The microstructure and properties of the alloy Ti-5Al-0.5V subjected to ECAP and ultrasonic treatment

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Abstract. This work presents the results of a study of the mechanical properties of a titanium alloy Ti-5Al processed by equal channel angular pressing (ECAP) and ultrasonic treatment (UST). The UST was carried out at a frequency of 20 kHz with an amplitude of oscillating tension-compression stresses of 100 MPa. It was shown that the alloy subjected to UST exhibited low temperature superplastic properties. Its elongation exceeded a value of 300%, the coefficient m was 0.3 at a strain rate of 1.7×10⁻⁴ 1/s.

1. Introduction

ECAP is an effective processing method, which results in a significant improvement of the technological and service properties of metals and alloys [1]. At room temperatures, the alloys subjected to ECAP possess high strength but low ductility due to their highly nonequilibrium structure. At high temperatures, these alloys exhibit low-temperature superplasticity.

Ultrasonic treatment (UST) affects the defect structure of metals and alloys that results in a change of their mechanical properties. Depending on the conditions of UST, the latter can lead either to an increase or to a decrease of internal stresses [2]. Also, the effect of UST depends on a material, its lattice type, alloy composition, initial microstructure etc. Most of the studies of the effect of ultrasound on the structure and properties of materials to date have been carried out on commercially pure fcc metals, while the studies on metals with hcp lattice are scarce. In the present work, we report on comparative studies of the properties of the titanium alloy Ti-5Al-0.5V subjected to ECAP and ECAP followed by UST with a frequency of 20 kHz and an amplitude of tension-compression stress of 100 MPa.

2. Experimental materials and procedure

The titanium alloy Ti-5Al-0.5V was chosen for this study. Rods of the alloy were subjected to 6 passes of ECAP in the die with an the angle between channels of 120° by Be rout at a temperature of 600 °C followed by extrusion at a temperature of 400 °C to a cross-sectional diameter of 16 mm. Then the samples were cut to cylinders with a length of 40 mm.

Some cylinders were treated by UST with an amplitude of oscillating tension-compression stresses of 100 MPa according to the scheme described in [3]. A standing wave with a sinusoidal stress distribution was excited in the waveguide. The antinode of compression-tension stresses was located in the centre of the sample; their amplitude was equal to 100 MPa.
Samples with a gauge length of 10 mm, a width of 3.4 mm and a thickness of 1.5 mm were used for tensile tests. The tensile tests were carried out at room and elevated temperatures in an Instron 5982 electromechanical-testing machine. The tensile tests in the conditions of superplasticity were performed with initial strain rates of 1.7, 3.3 and 6.7 times $10^{-4}$ s$^{-1}$ in isothermal conditions at 600 °C. The relative elongation to failure $\delta$, the true stress $\sigma$ and the true strain $\varepsilon$ on the stage of homogeneous elongation, and the strain rate sensitivity coefficient $m$ at $\varepsilon = 0.01$ were determined.

The Vickers microhardness of the samples was measured by an AFFRI DM8A testing instrument with a load on the indenter of 300 g and an exposure time of 10 s.

X-ray diffraction (XRD) analysis of the samples was carried out on a DRON-4 apparatus in the cross section of the cylinder. The Cu K$_\alpha$ radiation was used with Bragg-Brentano focusing. A Soller collimator for primary beam and a graphite monochromator for the diffracted beam were used. The experimental data were processed by means of the «Maud» (Materials Analysis Using Diffraction) software.

The microstructure of the samples was studied using a TESCAN MIRA 3 LMH FEG scanning electron microscope (SEM) in the regime of back-scattered electron imaging (BSE) and using a JEM 2000EX transmission electron microscope (TEM).

