

Investigation of static properties of medical alloys Ti-(20-30)Nb-(10-13)Ta-5Zr

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Abstract. In the work, static properties of TiNbTaZr titanium alloy were carried out. The search for a NiTi alloy replacement is necessary for medical products to eliminate the negative effects of nickel on the body. Conclusions are drawn about the adequacy of the mechanical properties of the test alloy for use in stent implants.

1. Introduction

Materials used in medicine for the manufacture of implants, should exhibit a set of properties that ensure the compatibility of medical products and the body, such as superelasticity, low values of the Young's modulus, high corrosion resistance and biocompatibility.

Low values of the Young's modulus (50-80 GPa) and superelastic (SU) behavior [4], which are close to the behavior of bone tissue, exhibit alloys with shape memory (SPF), in particular Ti-Ni alloys. This led to their widespread use in medicine. However, the toxic properties of nickel limit their further medical use in a number of developed countries (Japan, Germany) [5-10].

To satisfy the requirements of biochemical compatibility, the alloy should not cause inflammatory processes and allergic reactions in the body. The basis for this is the use of only safe elements as alloy components, which include: Ti, Nb, Ta, Zr.

Great attention was attracted to studies on the effect of tantalum on the functional properties of Ti-Nb-Ta-Zr alloys [1]. Tantalum alloying provides the maximum range of α -martensite concentration and the highest barrier for the formation of the ω phase by other β -stabilizers. In the immediate vicinity of the α + β / β boundary in quenched Ti-Nb-based alloys, a decrease in the Young's modulus and manifestation EhP associated with reversible $\beta \leftrightarrow \alpha$ "martensitic transformation.

In this case, alloys containing 10 and less% Ta consist of a β -phase and an ω -phase, while alloys containing more than 10% Ta consist of only β -phase. At the same time, the most perfect superelastic properties are Ti-30Nb- (5-10) Ta-5Zr alloys, while alloys with higher tantalum content lose their tendency to superelastic behavior. Also, doping Ti- (Nb, Ta) of zirconium alloys promotes hardening of the solid solution and reduces the probability of brittle ω -phase formation, thereby improving the functional properties of metastable Ti-Nb-based memory alloys.

Zirconium, usually in all titanium alloys, acts as a neutral hardener, however, as shown in [1] in β -titanium alloys, zirconium can also have a β -stabilizing effect by lowering the martensitic transformation temperature, and also suppressing the formation of the athermal ω phase. In addition, titanium, niobium



and tantalum have similar atomic radii (0.145 ... 0.146 nm), while zirconium has a large atomic radius (0.160 nm). Therefore, while zirconium doping with titanium should promote an increase in the interatomic distance in the alloy, a decrease in the bond strength between the atoms, and, consequently, a decrease in the modulus of elasticity, while titanium doping with niobium and tantalum the period of the β -phase lattice should at least not decrease.

It was shown in [2] that the Zr content in the range of 5% corresponds to the Young's modulus minimum for the Ti- (13-35.5) Nb- (5-22) Ta- (4-7,2) Zr (mass%) system alloys. .

In [3] the alloy Ti-29Nb-13Ta-4,6 Zr was studied, exhibiting high characteristics important for biomedical alloys: low Young's modulus, good mechanical properties and excellent fatigue properties.

Thus, it is possible to consider alloys of the composition Ti- (20-30) Nb- (10-13) Ta-5Zr as promising materials for the manufacture of medical products such as "stent" and "cava filter".

2. Materials and methods

For research in this work, thin wires of alloys of the following compositions were chosen: Ti-20Nb-10Ta-5Zr; Ti-20Nb-13Ta-5Zr; Ti-25Nb-10Ta-5Zr; Ti-25Nb-13Ta-5Zr; Ti-30Nb-10Ta-5Zr, Ti-30Nb-13Ta-5Zr, selected as optimal for use in the manufacture of medical devices.

Iodide titanium, iodide zirconium, technically pure niobium and technically pure tantalum were used (Table 1).

Table 1. Content of impurities in charge materials.

Material	O, %	N, %	C, %	H, %
Titanium	0,001	0,001	0,001	0,0001
Zirconium	0,005	0,005	0,008	0,0001
Niobium	0,0033	0,015	0,002	0,0002
Tantalum	0,0017	0,011	0,006	0,0004

Mechanical tests of wire tensile samples were carried out on a universal testing machine INSTRON 3382 with a loading rate of 1 mm / min, with accuracy of the crosshead speed $\pm 0.2\%$ of the value of the set speed. Accuracy of load measurement: $\pm 0.5\%$ of the measured value and up to 1/100 of the maximum value of the load cell, according to the data sheet of the instrument. The test data are given in Table. 2.

