Ta) that means 36.39-51.3192 GPa. With regard to the results of TMZT alloys compared to other biomaterials, these alloys have the closest value to human bone, which recommends their use in medical applications.

Based on the resulting values of the mechanical properties of TMZT alloys, equal or even better values were obtained compared to classical biomaterials, recommending them to be used successfully in medical applications.

Fractographic analysis consists in analyzing the tear-off surface, made with the naked eye, with the usual microscope or electron microscope. For the proper design and use of metals, it is important to know their behavior before breakage, and the conditions in which it occurs.
Breaking surface analysis allows the evaluation of the behavior of different mechanical stresses applied to the investigated alloys. Aspects of breakage surfaces of samples from TMZT experimental alloys resulting from tensile testing were analyzed by electronic microscope to highlight breakage at various magnifications.

![Figure 5.](image_url)

Figure 5. The appearance of the sample surface analyzed from the Ti15Mo7Zr5Ta alloy tensile strength tests observed by means of the scanning electron microscope at different magnification powers: a) 121X; b) 1000X; c) 2000X; d) 5000X.

In Figure 5 a), b), c), d), one can see the appearance of the Ti15Mo7Zr5Ta alloy surfaces. Surface analysis in different areas highlights a mixed rupture, containing ductile and fragile dots, Figure 5 d). Details are shown with a fragile fracture area (typical appearance of cleavage - plain sliding plane - Figure 5 b) and a ductile fracture area (typical appearance with recesses and connecting mesh - Figure 5 c), areas the ductile breaking properties being preponderant.

The appearance of the Ti20Mo7Zr5Ta alloy breaking faces is shown in Figure 6. Mixed rupture areas a), b) and tensile areas at breaking a) are visible. Figure 6 c) highlights a breakage crevice in a predominantly fragile area surrounded by ductile fracture areas and in Figure 6 d) a detail is observed on a ductile fracture area and compounds of different density (area white).
Figure 6. The appearance of the sample surface analyzed from the Ti20Mo7Zr5Ta alloy tensile strength tests observed by means of the scanning electron microscope at various magnification powers: a) 200X; b) 1000X; c) 2000X; d) 5000X.

In conclusion, the experimental alloys analyzed are characterized by the mixed (ductile and fragile) breaking mode for Ti15Mo7Zr5Ta and ductile breaking for Ti20Mo7Zr5Ta.

4. Conclusions
Metallic biomaterials are very used in medical fields, especially Ti-based alloys for proper properties. Paper contain a new titanium alloys with non-toxic elements such as Mo, Zr and Ta. As a result of the traction tests, it was revealed that, as the percentage of molybdenum increases, the tensile strength increases. Both alloys characterized presented a mixed breaking mode (ductile and fragile). The new alloys obtained present present mechanical strength and a modulus of elasticity close to the biological bone, improved properties beside classical alloys.

5. References
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**Acknowledgements**

This work was supported by a grant of the Romanian Ministry of Research and Innovation, CCCDI – UEFISCDI, project number PN-III-P1-1.2-PCCDI-2017-0239 / 60PCCDI 2018 , within PNCBDI III, research grant PNCBDI III – 9PFE/2018, and with the support of COMPETE project nr.9PFE/2018, financed by the Romanian Government, and under accordance research grant of the TUIASI, project number GnaC2018_48 / 2019.