Utrafine-grained structure and thermal stability of the two-phase titanium alloy VT8M-1

G. S. Dyakonov*, O.B. Kulyasova, T. V. Yakovleva, A. G. Stotskiy

Institute of Physics of Advanced Materials, Ufa State Aviation Technical University, 12 K. Marx str., Ufa 450008, Russia

Abstract: *In this work, the method of backscattered electron diffraction (EBSD) and transmission electron microscopy (TEM) was used for microstructural analysis of the improved VT8M-1 alloy (Ti-5.7 Al-3.8 Mo-1.2 Zr-1.3 Sn) subjected to equal-channel angular pressing (ECAP) and rotary forging (RF). It was found that the process of globularization induced during deformation processing is regulated by the conventional boundary-splitting mechanism. It was shown that an orientation relation is established between the spheroidized a - and b-phases. This result is achieved due to the high activity of dislocation sliding at the boundary of the a-and b-phases. The thermal stability of the VT8M-1 alloy with an ultrafine-grained (UFG) structure is studied. It is shown that at T=450□C and long-term (up to 500 hours) annealing the UFG structure is thermally stable. The mechanical properties and the effect of annealing on the microstructure are discussed. It is shown that particles of the Ti-Zr-Si system are isolated at the interphase boundaries.*

***KEY WORDS:** TWO-PHASE TITANIUM ALLOYS, ULTRAFINE-GRAINED STRUCTURE, ROTARY SWAGING, THERMAL STABILITY, STRENGTH*

1. *Introduction*

Two-phase Ti alloys combine low specific weight and high mechanical properties, which make them extremely attractive to aviation industry particularly for the fabrication of such critical components as stiffeners, engine pylon spar elements, fan blades, compressor discs, aircraft engine compressor blades, etc. [1].

This paper focuses on the heat-resistant two-phase VT8M-1 with a service temperature of 450-500°C. VT8M-1 alloy is considered as a replacement to the widely applied VT6 alloy with a service temperature of no more than 350°C. Severe plastic deformation techniques or combined strain treatment leading to the formation of an ultrafine grained (UFG) microstructure with high boundary density are increasingly frequently used to achieve enhanced strength properties in alloys [2, 3].

There are several aspects making UFG Ti alloys so attractive for aircraft industry: first, UFG microstructure has an enhanced ultimate tensile strength and fatigue life [3,4]. Second, superplasticity is manifested in UFG microstructures at rather low strain temperature, which optimises the manufacturing of semi-finished articles and products [5, 6]. The shaping of Ti alloys usually includes both thermal treatment and hot deformation, which leads to the modification of structural parameters and thus of mechanical properties in the context of UFG structures. Secondary intermetallic particles like $(Ti,Zr)_5Si_3$, $(Ti,Zr)_6Si_3$ and others are possible to precipitate in the highly doped alloy of this class at heat and thermomechanical treatments (TT) [7, 8]. With this in view, the paper briefly reviews the thermal stability of the VT8M-1 alloy with an ultrafine-grained (UFG) structure is studied. The mechanical properties and the effect of annealing on the microstructure are discussed.

2. *Material and Experimental Procedure*

A two-phase VT8M-1 rod (produced by VSMPO-AVISMA, Russia) with the chemical composition of Ti-5.7Al-3.8Mo-1.2Zr-1.3Sn (wt %) was used as a research material. In as-delivered state the alloy had a globular lamellar microstructure with the temperature of β-transus of 980°C ±5°C. A rod was processed by a rotary swaging at T=750°C with an incremental compression along a diameter from 70 to 32 mm (e~1.56 with a strain rate above 300 mm/s-1). The alloy also was subjected to 4 ECAP passes at 750oC via BC route using a die with a 120o round channel. The accumulated true strain was evaluated to be 2.8.

