EFFECT OF NONUNIFORM SIZE DISTRIBUTION OF SUBMICROCRYSTALLINE STRUCTURE ELEMENTS ON THE MECHANICAL PROPERTIES OF AN ALLOY Ti–6Al–4V

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The effect of nonuniform size distribution of grain-subgrain structure elements on the mechanical properties of an alloy Ti–6Al–4V *in a submicrocrystalline state produced by multiple pressing is investigated. The presence of a small number of coarse grains in the grain size distribution is shown to decrease the yield and ultimate strength at room temperature and the degree of fracture strain under superplastic flow conditions.*

INTRODUCTION

Current development of engineering calls for advanced materials with improved physicochemical and mechanical properties. To this end, considerable recent research and development have been focused on metals and alloys of submicrocrystalline or nanocrystalline structure. Interest in these materials has primarily been due to their unique physicomechanical properties essentially different from those found in materials of fine- or coarse-grained structure. While retaining adequate plasticity, this kind of materials has high strength and exhibits low-temperature and/ or high-rate superplasticity under certain conditions [1–4]. It is shown that the grain-boundary diffusion coefficients in the examined materials may be several orders greater than in their coarse-grained cousins [5, 6].

Up to now there has been no consensus of opinion among researchers as to the evolution pattern of the physicomechanical properties of metallic materials in the case where submicrocrystalline or nanocrystalline structure is formed. One conceivable reason is incomplete characterization of the structure-phase state of the materials used in experiments aimed at investigating particular properties of metals or alloys. The mechanical properties and diffusion parameters of the materials are substantially affected by the state of grain boundaries [2, 4, 7] and by nonuniform size distribution of grain-subgrain structure elements [3, 7–10]. On frequent occasions, however, investigations into submicrocrystalline materials produced by severe plastic deformation do not include adequate characterization of the resulting grain-subgrain structure. This makes it difficult to assess the influence of the structure on the properties of the examined materials.

It is the purpose of this work to investigate the effect of the parameters of grain-subgrain structure elements (size and nonuniform size distribution) on the mechanical properties of a titanium alloy Ti–6Al–4V.

MATERIAL AND EXPERIMENTAL TECHNIQUE

The structure and mechanical properties of a titanium alloy Ti–6Al–4V in a coarse-grained state and upon multiple pressing in different regimes [3] in the temperature interval from 823 to 1073 K have been studied in sufficient detail. Dumb-bell specimens with a gage section of $5 \times 1.7 \times 0.8$ mm^3 were subjected to tensile tests, using a PV-3012 M machine equipped with a tensometric system for load measurements with automatic registration of flow curves in load-time coordinates in a vacuum of 10^{-2} Pa at a rate of $6.9 \cdot 10^{-3}$ s^{-1} from room temperature to 1073 K. The specimens were

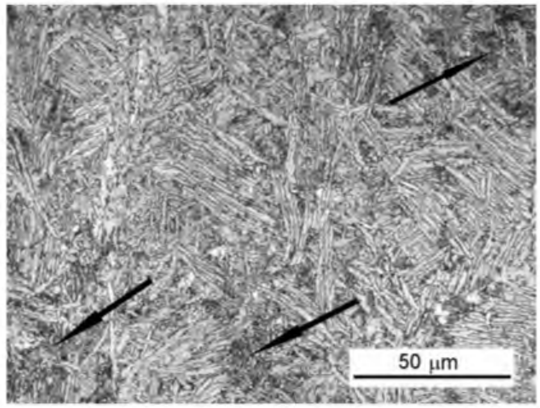

Fig. 1. Microstructure of a titanium alloy Ti–6Al–4V in a coarse-grained state. The arrows show regions of globular structure.

