

Effect of High Pressure Heat Treatment on Room Temperature Creep Property of Ti-6Al-4V Alloy by Nanoindentation Technique

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Abstract: Ti-6Al-4V alloy was treated at 5 GPa pressure and 1,000 °C for 20 minutes, the room temperature creep deformation of the alloy before and after 5 GPa pressure treatment was measured. According to the microstructure analysis, the effect of high pressure heat treatment on room temperature creep property of Ti-6Al-4V alloy was investigated. The results show that room temperature creep in Ti-6Al-4V alloy before and after 5 GPa pressure treatment can occur, 5 GPa pressure treatment can reduce room temperature creep deformation, and leads to the creep resistance of Ti-6Al-4V alloy rises.

Key words: Ti-6Al-4V alloy, 5 GPa pressure treatment, nanoindentation, creep.

1. Introduction

Ti-6Al-4V alloy is one of the important structural materials in aerospace industry because of its good mechanical properties and process performance [1-3]. The creep behavior of Ti-6Al-4V alloy, which affects their service life, will inevitably take place when subjected to external extrusion force at room temperature. Therefore, it is important to explore the room temperature creep property of Ti-6Al-4V alloy. Nanoindentation test system with high displacement resolution, precise test results, and without the sample shape and size restriction, is an effective method to study the mechanical properties of materials [4, 5]. In addition, recent studies have shown that high pressure heat treatment can improve the mechanical properties of metallic materials [6, 7]. For that reason, this paper explores the effects on the creep properties of Ti-6Al-4V alloy under 5 GPa pressure treatment at room temperature by using nanoindentation

technique.

2. Experiments

The experimental material is annealed Ti-6Al-4V alloy. And annealed samples with the size of $\Phi 8$ mm \times 10 mm were sealed into graphite heaters, then were pressurized to 5 GPa and heated to 1,000 °C for 20 min on the CS-IIIB type six-anvil high-pressure equipment which uses pyrophyllite as the pressure-transmitting medium. The pressure was released after the samples were cooled down to room temperature. Then the $\Phi 8$ mm \times 5 mm size specimens were cut out before and after high pressure treatment. The room temperature indentation experiments were performed on a triboindenter nano-mechanical test instrument at the condition of 1,000~3,000 μ N applied load and kept at these load for 10~200 s, using a loading and unloading rates of 100 μ N/s. The loading and displacement detectability of this testing system are 50 nN and 0.01 nm, respectively. Berkovich-type indenter with curvature radius of 150 nm was chosen in this experiment, the data are the mean value of three measured results. The microstructures of the specimen

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before and after high pressure treatment were observed by means of Axiovert200MAT type OM (optical microscope) and Jeol-2010 type TEM (transmission electron microscope).

3. Results and Discussion

3.1 Microstructures

Fig. 1 shows the microstructures of Ti-6Al-4V alloy before and after 5 GPa pressure treatment. It can be seen that the microstructure of annealed alloy is composed of coarse lath α phase and intragranular β phase, however, after 5 GPa pressure treatment it has been refined to form a thin lath α phase. Observed by TEM (transmission electron microscope) (Fig. 2) it can be seen that the microstructure of Ti-6Al-4V alloy is refined and the dislocation density is higher after 5 GPa pressure treatment when compared with the annealed condition. This can be attributed to that the Ti-6Al-4V alloy is in the beta single phase region when heated to 1,000 °C. In the subsequent cooling process, the beta phase will be transformed into alpha phase. The lattice distortion of Ti-6Al-4V alloy caused by high strain due

to high pressure will lead to the increasement of the dislocation quantity, which provided more nucleation sites for the new precipitate particles (i.e. increasing the nucleation rate). Meanwhile, ultra-high pressure can reduce the atomic diffusion coefficient and inhibit new phase nuclei to grow up. Therefore, the microstructure of Ti-6Al-4V alloy becomes refined after 5 GPa pressure heat treatment.

