Study of mechanical properties of rapidly quenched fiber from orthorombic alloy based on Ti$_2$AlNb

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Abstract. The mechanical properties of a rapidly quenched Ti$_2$AlNb-based alloy obtained by extraction of a hanging melt drop in the initial state and after heat treatment are investigated. It is stated that the rapidly quenched alloy has low tensile elongation, high strength and hardness, and a mechanism of brittle fracture during deformation. Heat treatment allows increasing the value of tensile elongation, reduces hardness, and results in tough fracture during deformation.

1. Introduction

One of the promising methods for producing alloyed powders of intermetallic titanium alloys is the grinding of rapidly quenched fibers from alloys obtained by extraction of a hanging melt drop. The possibility of obtaining fibers from Ti$_2$AlNb-based alloys with a fine-grained structure and a homogeneous β phase composition was shown in articles [1, 2]. Studies on the ball milling of the fiber showed that the alloy in a rapidly quenched state had a sufficiently high strength and ductility, and therefore, when deformed in a planetary ball mill, it was compacted without destruction [3]. However, there is no data on the mechanical properties of Ti$_2$AlNb in a rapidly quenched state; therefore, in this work, we study some mechanical properties of an orthorhombic alloy fiber.

2. Materials and procedures

The study was carried out on fibers of Ti$_2$AlNb-based alloy (VTI-4) in the initial state (after rapid quenching of the melt) and after heat treatment (vacuum annealing, VA) at 800 and 1100 °C for 1 hour. The purpose of the heat treatment was to relieve the crystal lattice stresses of a rapidly quenched alloy (800 °C) as well as decomposition of the high-temperature β phase (figure 1a) and the formation of a single-phase orthorhombic state (1100 °C). Tensile tests were carried out using the INSTRON-5982 testing machine; tensile strength and elongation of the fiber were determined from the test results. Fractographic analysis of fractures and microhardness measurements were also performed.

3. Experimental results and discussion

The results of X-ray diffraction analysis showed that vacuum annealing at 800 °C did not lead to β phase decomposition, and after 1100 °C a single-phase composition was formed in the alloy presented by the orthorhombic phase (O-phase) (figure 1b).
Figure 1. X-ray diffraction patterns of the fiber from VTI-4 alloy: (a) – initial rapidly quenched state, (b) – after VA at 1100°C.

Mechanical tests of the fiber in the initial state showed that the alloy in the rapidly quenched β phase state had low plasticity, and the average elongation was 0.76%. Tensile strength was 907 ± 127MPa. Such a low plasticity may be conditioned by the stress state of the alloy with a high density of defects in the crystal structure formed due to rapid quenching of the melt [4]. A major contribution can also be made by the surface state of the fiber which has a sickle-shaped cross-section of a variable width with rough surface and many curved sections along the length of the fiber (figure 2a). Despite the fact that fiber fragments without bending were selected for testing, the contribution of the geometry features of this semi-finished product to the tensile deformation is undoubtedly obvious. The factographic analysis of fiber fractures confirmed the low plasticity of the fiber – the fracture is brittle, chips and cracks are observed (figure 2b). The microhardness of the fiber is 516 HV0.05, which exceeds the hardness of the alloy in a deformed (hot-rolled) state – 467 HV0.05.

Annealing at 800 °C resulted in the formation of a fine-grained brittle fracture, which may indicate the initial processes of grain growth in the alloy (figure 2c). The plasticity of the alloy increased, and the average elongation was 1.26%. It is difficult to determine the strength of the fiber due to the complexity of accurately measuring the area of separation surface. Measurement of the fiber microhardness showed its significant increase up to 621 HV0.05. This can be associated with structural transformations in the alloy indirectly observed on the fracture, or the initial processes of the high-temperature β phase decomposition, which is not fixed by the X-ray diffraction analysis.
After annealing at 1100 °C a single-phase orthorhombic state formed and recrystallization occurred in the alloy, which affected the nature of the fracture. The fracture was tough and cellular, and rounded grains of 5-10 μm in size are observed (figure 2d). The fiber elongation was about 1%, and the microhardness equaled 413 HV₀.₀₅.

4. Conclusions
Studied mechanical properties of the VTI-4 alloy fibers showed that the alloy in the rapidly quenched state has high hardness and strength but possesses significantly lower plasticity than the alloy in the deformed state (0.76% and 6-12%, respectively). It is possible to increase the plasticity of the alloy by annealing, which leads to a change in the mechanism of fiber destruction from brittle to tough, reduces the microhardness of the alloy (after VA at 1100 °C) and slightly increases tensile elongation.

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