The length of the working part of the samples is 28 mm. At one experimental point, 3 samples are tested, samples were polished before testing. The installation and fixing of samples in the testing machine does not cause additional stresses from misalignment of the specimens and grippers. All samples of the intended series are tested on the same machine, which satisfies metrological requirements. The total error in measuring the samples during the test does not exceed 0.5% of the measured stretching tension, according to the data sheet of the instrument.

3. Results and discussion

Table 2. Results of mechanical testing of samples.

Deformation (%)	Yield strength (MPa)	Ultimate strength (MPa)	Young's modulus (GPa)	Alloy composition
0,5	503,0	547,0	40,8	Ti-20Nb-13Ta-5Zr
0,7	627,7	743,3	48,2	Ti-25Nb-13Ta-5Zr
0,6	414,3	550,3	37	Ti-25Nb-10Ta-5Zr
0,5	504,0	586,7	38,6	Ti-20Nb-10Ta-5Zr
0,6	576,0	680,7	42,5	Ti-30Nb-13Ta-5Zr

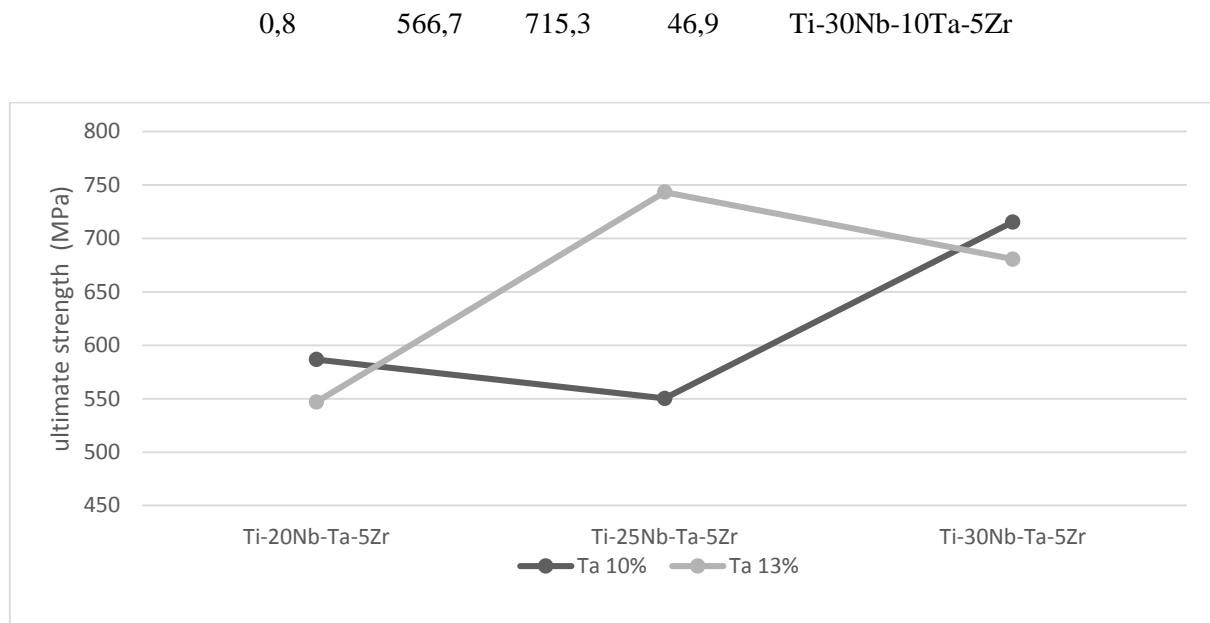


Figure 1. Dependence of the ultimate strength on the composition of the alloy.

