Effect of 5 GPa Pressure Treatment on Nanoindentation Creep Property of TC6 Titanium Alloy

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Abstract: TC6 titanium alloy was heat treated with 5 GPa pressure, and the effect of high pressure treatment on nanoindentation creep property of TC6 titanium alloy was investigated by using nanoindentation. The results show that indentation creep in TC6 titanium alloy before and after 5 GPa pressure treatment can occur at room temperature, 5 GPa pressure treatment can reduce creep deformation of TC6 titanium alloy at room temperature with different pressure and time, and improve the creep resistance of the alloy.

Key words: TC6 titanium alloy, 5 GPa pressure treatment, nanoindentation, creep.

1. Introduction

In recent years, there are many studies on optimizing microstructure and properties of the metal materials achieved by high pressure treatment [1-3], but there are few reports about the effect of high pressure treatment on creep properties of the metal materials. The creep property is one of the main bases for the evaluation of the mechanical properties of the metal materials. Traditional testing methods are usually used to study creep properties of the metal materials at high temperature [4, 5], but is not suitable for measuring the creep properties of the materials at room temperature. With high loading and displacement detectability and without the limitation of shape and size of the materials, nanoindenter is an effective method for studying the creep properties of materials at room temperature [6, 7]. TC6 titanium alloy is attractive for many structural applications in the aerospace industry due to its unique combination of strength and lightness [8-10]. In this paper, the indentation creep property at room temperature of TC6 titanium alloy was studied by nanoindentation technique, and the effects of 5 GPa pressure treatment on indentation creep property at

room temperature of TC6 titanium alloy was discussed.

2. Experiments

The experimental material was annealed TC6 titanium alloy, with the chemical composition (mass fraction %) of 6.12 Al, 2.64 Mo, 1.86 Cr, 0.44 Fe, 0.32 Si, and 88.62 Ti. The samples with the size of Φ 6 mm $\times$ 10 mm were sealed into graphite heaters, and then were pressurized to 5 GPa; after that, the samples were heated to 1,040 °C and lasted for 20 min on the CS-IB type six-anvil high-pressure equipment which uses pyrophyllite as the pressure-transmitting medium, and cooled to room temperature. The samples before and after high pressure treatment were cut into nanoindentation samples with the size of Φ 6 mm $\times$ 4 mm, and then the creep deformation was measured by a triboindenter nano-mechanical test instrument under the condition of 1,100~3,500 μ N pressure and 10~240 s retention time. Berkovich-type indenter with curvature radius of 150 nm was chosen to determine the creep deformation. The loading and displacement detectability of this testing system were 50 nN and 0.01 nm, respectively, and the loading and unloading rates were 100 μ N $\cdot$ s⁻¹. The data was obtained by averaging the test values of repeated three

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measurements. The microstructure of the samples were observed on the Axiovert 200MAT metalloscope and JEM-2010 type transmission electron microscope.

3. Results and Discussion

3.1 Microstructures

Fig. 1 shows the microstructure of TC6 titanium alloy in different states. It can be seen that the annealed alloy were composed of the thick flake α phase and intergranular β phase; after 5 GPa pressure treatment, straight α phase piece was destroyed, generating local necking-down joint and broken parts in the α phase pieces, and then irregular blocks and thin strips of α phase were formed. The density of dislocation increases obviously in microstructure of the alloy after 5 GPa treatment (Fig. 2), this is due to that the alloy was in the β single phase region when TC6 titanium alloy was heated to 1,040 °C, and the β phase would be transformed into α phase during the following cooling process. Lattice distortion caused by high strain is generated in the TC6 titanium alloy under high pressure treatment, which leads to an increase of

dislocation, and provides preferential nucleation sites for the phase transformation, while the ultra-high pressure treatment can reduce the diffusion coefficient of atoms and inhibit the growing of the crystal nucleus. Thus, after 5 GPa pressure heat treatment, thin strip α phase is formed within the TC6 titanium alloy and the microstructure is refined.

3.2 Indentation Creep

Fig. 3 shows the load-displacement curves for nanoindentation test of the TC6 titanium alloy before and after 5 GPa pressure treatment. It can be seen that the indent depth after high-pressure treatment is shallower than before under the same load, which means the high-pressure treatment can increase the plastic deformation resistance of the alloy. In addition, the narrow plateau region of the load-displacement curves (Fig. 3) exhibit creep behavior after keeping the maximum load for 10 s. The length of the plateau of the TC6 titanium alloy before and after high pressure heat treatment is 5.76 and 4.74 nm, respectively. The nanoindentation hardness of the TC6 titanium alloy

Fig. 1 Microstructure of TC6 titanium alloy: (a) As-annealed and (b) 5 GPa treatment.

Fig. 2 TEM images of TC6 titanium alloy: (a) As-annealed and (b) 5 GPa treatment.

before and after 5 GPa pressure treatment were 4.51 GPa and 5.68 GPa, respectively. Thus it can be seen that both the nanoindentation hardness and creep resistance of TC6 titanium alloy after 5 GPa pressure treatment are higher than before.

Fig. 4 shows the relationship between applied load or hold time and creep deformation. It can be seen that the creep deformation of TC6 titanium alloy before and after 5 GPa pressure treatment showed an increasing trend with the increase of the applied load and hold time, and the deformation after 5 GPa pressure treatment is less than that of before pressure treatment. Staying 180 s under 3,000 μN , the creep deformation of TC6 titanium alloy before and after 5 GPa pressure treatment was 13.86 nm and 12.35 nm, respectively. The creep deformation of TC6 titanium alloy after 5 GPa pressure treatment decreased 10.89% compared with the deformation before pressure treatment. This illustrates that 5 GPa pressure treatment can improve the creep resistance of TC6 titanium alloy at room temperature. The creep of metal materials is mainly caused by dislocation slipping and grain boundary sliding [11]. The creep at room temperature is mainly caused by intragranular dislocation slipping [12]. The grain boundary is the barrier of dislocation glide, and the resistance to dislocation motion will be greater with the increase of grain boundaries, and then the materials

have few chances to creep. In addition, 5 GPa pressure treatment can increase the dislocation density in TC6 titanium alloy microstructure, resulting in work-hardening caused by the interaction of the slip dislocations, thereby reducing the creep rate. Furthermore, the bigger hardness of materials will increase the resistance of the dislocation movement, and the ability to resist creep also will be stronger. 5 GPa pressure treatment can refine the microstructure of TC6 titanium alloy and increase the number of the grain boundary and dislocation density, then the hardness of the alloy increased. Thus, the creep resistance of TC6 titanium alloy can be improved effectively after 5 GPa pressure treatment.

Fig. 3 Load-displacement curves for nano-indentation tests of TC6 titanium alloy (at 3,000 μN for 10 s).

Fig. 4 Relationship between applied load or hold time and creep deformation. (a) Relationship between hold time and creep deformation (at 1,500 μN) and (b) Relationship between applied load and creep deformation (for 10 s).

4. Conclusions

(1) 5 GPa pressure treatment can refine the microstructure of TC6 titanium alloy, increase its hardness, and improve the creep resistance of the alloy effectively at room temperature.

(2) The indentation creep of TC6 titanium alloy before and after 5 GPa pressure treatment increased with the increase of the load and the hold time. When the TC6 titanium alloy after 5 GPa pressure treatment stayed 180 s under 3,000 μN load, its creep is 12.35 nm, which reduced 10.89% compared with the creep before treatment.

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