3.2 Indentation Creep

Fig. 3 shows the load-displacement curves of the Ti-6Al-4V alloy before and after 5 GPa pressure treatment. It can be seen that the indentation depth of the alloy becomes shallow and plastic deformation resistance that was increased after high pressure treatment under the same conditions. Fig. 3 also tells us that the two curves present a tiny platform after keeping the load of 3,000 μ N for 10 s, indicating that the two alloys both produce creep behavior. The creep deformation and nanoindentation hardness of Ti-6Al-4V alloy before and after 5 GPa pressure treatment are 5.53 nm, 4.35 GPa and 4.18 nm, 5.24 GPa,

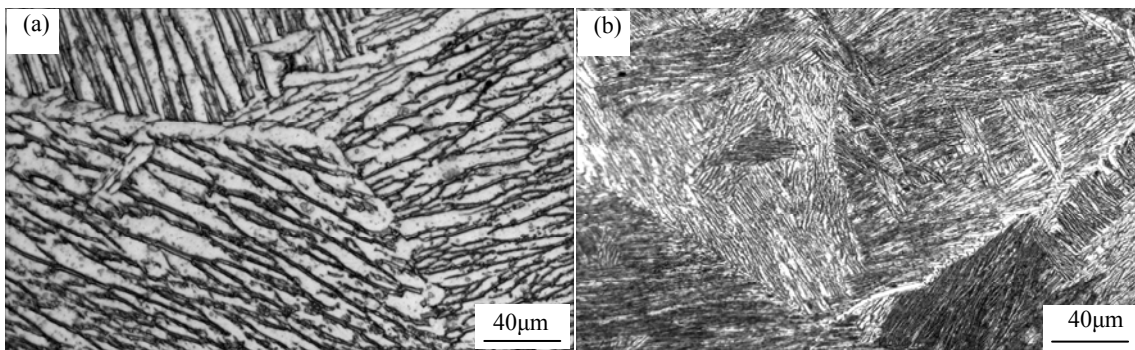


Fig. 1 Microstructure of Ti-6Al-4V alloy: (a) As-annealed; (b) 5 GPa treatment.

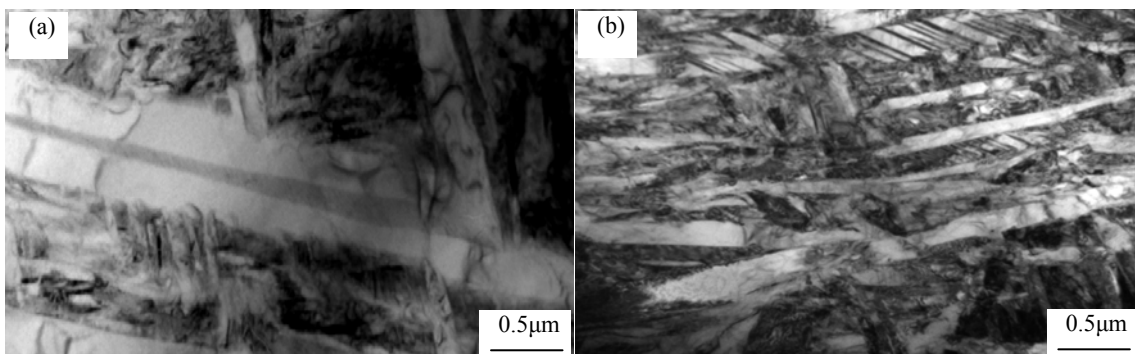


Fig. 2 TEM images of Ti-6Al-4V alloy: (a) As-annealed; (b) 5 GPa treatment.

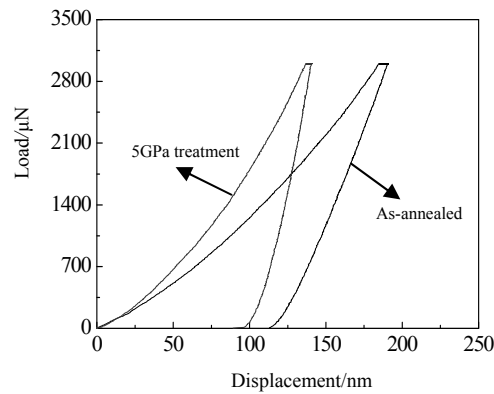


Fig. 3 Load-displacement curves for nano-indentation tests of Ti-6Al-4V alloy (at 3,000 μN for 10 s).

