Microstructure and performance characteristics of experimental forged billets of ultrafine-grained structure two-phase titanium alloy VT8M-1

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Abstract: *The UFG structure in the VT8M-1 alloy was formed by rotary swaging (RS). Experimental forged billets of ultrafine-grained structure (UFG) were obtained by isothermal die forging (IDF). The structural parameters and the homogeneity of the UFG structure were analyzed. Microstructure and mechanical properties of experimental workpieces of the ultrafine-grained VT8M-1 alloy produced by isothermal die forging was analyzed. The relationship between the microstructure and mechanical properties of the forged workpieces of the UFG VT8M-1 alloy is discussed.*
Keywords: *TWO-PHASE TITANIUM ALLOYS, ULTRAFINE-GRAINED STRUCTURE, ROTARY SWAGING, FORGED BILLETS, STRENGTH*

1. Introduction

Among structural materials, titanium alloys are widely applied in aviation and engine building due to their high specific strength, corrosion resistance and specific hot strength [1]. For example, the two-phase Ti alloy VT8M-1 (Ti-5.7Al-3.8Mo-1.2Zr-1.3Sn) is applied in modern engine building for the production of compressor blades. Compressor blades operate under the severe conditions of high static and dynamic loads, corrosive attack and temperature exposure. In this connection, a higher set of requirements is imposed on them, such as a combination of high strength, ductility, fracture toughness and fatigue resistance.

The conventional technology for the fabrication of blade workpieces from Ti alloys, having a rather complex surface configuration, is die forging [2]. It is known that the temperature of isothermal forging for coarse-grained Ti-based materials is about 950 °C, and the use of UFG billets in the shape-forming of blades creates an opportunity to implement isothermal forging at lower temperatures of 750-780 °C. The decrease in the forging temperature is related to the manifestation of superplasticity in UFG materials at lower temperatures and higher strain rates [3]. Such a temperature range makes it possible to preserve a homogeneous UFG structure, which ensures a higher level of properties in an experimental item.

2. Material and experimental procedure

For the investigation, we used the VT8M-1 alloy (VSMPO-AVISMA Corporation, Russia) with the following composition: Ti–5.7Al–3.8Mo–1.2Zr–1.3Sn–0.16Fe (wt.%). The β-transus temperature in the alloy is 980 ± 5 °C. The ultrafine-grained structure of the VT8M-1 alloy was formed by rotary swaging (RS) at 750 °C with a gradual reduction along the diameter of the billets from 70 to 32 mm (true strain e ≈ 1.56, the strain rate was higher than 300 mm s-1).

An experimental forging simulating a compressor blade was produced by IDF at a temperature of 780±10°C (figure 1).

Fig. 1. *Experimental forging produced from the UFG alloy VT8M-1.*

The microstructure was characterized by scanning electron microscopy (SEM) using a JSM 6390 microscope, and by transmission electron microscopy (TEM) using a JEM-2100 microscope. Tensile mechanical tests of flat specimens with a gage length of 16 mm and a width of 3 mm, cut out from the root and airfoil of the experimental forging, were performed using an Instron universal testing machine at room temperature with a strain rate of 1×10-3 s-1 in compliance with ASTM E8/E8M.

In this connection, the aim of the present paper is to study the effect of isothermal forging at lower temperatures on the microstructure of the UFG VT8M-1 alloy, and also to evaluate the mechanical properties of the produced workpiece.

3. Results and discussion

The microstructure of the forged workpieces produced by IDF (T=780 °C) is shown in figure 2. The SEM study of the microstructure of the forgings revealed a similar character of microstructure in the airfoil part and in the root part. The primary α-phase grains are elongated along the deformation direction and their thickness is 2-3 μm (figure 2 a,c). As it was noted above, such an elongated shape formed at the stage of processing by rotary swaging.

TEM study at a larger magnification revealed (figure 2b,d) that the microstructure of the (α+β)-region is represented by equiaxed recrystallized and deformed grains, the average grain size in the root part being larger than that in the airfoil and amounting to 0.9 and 0.7 μm, respectively. This is related to the fact that in the more massive root part, cooling after forging is slower than in the airfoil, which promotes more intensive recrystallization processes.

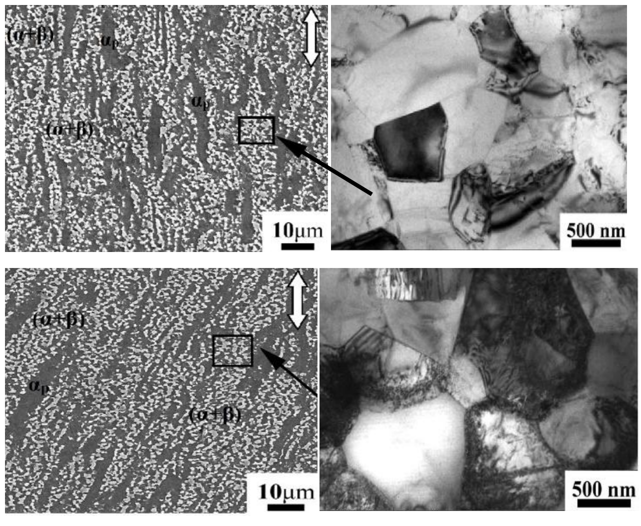

Figure 2. *Microstructure of the experimental forging: (a,b) the airfoil of the forging; (c,d) the root of the forging; (a,c) SEM; (b,d) TEM. The arrow indicates the draw direction.*

The mechanical properties of the specimens are listed in table 1. In the longitudinal direction of the experimental forging's airfoil (figure 1) strength declines to 1100 MPa as compared to the condition after RS (UTS = 1290 MPa), but at the same time ductility increases visibly, in particular, the uniform and percentage elongations grow to 7 and 15%, respectively (table 1). Such a decline in strength in conditioned by a decrease in dislocation density, the propagation of recrystallization and an increase in the sizes of small globular grains of the α- and β-phases (from 0.3 to 0.7 μm) (figure 2). The mechanical properties of the specimens in the longitudinal and cross directions of the airfoil zone have some differences. In particular, the ultimate tensile strength (UTS) in the cross section of the airfoil is slightly higher (1118 MPa), while the ductility, percentage and uniform elongations are lower. This is apparently conditioned by the presence of the inherited after RS metallographic and crystallographic texture in the forged workpiece.

Therefore, the results of this investigation demonstrates a possibility in principle of preserving a UFG structure during the shape-forming of an item by isothermal forging, and correspondingly, of preserving enhanced mechanical properties.

Table 1. *Mechanical properties of the Ti alloy VT8M-1 in different conditions.*

Condition	UTS, MPa	YS, MPa	Elong., %
As-received	1056±10	967±5	13±0.5
RS	1290±5	1195±10	9±1
Airfoil zone longitudinal direction	1100±30	947±25	15±1
Airfoil zone cross direction	1118±10	1048±20	10±0.6

4. Conclusions

1. The UFG structure with ultrafine α- and β-grains ~ 0.3 μm was obtained by the rotary swaging. This type of UFG structure leads to an increase in the ultimate tensile strength to UTS = 1290 MPa and some decline in elongation to δ=9%, as compared to the initial condition.

2. It is shown that as a result of isothermal forging at a temperature of 780°C, the high strength workpiece retains the ultrafine grain size which increased to 0.7 μm due to the processes of recovery and recrystallization.

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