Obtaining and Mechanical Properties of Ti-Mo-Zr-Ta Alloys

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Abstract. Ti-based alloys are successfully used in the area of orthopedic biomaterials for their enhanced biocompatibility, good corrosion and mechanical properties. The most suitable metals as an alloying element for orthopedic biomaterials are zirconium, molybdenum and tantalum because are non toxic and have good properties. The paper purpose development of two alloys of Ti-Mo-Zr-Ta (TMZT) prepared by arc-melting with several mechanical properties determined by microindentation. The mechanical properties analyzed was Vickers hardness and dynamic elasticity modulus. The investigated alloys presents a low Young’s modulus, an important condition of biomaterials for preventing stress shielding phenomenon.

1. Introduction

Use of metals as biomaterials started from the ancient time used to replace a part of the human body or to function directly with tissue. Despite the large number of metals and alloys able to be produced in industry, only a few are biocompatible and capable of long-term success as an implant material. Typical materials currently found in medical applications are classical metal alloys: titanium alloys (Ti6Al4V), cobalt alloys (CoCrMo) and stainless steels in many important medical applications such as orthopedic implants, dental materials, cardiovascular devices and others [1-4].

The number of titanium alloy biomaterials is higher than cobalt alloys and stainless steels because of low elasticity (close to bone), high corrosion resistance, high biocompatibility, high strength and density low [5-7].

Research in the field of biomaterials over the last decade has helped to improve properties by introducing non-toxic elements, for improving surface characteristics, mechanical properties, corrosion resistance, biocompatibility etc., thus aiming at replacing existing ones [8-10].

Designing and selecting biomaterials consists in choosing the correct material compositional limits so that unwanted reactions do not occur in the human tissue-implant interaction.

The literature has provided information on the negative influence of some components on classical biomaterials, such as Al, which show acute toxicity at very high doses, favoring an increased risk of breast cancer and other neurological conditions such as Alzheimer’s disease. While elements like Mo,
Zr and Ta do not produce toxic corrosion products in human tissue and have minimal cytotoxicity, highlighting excellent biocompatibility, thus favoring vascularization in the tissue [11-14].

Despite this facts, I selected elements non-toxic like Mo, Zr and Ta to development a a new Ti-based alloys to decreased the elastic modulus to avoid stress shielding effect for designing a new β-type of Ti-based alloy with lower elastic modulus, corrosion resistance and good biocompatibility.

This paper is proposing elaboration of two alloys and obtain mechanical properties of TiMoZrTa (TMZT) samples.

2. Experimental procedures

For the elaboration of TMZT alloys, were used as raw materials with a high purity, elements such as: Ti - 99.8%, Mo - 99.7%, Zr -99.2% and Ta - 99.5%. In order to obtain TMZT alloys, it has been chosen to use a vacuum arc remelting MRF ABJ 900 [15].

The preparation of TMZT alloys in the vacuum arc remelting furnace comprised a succession of operations as described in figure 1.

![Technological flow of TMZT alloys](image1.png)

At weighting the load, account was taken of the characteristics of the different alloying elements and their physicochemical properties. Accordingly, account must be taken of the method of elaboration, the construction of the melting furnace used because this can influences in many parts the losses of metal, at melting [16].

In figure 2 are presented all stages of TMZT alloying, which included the weighing of the raw material, the loading of the alloying elements and the final semi-finished products obtained.

![Stages of development of TMZT alloys](image2.png)

**Figure 1.** Technological flow of TMZT alloys.

**Figure 2.** Stages of development of TMZT alloys: a) weighing of raw materials and gravimetric dosing; b), c) loading of the raw material; D), e) TMZT semi-products obtained after solidification.
Determination of the chemical composition was performed by EDX chemical analysis. The chemical composition of the alloy was analysed with an EM VEGA II LSH scanning electron microscope manufactured by the TESCAN Co., the Czech Republic, coupled with an EDX QUANTAX QX2 detector manufactured by the BRUKER/ROENTEC Co., Germany.

The Vickers hardness measurements were measured using a Wilson Wolpert universal hardness tester, 751N model with a load of 9,807 N and 12 s.

Apparent coefficient of friction and elastic modulus were measured using CETR UMT-2 Tribometer. For micro-scratch analysis it was used a constant load method with a load of 5N on a distance of 4 mm, for a single determination.

3. Results and discussions
The chemical composition are shown in table 1. The chemical analyses (EDX) of the alloys studied were performed in many different points for a precise determination, with an uniform distribution of elements and a homogeneous alloy.

| Table 1. Chemical composition of the TiMoZrTa (TMZT) sample after melting. |
|------------------|---|---|---|---|
| Element          | Mo | Zr | Ta | Ti |
| wt.(%)           | 12.56 | 6.99 | 14.45 | Balance |
|                  | 18.45 | 6.48 | 11.7 | Balance |

The variation-curve of the micro-indentation test is presented in figure 3. This represents the response of the material during a load–displacement curve. For this measurement were carried out three determinations and their average was calculated.

![Figure 3](image)

Few mechanical properties of TMZT alloys are presented in table 2 (hardness, young modulus, stiffness).

| Table 2. Some mechanical properties of TMZT samples. |
|------------------|---|---|---|
| Alloy             | Hardness (HV) | Young Modulus (GPa) | Stiffness (N/µm) |
| Ti15Mo7Zr15Ta     | 390.88 | 51.93 | 3.01 |
| Ti20Mo7Zr15Ta     | 397.56 | 43.57 | 3.20 |

The hardness values of alloys were close, between of 390.88 – 397.56 HV. Compared to other biomaterials, TMZT alloys have a higher hardness than stainless steels (155 HV), less than CoCrMo (601 HV), but close to the Ti6Al4V alloy (349 HV), which is the most used in implantology [1,17].

The modulus of elasticity is a very important criterion underlying the choice of metallic materials used in orthopaedics and should be as close as possible to that of the human bone (17-30 GPa). TMZT
alloys exhibit values of the elastic modulus close to those of human bone, values between 51.93-43.57 GPa. Compared to other metallic biomaterials: CoCrMo alloys (210-253 GPa) and stainless steels (190-210 GPa), the investigated TMZT alloys exhibit much lower values and the closest values to the human bone (17-30 GPa). TMZT alloys show a significant improvement in mechanical properties even for the titanium alloys: Ti6Al4V (100-114 GPa) and C.P. Ti (102-104 GPa) [14,18,19]. Due to Mo and Ta stabilizing elements, these alloys have the advantage of increasing mechanical strength and a modulus of elasticity close to that of the biological bone. It can be seen that with the increase of the molybdenum percentage, the properties of the experimental TMZT alloys improve.

4. Conclusions
The paper presents the steps of elaborating two new titanium alloys with non-toxic elements such as Mo, Zr and Ta. For these alloys were studied mechanical properties like hardness, young modulus and stiffness. These alloys have the advantage of increasing mechanical strength and a modulus of elasticity close to the biological bone due to alloying with elements like Mo, Zr and Ta.

In order to use these alloys in medical applications it will be necessary to continue with future studies to establish the cytotoxic behavior and corrosion resistance.

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