# Titanium-based alloys with a silicide nanophase

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**Introduction**

The manufacturing of titanium and its alloys is a very important task, in particular for medicine use, due to its biological inertness and corrosion resistance. However, titanium itself is not robust, and the specific medical requirements are disallow to use traditional methods of its increase. Nowadays perspective and advanced work is aimed at the create of new titanium alloys without any toxic metals to replace traditional medical $Ti_6Al_4V$. This work proposes to do this by alloying titanium with Nb, Zr and Si, which increases its robustness and save the required plasticity.

**Experiments**

The manufacturing of TiNbZrSi alloys ingots was by the method of melting on an electron beam unit by double remelting with using an intermediate container [1]. The initial materials were sheet titanium, niobium and zirconium rods, lumped silicon. For high-quality fusion and homogeneity, small pieces of 40x40 mm, 2-7 mm thick were used. The amount of silicon in all samples was 0.9-1.1 wt.%, because its increase led to a dramatic decrease in plasticity. In one group of samples with 11-13 wt.% niobium and in another with 18-20 wt.% amount of zirconium varied from 1.9 to 15.2 wt.%.

The chemical composition of the alloys is shown in the following table.

| No. samples | Nb, wt% | Zr, wt% | Si, wt% | Ti, wt% |
|---|---|---|---|---|
| 1 | 11-13 | 1.9-2.2 | 0.9-1.1 | 84-86 |
| 2 | 11-13 | 3.9-4.2 | 0.9-1.1 | 82-84 |
| 3 | 11-13 | 5.9-6.2 | 0.9-1.1 | 80-82 |
| 4 | 11-13 | 9.9-10.2 | 0.9-1.1 | 76-78 |
| 5 | 11-13 | 14.8-15.2 | 0.9-1.1 | 71-73 |
| 6 | 18-20 | 1.9-2.2 | 0.9-1.1 | 77-79 |
| 7 | 18-20 | 3.9-4.2 | 0.9-1.1 | 75-77 |
| 8 | 18-20 | 5.9-6.2 | 0.9-1.1 | 73-75 |
| 9 | 18-20 | 9.9-10.2 | 0.9-1.1 | 69-71 |
| 10 | 18-20 | 14.8-15.2 | 0.9-1.1 | 64-66 |

The chemical analysis of the samples was determined on a multi-element express analyzer by the method of energy dispersive X-ray fluorescence analysis. The absolute error was: ±0.1 wt.% for Ti, ±0.05 wt.% for Zr and Nb, ±0.07 wt.% for Si.

Visual examinations showed that the obtained alloy ingots do not have shrinkage shells, cracks, pores, or other surface defects.