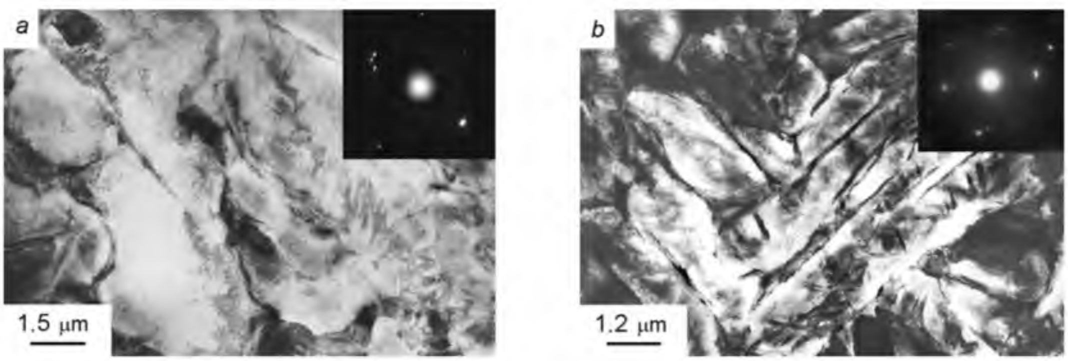

Fig. 2. Electron micrograph of the Ti–6Al–4V microstructure in a coarse-grained state: globular structure (*a*) and lamellar structure (*b*).

prepared for the tests by the electrospark technique. A 100 μm thick layer was removed by mechanical and electrolytic polishing. Structural analysis was performed by means of an optical microscope (Olympus GX 71) and a transmission electron microscope (EM-125 K). Foils for electron microscopy were prepared by a standard technique, using a polishing machine (Mikron 103). The electrolyte was 20% $HClO_4$+80%CH_3CO_2H. The size of the grain-subgrain structure elements was determined from dark-field images. No less than 200 grains were examined.

RESULTS AND DISCUSSION

Experimental results show that the structure of the alloy Ti–6Al–4V in the initial (coarse-grained) state exhibits two components: regions with globular grains and those with lamellar (martensitic) structure (Fig. 1). It follows from the data obtained by electron microscopy that the size of fragments of globular shape varies between 1 and 5 μm (Fig. 2*a*). A major part of the bulk of the material is of lamellar structure, with the lamellas being 1–2 μm in width and 3–7 μm in length (Fig. 2*b*). The microdiffraction patterns for this structure are typical of a coarse-grained material. Upon multiple pressing, a homogeneous grain-subgrain structure with an average size of elements d_{av} ~0.25 μm (Figs. 3 and 4*a*) is formed in the alloy. The size of the structure elements varies, as a rule, between 0.1 and 0.6 μm. Formation of the submicrocrystalline structure increases the ultimate strength σ_B and yield strength $\sigma_{0.2}$ by 45% at room temperature as compared to an alloy with a coarse-grained structure. Notably, the fracture strain δ is at the initial level. The temperature dependence of the strength characteristics σ_B and $\sigma_{0.2}$ of the alloy in a submicrocrystalline state shows that

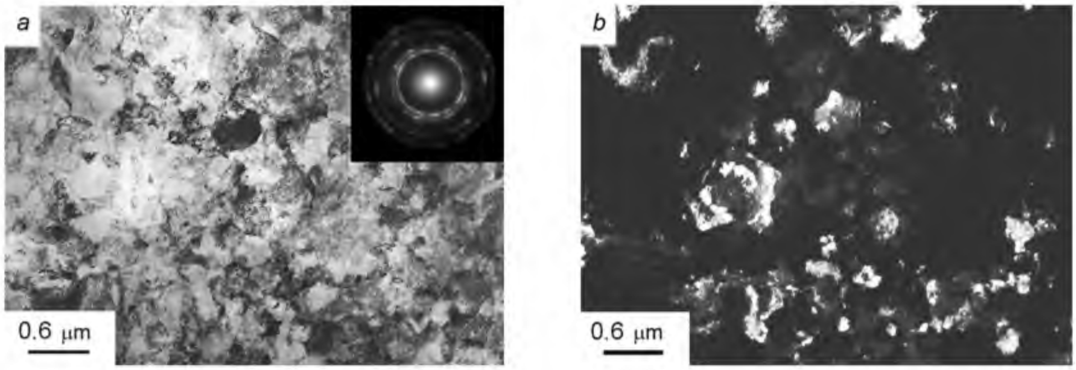

Fig. 3. Electron micrographs of the Ti–6Al–4V microstructure upon multiple pressing: bright-field (*a*) and dark-field images (*b*).