Isothermal die forging of the UFG VT8M-1 was performed at T=780±10°C. The alloy was subjected to annealing in Noberterm furnaces. The alloy mechanical properties were examined in the course of tensile testing using Instron universal testing machine with a strain rate of 1×10^{-3} s^{-1} in correspondence with ISO 6892-1-2009, and microhardness was measured based on ASTM E384-16. TEM and SEM techniques were applied to study the alloy microstructure (JEOL JSM 6390 and JEOL JEM 2100), and EDS on JEOL JEM 2100 microscope was used to analyse the alloy elementary composition.

3. *Results and discussion*

In this work, the evolution of the microstructure and mechanical properties of the UFG VT8M-1 alloy after prolonged annealing at a temperature of 450 ° C were studied. It was found that after 50 hour annealing, an increase in the strength of the UFG alloy VT8M-1 by an average of 50 MPa is observed (Fig. 1). Prolonged annealing (over 400 hours) of the short-circuit state leads to a decrease in strength and an increase in plasticity (Fig. 1). It was found that after 50 hour annealing, an increase in the strength of the UFG alloy VT8M-1 by an average of 50 MPa was observed (Fig. 1).

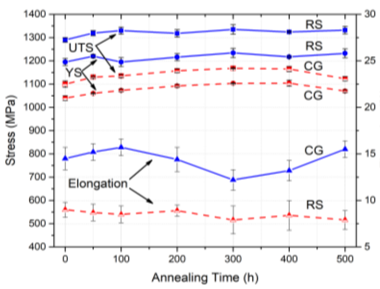
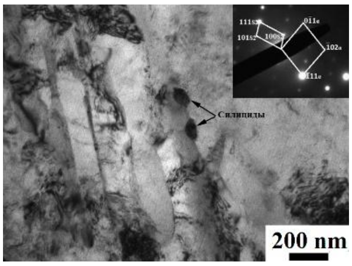


Figure 1 – Dependence of the mechanical properties of VT8M-1 alloy specimens under tensile tests on the exposure time in the range from 0 to 500 hours at a temperature of 450°C

By transmission electron microscopy (TEM) it was found that small ellipsoidal particles with an average size of 50–100 nm are formed at the interfaces between α and β plates (Fig. 2). Results of EDS analysis indicate the Si and Zr content of the particles. Deciphering the diffraction patterns showed that the particles are silicides of the $(TiZr)_6Si_3$ type with a hexagonal close-packed lattice [9].



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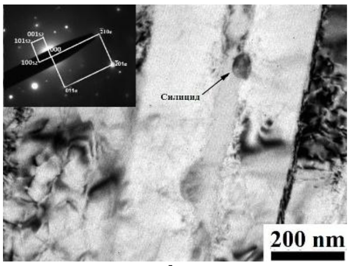

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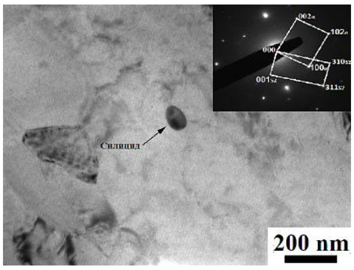

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Figure 2 – Microstructure of VT8M-1 alloy after: a) RS; and subsequent annealing at a temperature of 450C for: b) 50 hours; c) 500 hours.

Thus, the results of the study indicate the thermal stability of the UFG structure of the VT8M-1 alloy. The research results indicate that silicides of the $(TiZr)_6Si_3$ type can help maintain the thermal stability of the nonequilibrium UFG structure at temperatures up to 450 C.

Conclusions

1. An ultrafine-grained microstructure processed by rotary swaging maintains thermal stability within the area of the alloy service temperature (≤450ºC) and contributes to UTS enhancement from 1050 MPa in an initial coarse-grained state up to 1290±10 MPa in an UFG state.
2. Hot isothermal forging of the UFG alloy at T~780ºC led to the recrystallization development and growth of secondary α- and β-phases up to 0.7 μm. The resulting strength of the alloy constituted 1100±30 MPa.
3. It has been shown that a thermal treatment of a forged VT8M-1 blade at T~500÷550%C can promote additional strengthening of the material by 10-15% due to the formation of extra interphase α/β boundaries with the precipitation of a tertiary α-phase as well as a silicide disperse strengthening.

Acknowledgements

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