Effect of Heat-Treatment Conditions on Structural and Phase Transformations in a Two-Phase α + β Titanium Alloy Subjected to Thermomechanical Treatment


*Ural State Technical University (UPI), ul Mira 19, Ekaterinburg, 620002 Russia

B Institute of Metal Physics, Ural Division, Russian Academy of Sciences, ul. S. Kovalevskoi 18, Ekaterinburg, 620990 Russia

Received October 14, 2009; in final form, November 20, 2009

Abstract—Effect of heat-treatment parameters (heating temperature in a range of 550 to 700°C and holding time from 0.5 to 2 h) on the occurrence of structural and phase transformations in the Ti-6-4 Eli titanium alloy, which was preliminarily subjected to warm rolling at 550°C after quenching from 945°C, has been studied. During the heating of the rolled alloy to 550°C, the formation of recrystallized nanosized grains in the martensitic matrix was found to occur. The increase in the temperature and time of holding favors the activation of recrystallization processes and increase in the size of arising grains to a micron level. It has been found that the decomposition of the α’ martensite can occur at the expense of both the precipitation of nanosized β-phase particles via a heterogeneous mechanism (Tₜ₅ = 550–600°C) and through the formation of individual β-phase grains between recrystallized α’ particles at the higher heating temperatures (650–700°C). The prevalence of one of these processes, namely, recrystallization or decomposition, during the heat treatment of the deformed alloy determines the character of changes of microhardness characteristics.

Key words: titanium alloys, deformation, annealing, recrystallization

DOI: 10.1134/S0031918X1006013X

INTRODUCTION

To improve the service properties of metallic alloys, in particular, based on titanium, treatments that allow one to refine the structure to submicrocrystalline (SMC) and nanocrystalline (NC) states become more widely used [1]. The following methods of severe plastic deformation (SPD) were used for titanium alloys as such thermomechanical treatments: high-pressure torsion [2], equal-channel angular pressing (ECAP) [3], and overall forging [4]. The principal disadvantage of these methods is the limited dimensions of samples prepared and low technological efficiency. At the same time, intense studies into the refinement of the structure of martensitic (α + β) titanium alloys by traditional methods of thermomechanical treatment (TMT), namely, high-temperature treatment (HTMT) and low-temperature treatment (LTMT) [5, 6], have been performed in recent times. The use of TMT for the preparation of submicrocrystalline and nanostructured states has its own limitations. During HTMT, the deformation should be performed within the β-phase field. Such a deformation results in intense grain growth, and, in this case, the required refinement of the structure is by no means always possible. The application of LTMT is possible only for a limited range of martensitic (α + β) titanium alloys of the VT16 type [6], which are quenched for the formation of the α” martensite and can undergo substantial deformations in the martensitic state. The following data indicate the possibility of such a treatment. The fragmentation of the structure of the VT6 alloy up to the NC state in the course of warm rolling at 550°C after preliminary ECAP is shown in [7]; it was there noted that, along with the structure-refinement processes, phase transformations can occur intensely, which also affect the final structure and properties of the alloys. In this work, the warm rolling was performed for the martensitic structure preliminarily formed by thermal methods rather than for the structure formed by ECAP. After the warm rolling, the final “refining” treatment was effected. The studies performed in this direction in [8] showed that, to obtain a disperse martensitic structure and retain fine recrystallized β-phase grains, the optimum temperature range for quenching is Tₚₘ – (10–20) K. Along with this fact, it was found in [9] that in the Ti-6-4 Eli alloy, whose composition is close to that of the VT6 alloy but is characterized by a higher impurity content, during heating above 700°C after ECAP there is formed a structure with a grain size exceeding the SMC and NC levels. Based on these data, in our opinion, it is of interest to study the effect of the time—temperature
parameters of heating on the formation of the structure and phase composition in the Ti-6-4 Eli alloy subjected to warm rolling after quenching from a temperature of $T_{pt} - 15$ K.

**EXPERIMENTAL**

The study was performed using a commercial Ti–6Al–4V Eli alloy (whose average chemical composition is Ti–6.05 Al–3.42 V–0.12 Fe–0.11 O$_2$ wt %) in the form of rods 20 mm in diameter, which was subjected to hot rolling at a temperature corresponding to the $\alpha + \beta$ field and subsequent TMT that included the quenching of samples 200 mm long from 945°C ($T_{pt} - 15$ K) and repeated warm rolling with intermediate annealings at 550, 600, 650, and 700°C for 0.5, 1, and 2 h. The structural studies were performed using an SEM-535 (Philips) scanning electron microscope and a JEM-200 CX transmission electron microscope. The qualitative phase analysis of the samples was performed in an angular range $2\theta = 33–70$° using a DRON-3 diffractometer and Cu $K_{\alpha}$ radiation. The microhardness measurements were performed under a load of 100 g using an attachment to a Neophot-21 optical microscope.

**RESULTS AND DISCUSSION**

The heating of the Ti-6-4 Eli alloy for quenching from 945°C (close to $T_{pt}$) favors the primary recrystallization in the $\beta$ phase and formation of $\beta$-phase grains 30–50 µm in size, whose growth is limited by equiaxed $\alpha$-phase particles 3–4 µm in size located mainly at grain boundaries. Upon water quenching, the $\beta$ solid solution undergoes a martensitic ($\beta \rightarrow \alpha'$) transformation with the formation of packets of martensite plates in the bulk of grains. After warm rolling, the shape of primary $\alpha$-phase particles changes; namely, the equiaxed particles become elongated along the rolling direction (Fig. 1a) and some of the martensite-plate packets become curved. The $\alpha'$ martensite plates are characterized by a high density of dislocations and, sometimes, are divided into fragments less than 300 nm in size (Fig. 1b). The residual $\beta$ phase remains in the structure in the form of very thin interlayers between $\alpha'$ martensite plates (Fig. 1b, the $\beta$-phase is shown by arrows). The microhardness of $\alpha'$ martensite in the deformed state is sufficiently high and is 4100 MPa on average.

The data obtained by scanning electron microscopy (SEM) indicate that, within the time–temperature ranges under study, the primary $\alpha$ phase is characterized by the occurrence of the following processes: formation of internal substructure upon heating to 550 and 600°C with holdings for 1–2 and 0.5–1 h, respectively; and recrystallization upon heating to 600, 650, and 700°C with holdings for 2, 1–2, and 0.5–2 h, respectively.

The typical structures corresponding to the above processes are given in Fig. 2. Figure 2a shows that, within the primary $\alpha$ phase there is observed a diffraction contrast that is due to a thin network of sub-boundaries, which is likely to result from the occurrence of polygonization processes. An increase in the treatment temperature favors a further development of these processes and transition from polygonization to recrystallization of the primary $\alpha$ phase. This results in the formation of new recrystallized grains within the bulk of $\alpha'$-phase grains (Fig. 2b).

It is also seen from the microstructures that, as the heating temperature increases, the martensitic structure also undergoes a transformation; namely, the directivity typical of $\alpha'$-martensite packets (see Fig. 2) disappears with increasing temperature at the expense of the decomposition of martensite and recrystallization (see Fig. 2b). The development of these processes...