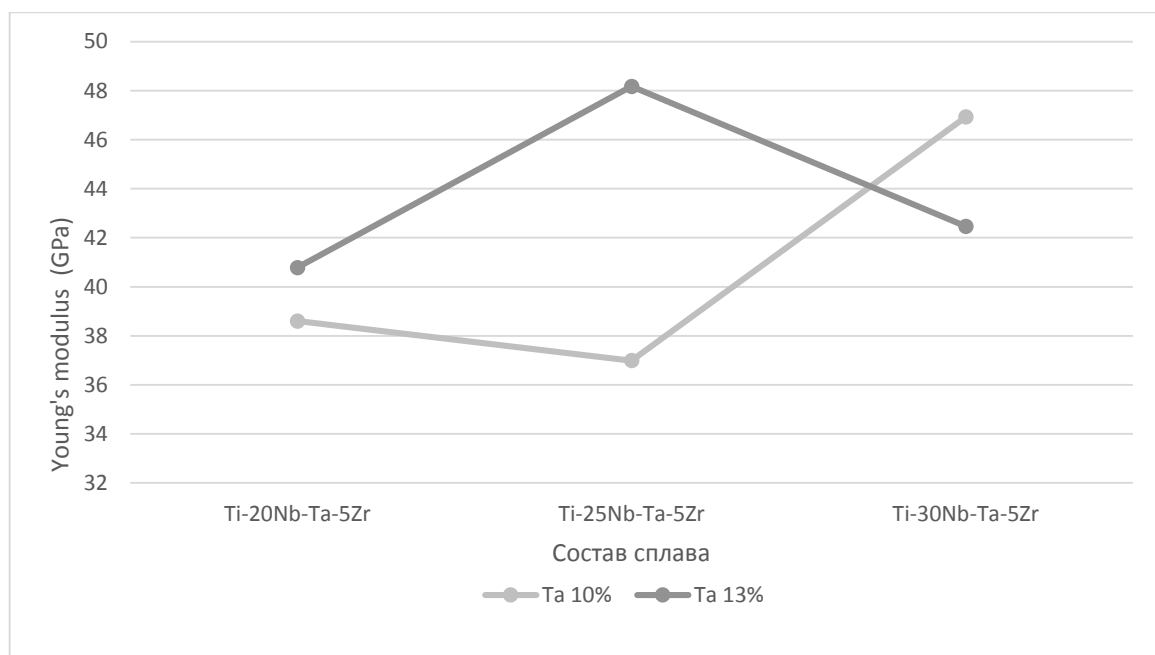


Figure 2. Dependence of the Young's modulus on the composition of the alloy.

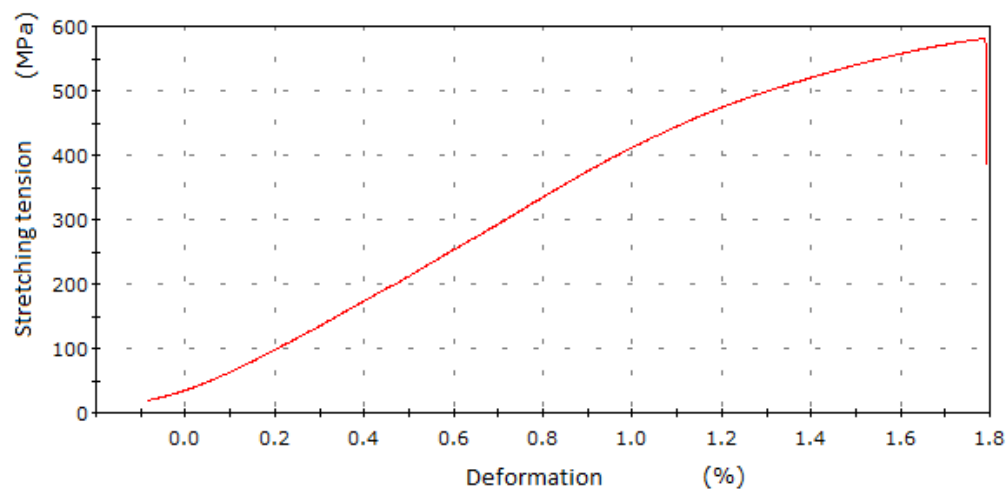


Figure 3. Diagram of stretching tension of Ti-20Nb-13Ta-5Zr.