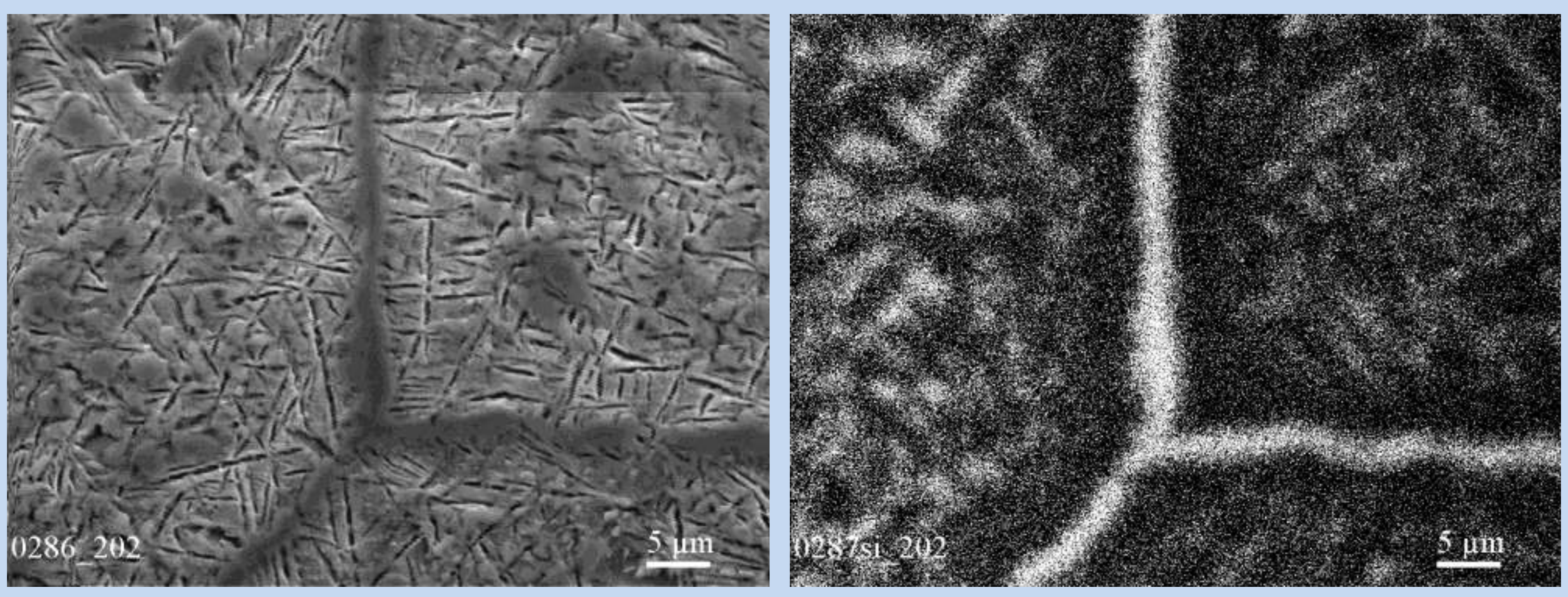


Fig 1. The microstructure of alloy sample No 6 (a) and the distribution of silicon in the irradiated $SiK_a$ (b).

As can be seen, the structure of this alloy consists of primary β-grains, along which the silicide nanophase $Ti_5Si_3$ is located. Inside the primary β-grains there is a finely dispersed α-phase with highly dispersed silicides that were allocated along its borders.

**Results and discussion**

Corrosion resistance tests by the gravimetric method in distilled, tap and sea water for 100 hours (with control every 10-20 hours) showed that the corrosion resistance is 4-5 points on a 10-point scale [2].