3. Experimental results and discussion

The microstructure of the $\alpha$ titanium alloy after ECAP is presented in figure 1. The ECAP did not result in a transformation of the initial plate-like structure into an equiaxed nanosized structure (figure 1 a). The alloy retained a plate-like microstructure with $\alpha$-plates having the thickness in between 1 and 10 $\mu$m. In the longitudinal section of the sample, plates aligned along its axis dominate. In the cross section, colonies of curved $\alpha$-plates are observed. The boundaries of the plates are decorated with dispersed particles, the fraction of which is about 3% and the sizes are less than 0.5 $\mu$m. According to [4], these are particles of $\alpha$-phase with an enhanced content of vanadium and reduced content of aluminum.

![Figure 1](image1.png)

**Figure 1.** BSE images of microstructure of the Ti-5Al-0.5V alloy after ECAP in longitudinal (a) and cross sections (b).

The TEM micrographs of samples after ECAP show that in the bulk of $\alpha$-plates there are weakly misoriented fragments with sizes of about 1 $\mu$m with a high density of dislocations (figure 2 a). The estimates of microstrains and dislocation density obtained by XRD have given the values of approximately $2.6\times10^{-5}$ and $4\times10^{14}$ m$^{-2}$, respectively. The UST did not result in considerable changes of the fine structure of the alloys (figure 2 b), the microstrain and dislocation density values are approximately equal to $2.9\times10^{-5}$ and $5\times10^{14}$ m$^{-2}$.
Figure 2. TEM images of microstructure of Ti-5Al-0.5V alloy after ECAP (a.) and ECAP+UST (b).

The strength properties of the alloy at room temperature after ECAP and additional UST are similar. The microhardness values in the two states are equal to 3090±130 and 3170±130 MPa, respectively, and the ultimate tensile strength values are equal to 1401±50 and 1433±50 MPa, respectively. These values are typical for the titanium alloys subjected to SPD [1].

The UST did not affect significantly the deformation behavior of the Ti-5Al-0.5V alloy tested in the conditions of low-temperature superplasticity (figure 3 and table 1). The flow stress for all samples attains a maximum value near \( \varepsilon \approx 0.01 \) and then gradually decreases in a fairly large strain interval. The features of superplasticity are observed only at the strain rates about \( 10^{-4} \) s\(^{-1} \). During deformation with initial strain rate of \( 1.7 \times 10^{-4} \) s\(^{-1} \), the steady stage flow strain is observed and the strain rate sensitivity coefficient is close to the value of 0.3. Values of the uniform elongation and elongation to failure increase with decreasing strain rate (table 1). The maximum elongation of 342\% is demonstrated by the Ti-5Al-0.5V alloy subjected to ECAP followed by UST at a strain rate of \( 1.7 \times 10^{-4} \) s\(^{-1} \).

Figure 3. True stress – true strain curves of tensile deformation of UFG Ti-5Al after ECAP and ECAP followed by UST.
Table 1.

| $\dot{\varepsilon}$, s$^{-1}$ | ECAP | ECAP+UST | ECAP | ECAP+UST | ECAP | ECAP+UST |
|-------------------------------|------|----------|------|----------|------|----------|
| $6.7 \times 10^{-4}$           | 143  | 117      | 77   | 51       | -    | -        |
| $3.3 \times 10^{-4}$           | 191  | 184      | 122  | 87       | 0.29 | 0.33     |
| $1.7 \times 10^{-4}$           | 257  | 342      | 191  | 203      | 0.30 | 0.29     |

It should be pointed out that $\alpha$-titanium alloys usually do not exhibit features of superplastic deformation both in the fine grained [5] and submicrocrystalline states [6]. This is explained by the limited number of slip systems in the hcp lattice of titanium and quick growth of $\alpha$-grains at test temperatures.

4. Conclusions

The results of the present study show that the single-phase $\alpha$-alloy Ti-5Al-0.5V subjected to ECAP and UST can demonstrate superplastic behavior and allow significant elongations of up to about 340% at a temperature of 600 °C and the initial strain rate of $1.7 \times 10^{-4}$ s$^{-1}$.

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