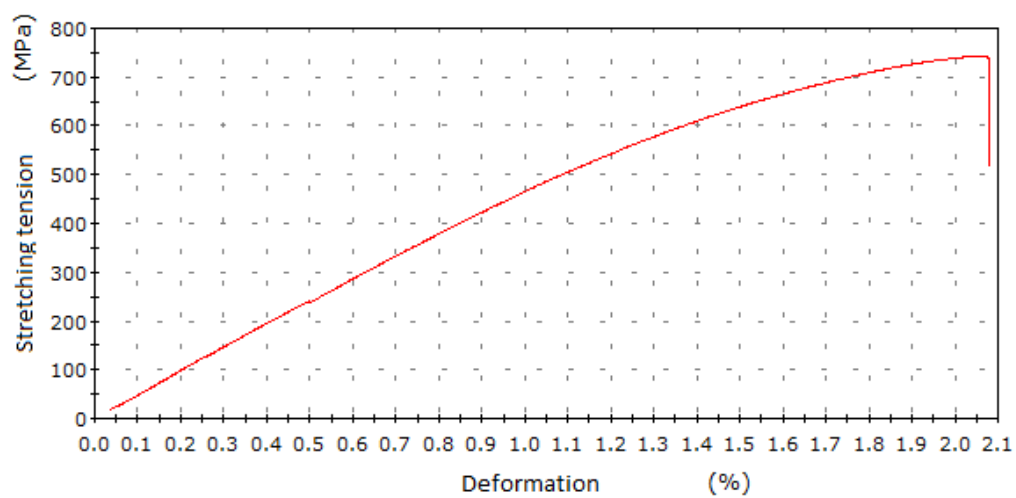


Figure 4. Diagram of stretching tension of Ti-25Nb-13Ta-5Zr.

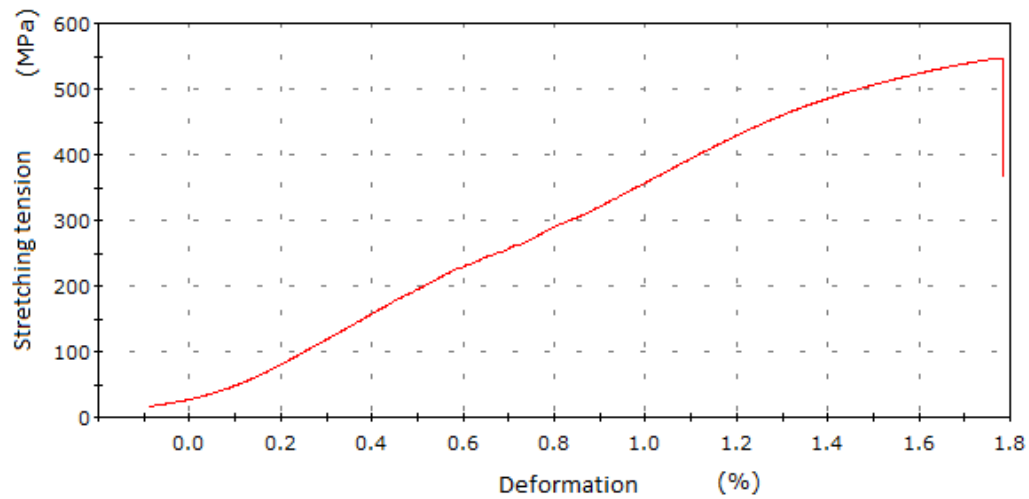


Figure 5. Diagram of stretching tension of Ti-25Nb-10Ta-5Zr.

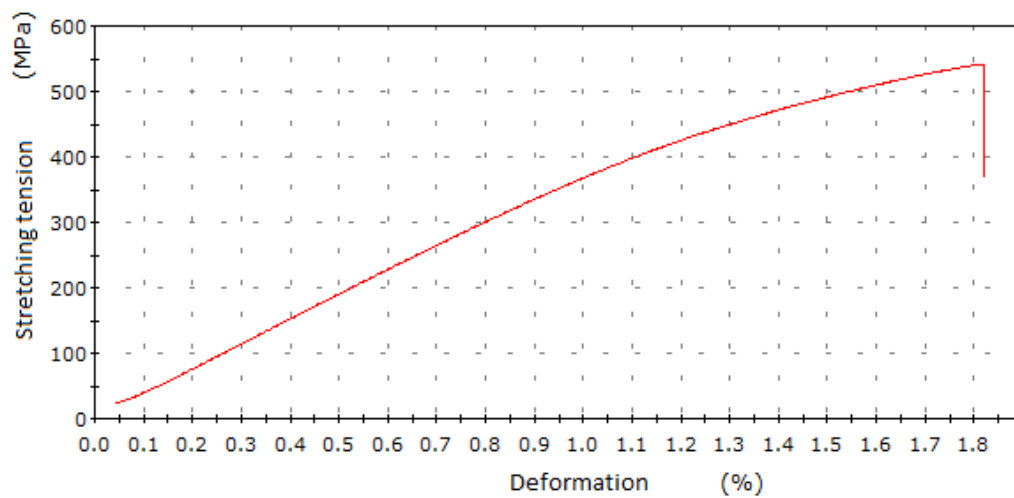


Figure 6. Diagram of stretching tension of Ti-20Nb-10Ta-5Zr.