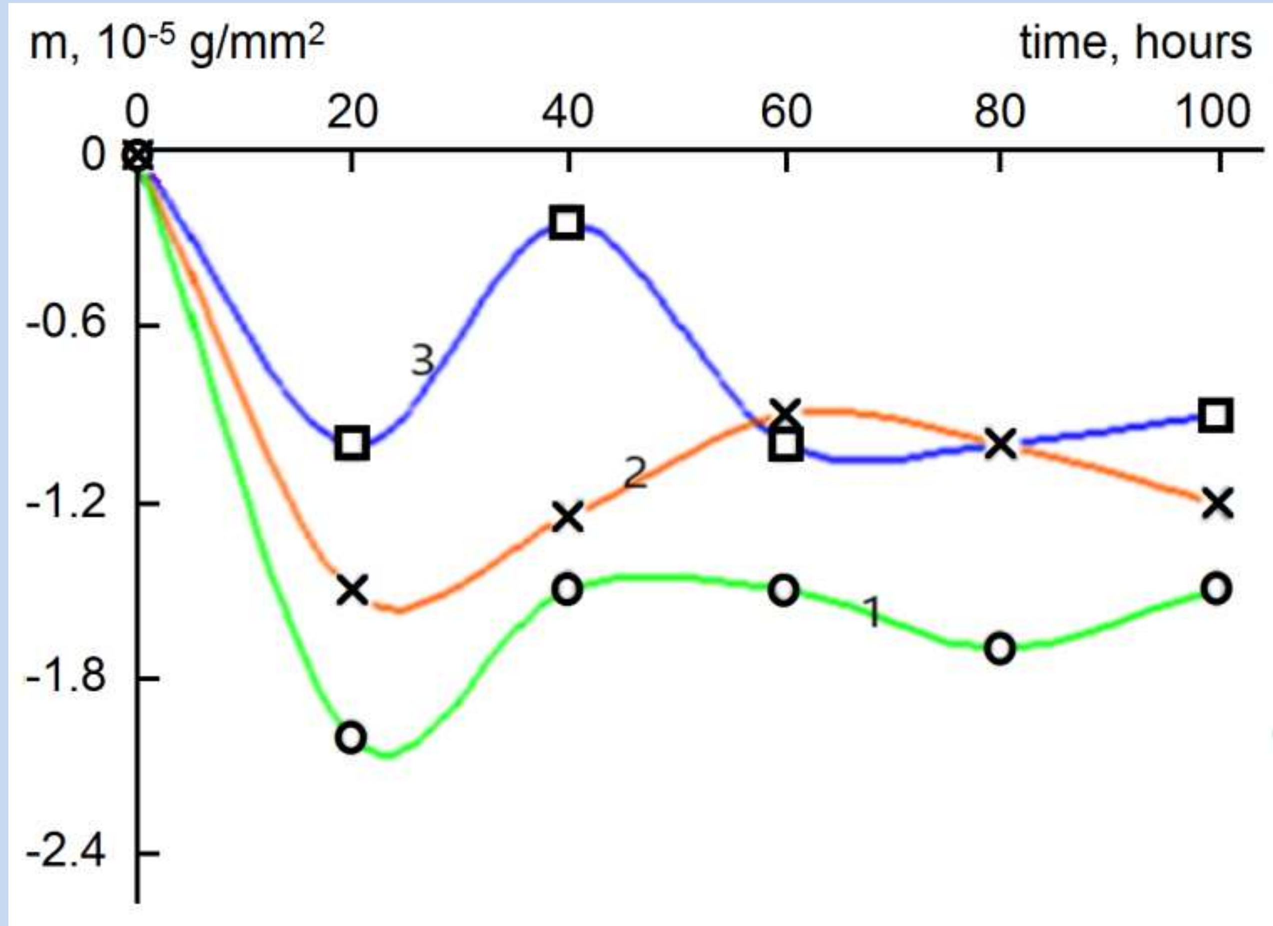


Fig 2. Gravimetric corrosion dependences of the TiNbZrSi system in different environments: 1 – distilled water, 2 – sea water, 3 – tap water.

Corrosion was determined by weight and depth indicators, that is, by the change in mass and linear size over time.

| Environment | weight indicators | depth indicators | Corrosion resistance |
|---|---|---|---|
| tap water | 0.05 | 0.043 | 4 |
| sea water | 0.08 | 0.069 | 5 |
| distilled water | 0.09 | 0.077 | 5 |

A result of the study of the structure, chemical and phase composition, as well as mechanical and corrosion characteristics of alloys of the TiZrNbSi system, it have been fined the optimal content of alloy components, which causes the highest mechanical properties in the cast state. Studies of these titanium alloys in a wide range of concentrations of zirconium and niobium show that the optimal composition is 18-20 wt.% Nb, 1.9-2.2 wt.% Zr (sample No 6). This sample was characterized by the highest values of strength limit of 900-950 MPa, yield strength of 840-890 MPa, relative elongation of 0.3-2.5%, and Young's modulus of 70-100 GPa.

**Conclusions**

The structure of titanium-based alloys was studied. It was found that the silicon nanophase is formed in the alloy. The structure of the alloy consists of primary β-grains surrounded by silicide nanophase $Ti_5Si_3$. Inside of the primary β-grains there is a finely dispersed α-phase with highly dispersed nanosilicides that stand out along its borders.

It was found the optimal composition of titanium-based alloys with zirconium and niobium dopants with a high level of mechanical properties and corrosion resistance. The method of melting on an electron beam unit by double remelting with using an intermediate container turned out to be promising for obtaining homogeneous samples without defects.

**References**

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