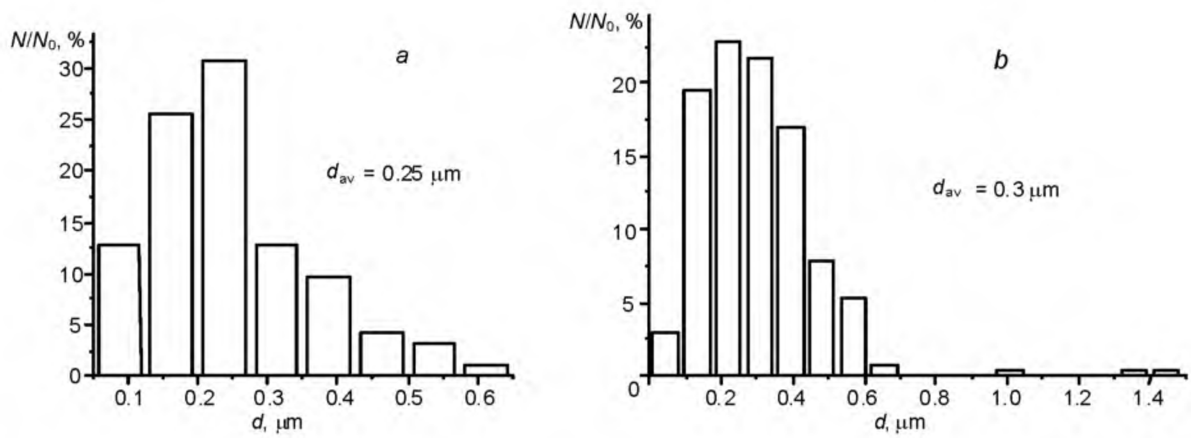

Fig. 4. Histograms of the size distribution of the grain-subgrain structure of a titanium alloy Ti–6Al–4V subjected to multiple pressing: homogeneous structure (*a*) and nonhomogeneous structure (*b*).

these properties are higher than in a coarse-grained material up to ~673K (curves *1* and *2* in Fig. 5*a* and *b*). As the test temperature is further increased more drastic softening of the alloy in the submicrocrystalline state takes place as compared to that in the coarse-grained state. As a result σ_B and $\sigma_{0.2}$ are found to be much lower than in the coarse-grained state, whereas the elongation at rupture increases dramatically and is as high as ~500% at 873 K (curve *2* in Fig. 5*c*).

In the case where optimum conditions for multiple pressing of the examined material are violated, fairly large grains 1–1.5 μm in size can be formed or inherited by the alloy from the initial structure (Fig. 4*b*). As is seen from the histograms, the size distribution of the grain-subgrain structure elements for specimens of homogeneous or nonhomogeneous structure with d_{av} up to 0.5 μm is similar in qualitative terms. A salient difference between the histograms is a tail in Fig. 4*b* formed by single grains of fairly large size. While the relative volume fraction of such structure elements is no greater than 10–15%, there is a marked change in the mechanical structure both at room temperature and at elevated temperatures. For example, σ_B = (1350±50) MPa and $\sigma_{0.2}$ =(1270±50) at room temperature. Thus, a decrease in the quantities under consideration as compared to those for an alloy with homogeneous structure (Fig. 5) may be up to 10%. The structure nonhomogeneities may adversely affect the superplasticity characteristics of the alloy as well. At 973 K, elongation at rupture of specimens with nonhomogeneous structure is reduced by a factor of 1.5 as compared to specimens with homogeneous structure (700 and 450%, respectively). The average grain size in such a material changes but little (in our case, d_{av} ~ 0.3 μm for a nonhomogeneous structure, Fig. 4*b*). It should be noted

