EFFECT OF VANADIUM AND HEAT TREATMENT ON
THE ELASTIC CHARACTERISTICS OF NIOBUM

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Alloys based on niobium are promising for elastic elements operating at elevated temperatures, since existing spring alloys do not meet present requirements — at temperatures above 500°C their elastic properties decrease sharply. The selection of niobum for this purpose is due to its low modulus of elasticity and low temperature coefficient as well as the broad possibility of hardening niobium by alloying and heat treatment [1]. However, the data in the literature concerning the effect of alloying elements on the elastic characteristics of niobium are quite limited.

We present results from a study of the effect of vanadium and the heat treatment conditions on the elastic characteristics of niobium at temperatures from 20 to 800°C.

Nb–V alloys (0.5, 1, 3, and 5 wt. % V) were melted by the double vacuum remelting technique in an electric arc furnace with a consumable electrode. The ingots were annealed in vacuum at 1500°C for 5 h, after which they were extruded to bars 15–16 mm in diameter, which were turned to a diameter of 12–14 mm, annealed in vacuum at 1200°C, and rolled to strips 1 mm thick in air with heating to 300–350°C. After secondary annealing at 1200°C the strips were rolled to sheets 0.3 mm thick. The total deformation was about 95%. Samples 0.3 × 5 × 70 mm were cut in the rolling direction for measurements of the microhardness, electrical resistivity, modulus of elasticity (by the resonance method from the natural frequency of vibrations), and the elastic limit σ0,002 (by the longitudinal bending method) [2] at room temperature; the elastic limit and modulus of elasticity were also determined at temperatures from 200 to 800°C.

The temperature dependence of the modulus of elasticity was determined with the apparatus developed at the Bauman Moscow Technical College. The method of determining this dependence is based on the loss of resistance of a rod compressed along the axis to obtain a load defined as the critical load Pcr. In turn, the latter was related with the modulus of elasticity by Eilerr's equation [3]:

\[ P_{cr} = \frac{n \pi^2 E I}{t^2}, \]

where P is the force compressing the sample, kg; E is the modulus of elasticity, kg/mm²; I is the minimal moment of inertia of the section, mm⁴; n is an arbitrary whole number.

Finding the modulus of elasticity comes down to experimental determination of Pcr (with n = 1) and calculation by the formula

\[ E = \frac{P_{cr} \cdot t^2}{\pi^2 \cdot J}. \]

The properties of the alloys after deformation are given in Table 1. It can be seen that alloying with vanadium leads to a higher elastic limit, modulus of elasticity, microhardness, and electrical resistivity, the effect increasing with the amount of the alloying element. This is evidently due to the difference in the atomic radii of niobium and vanadium (rNb = 1.47 Å, rV = 1.33 Å), due to which there is considerable distortion of the crystal lattice.

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Fig. 1. Properties of Nb-V alloys in relation to annealing temperature (after cold deformation).

Fig. 2. Elastic limit and modulus of elasticity of Nb-V alloys in relation to testing temperature (after deformation of the alloys + annealing at 700°C for 1 h and after deformation of niobium + annealing at 650°C for 1 h).

After deformation, the samples were annealed in vacuum at different temperatures from 600 to 1000° in the TVV-Ch electric furnace, with holding at each temperature for 1 h. The residual pressure in the furnace was $1 \times 10^{-5}$ mm Hg.

The effect of annealing temperature on the properties of the alloys is shown in Fig. 1.

Annealing at 600-700° substantially increases the elastic limit; the modulus of elasticity, microhardness, and resistivity increase somewhat. At higher annealing temperatures the elastic limit decreases, probably due to the beginning of recrystallization processes.

The nature of the increase in the elastic limit due to subrecrystallization annealing is unclear. It was proposed in [4] that it is due to small local changes in the concentrations of impurity atoms around dislocations and also the formation of cellular and polygonal structures in the process of annealing, causing a reduction in the mobility of dislocations and consequently an increase of the elastic limit.

Of particular interest are studies of the temperature dependence of the elastic limit and modulus of elasticity, for which data are almost completely lacking. Such experiments are of considerable interest in order to determine the possibility of using these alloys at elevated temperatures.

The elastic limit and modulus of elasticity were measured at 200-800°. The results are shown in Fig. 2.

It should be noted that the modulus of elasticity varies negligibly with temperature up to 600°, declining sharply only above this temperature. However, with increasing amounts of vanadium in the alloy the modulus of elasticity begins to decrease at higher temperatures. The elastic limit decreases more noticeably than the modulus of elasticity with increasing temperatures, although the absolute values remain higher at all temperatures than for the unalloyed niobium, which indicates the hardening influence of vanadium under these conditions.

**CONCLUSIONS**

1. Alloying with vanadium increases the elastic limit of niobium at room and elevated temperatures, the elastic limit increasing with the vanadium content of the alloy.