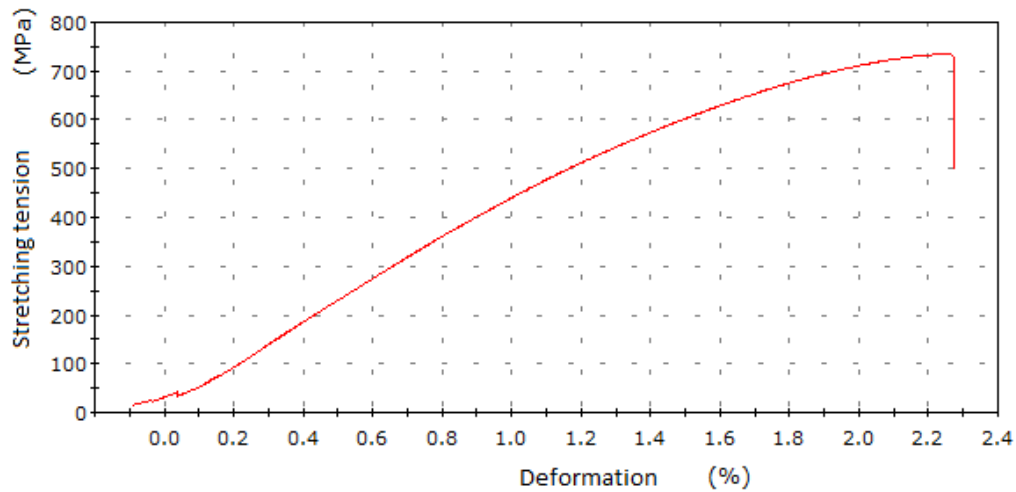


Figure 7. Diagram of stretching tension of Ti-30Nb-13Ta-5Zr.

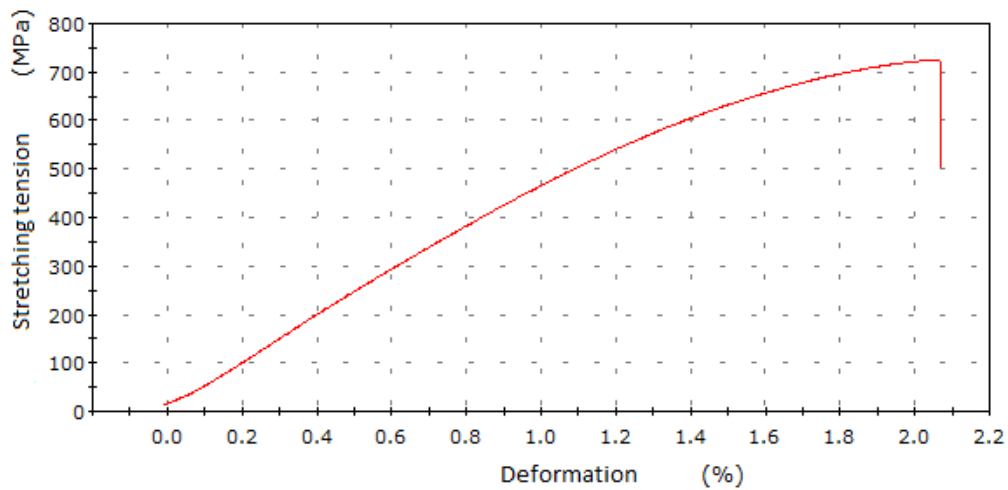


Figure 8. Diagram of stretching tension of Ti-30Nb-10Ta-5Zr.

According to the tests carried out, it can be concluded that the wire from biocompatible Ti-Nb-Ta-Zr alloys satisfies Jung's modulus as a material for making Cava filters and stents. It can also be noted that the composition of Ti-30Nb-10Ta-5Zr differs in the best complex of properties, in relation to other tested ones.

4. Conclusions

The use of stents and Kava filters from materials with shape memory effect in medical practice is a relatively new direction of the method of treatment. In this regard, the problem of negative effects of the implants on the body remains an important task. The search for nickel-free alloys that satisfy the necessary mechanical and functional properties is the most important task for the further development of this direction in medicine. The studied Ti-Nb-Ta-Zr alloy satisfies Jung's modulus and ultimate strength as a material for the manufacture of Kava filters and stents.

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