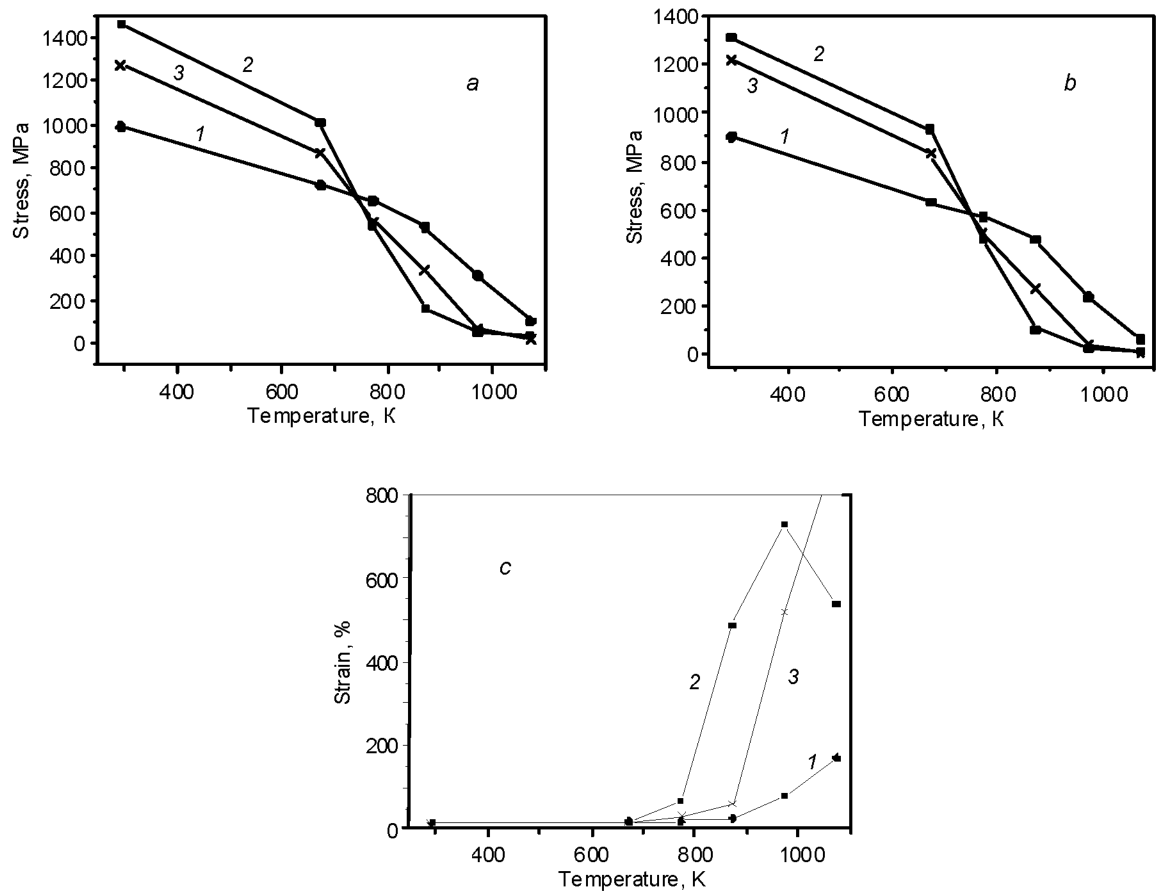

Fig. 5. Temperature dependence of ultimate strength (*a*), yield strength (*b*), and plasticity (*c*) of Ti–6Al–4V in a coarse-grained state (*1*) and upon multiple pressing for d_{av} = 0.25 (*2*) and 0.45 μm (*3*).

that it is rather difficult to reveal the nonhomogeneities and especially to estimate their volume fraction in the examined material. This is due to the fact that the nonhomogeneities are not seen on metallographic micrographs and cannot be registered by electron microscopy because of a small foil area. The mechanical properties of the examined specimens can change perceptibly (and virtually in an unpredictable way) depending on the region in the initial piece of metal where coupons for tests were removed. For comparison, Fig. 5 shows data for an alloy Ti–6Al–4V with average grain size of 0.45 μm. It follows from the figure that the mechanical properties of the specimens of nonhomogeneous structure approach those with d_{av} ~0.25 and 0.45 μm. This is the case in the entire temperature interval studied. Clearly, it is rather difficult to draw conclusions relating to the effect of the average grain size on the properties of submicrocrystalline materials on the basis of an interpretation of the data available.

CONCLUDING REMARKS

The mechanical properties of a titanium alloy Ti–6Al–4V are shown to change perceptibly even in the presence of relatively small nonuniformities in the size distribution of elements of a grain-subgrain structure formed upon severe plastic deformation. Therefore, consideration of the nonhomogeneity of the grain structure is of fundamental importance in analyzing the mechanical properties of the material dependent on the structure parameters. The presence of a small number of large grains in the size distribution causes the yield and ultimate strength at room temperature and the degree of fracture strain under superplastic flow conditions to decrease.

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