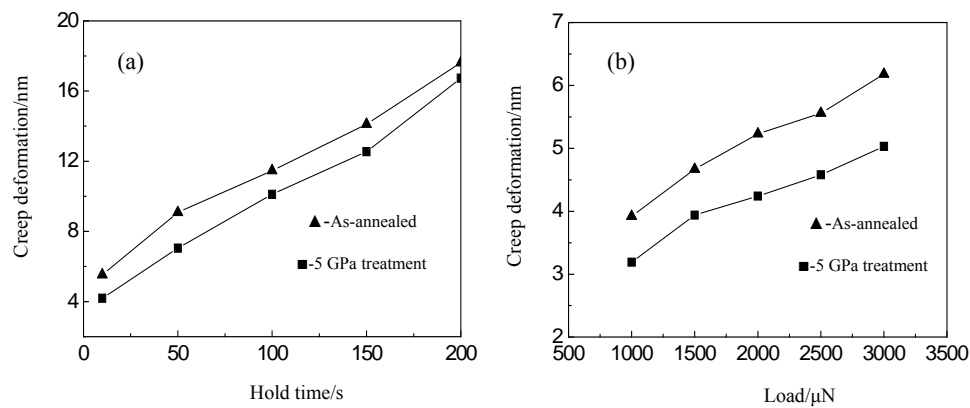


Fig. 4 Relationship between applied load or hold time and creep deformation. (a) Relationship between hold time and creep deformation (at 3,000 μN); (b) Relationship between applied load and creep deformation (for 20 s).

respectively. Thus it can be concluded that the hardness and creep resistance of Ti-6Al-4V alloy are enhanced after 5 GPa pressure treatment.

Fig. 4 shows the relationship between applied load or hold time and creep deformation. It can be seen that the creep deformations of Ti-6Al-4V alloy both increased with the increase of applied load and hold time before and after 5 GPa pressure processing, and the latter is smaller. The creep deformations are 4.67 nm and 3.94 nm at the applied load of 1,500 μN for 20 s after 5 GPa pressure treatment, respectively. The creep deformation decreased by 15.63% after 5 GPa pressure treatment compared with untreated. This suggests that the room temperature creep resistance of Ti-6Al-4V alloy can be improved by 5 GPa pressure treatment. The reason can be attributed to that the metal material creep behavior produced mainly by two

ways: Dislocation glide and grain boundary sliding [8], and the room temperature creep is mainly caused by the intragranular dislocation glide [9]. The grain boundary is an obstacle to the dislocation slip. The more grain boundary, the greater the resistance of dislocation motion, and the material less prone to creep. On the other hand, the dislocation density of Ti-6Al-4V alloy is increased by 5 GPa pressure treatment, leading to the creep rate decreased due to the work hardening caused by the interaction between slip dislocations with other dislocations. In addition, the higher hardness of materials, the greater resistance to dislocation motion, and the greater resistance to creep. In a word, the hardness of Ti-6Al-4V alloy is enhanced when subjected to 5 GPa pressure treatment due to microstructure refinement and grain boundary and dislocation density increase. Therefore, the

creep resistance of Ti-6Al-4V alloy can be improved through 5 GPa pressure processing.

4. Conclusions

(1) High pressure treatment under 5 GPa refines the microstructure and enhances the hardness of Ti-6Al-4V alloy, therefore improves the resistance of indentation creep deformation at room temperature, effectively.

(2) The indentation creep deformations of Ti-6Al-4V alloy before and after high pressure treatment under 5 GPa are both increased with the increasing of applied load and kept time, respectively. In particular, the indentation creep deformation is 4.01 nm, decreased by 15.63% compared with untreatment, at the applied load of 1,500 μ N for 20 s after 5 GPa pressure treatment.

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