Study on High Temperature Tensile Properties and Microstructure of a Tial-Based Alloys

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Abstract. The high temperature tensile test of a Ti-45Al-5Nb alloy was carried out at deformation temperatures of 880 °C and 1000 °C, with strain rates of 0.001 s⁻¹ and 0.0125 s⁻¹, respectively. Scanning electron microscopy (SEM) and electron back scattered diffraction (EBSD) were used to analyse the microstructure of different tensile parts. The results showed that under the deformation conditions of 880 °C / 0.001 s⁻¹ and 880 °C / 0.0125 s⁻¹, the alloy underwent brittle fracture, and microstructure was basically unchanged, compared with the original one. Deformed at 1000 °C/0.001s⁻¹, the alloy exhibited plastic deformation and mixed brittle and plastic fracture. Dynamic recrystallization was the main softening mechanism, and the γ phase and B2 phase contents increased by 6.7% and 190.2%, respectively, compared with that deformed at 880 °C/0.0125s⁻¹.

1. Introduction

TiAl-based alloys have become one of the most promising lightweight and high-temperature structural materials in the aerospace field due to their low density, high specific strength, excellent flame retardancy and creep resistance [1-2]. However, the intrinsic brittleness and poor hot workability of TiAl-based alloys largely limited its practical engineering applications in aeroengines [3-4].

In recent years, many researchers have carried out a large number of works on the above-mentioned defects of TiAl-based alloys. Clemens et al. [5] reports that with the increase of volume fraction of β phase at high temperature, the deformation resistance of Ti-43Al-4Nb-1Mo-0.1B alloy decreases during hot extrusion process, the high temperature deformation of the alloy becomes easier, and the grain size of the alloy is further reduced. Wang et al. [6] reports that the strength of Ti-46Al-4Nb-1.8Cr-0.2Ta alloy can be improved by reducing the content of Al element appropriately, and the hot workability of the alloy can also be improved. Zan et al. [7] reports that when the content of Cr in Ti-46.5Al-2Nb-2Cr alloy increases from 2 at. % to 8 at. %, the volume fraction of β phase increases to 30%, and the volume fraction of α2 phase is about 20%. At 850°C, the alloy exhibits excellent plastic deformation and its elongation reaches 628%. The macroscopic mechanical behavior of TiAl-based alloys is very sensitive to process parameters when subjected to high temperature tensile deformation. At the same time, the microstructure of the materials will change obviously when they are stretched at high temperature, and the microstructure evolution will in turn affect the macroscopic mechanical behavior of the materials [8]. Therefore, it is very important to study the macroscopic mechanical behavior of TiAl-based alloy during high temperature tensile deformation and to investigate the phase
composition and distribution characteristics of the alloy during hot deformation for controlling the mechanical properties of the parts.

Therefore, the high temperature tensile test and microstructure observation of a Ti-45Al-5Nb alloy were carried out in this paper. The fracture behavior of TiAl-based alloy under different conditions was analyzed. The microstructure evolution and its effects on high temperature tensile deformation of the TiAl-based alloy were investigated. Finally, the interaction mechanism between microstructure evolution and macroscopic mechanical behavior was revealed.

2. Experimental procedure
The experimental material was an as-cast Ti-45Al-5Nb (at.%) alloy, which was subjected to hot isostatic pressing at 1260 °C / 15 MPa / 4 h, and then followed by a homogenization heat treatment of 900 °C / 12 h. The tensile specimen was machined from the ingot by wire-electrode cutting. Base on previous works, the unidirectional tensile test was carried out on the GNT-600 microcomputer-controlled electronic universal testing machine by the isostrain rate tension method [9]. The test temperatures were 880 °C and 1000 °C, and the strain rates were 0.001 s⁻¹ and 0.0125 s⁻¹, respectively. The engineering stress-strain curve was finally obtained.

The tensile cross section of Ti-45Al-5Nb alloy after tension deformation was cut by wire-electrode cutting, and the sample was used for micro-morphology analysis. Before the microstructure observation, the corresponding surface polishing should be performed. The samples were grounded by 400-1500 grit SiC papers, and subsequently polished by electrolytic polishing instrument at -25°C. Finally, the polished samples were corroded by picric acid for 3s~5s. The microstructures of samples were investigated under the scanning electron microscopy (SEM, Philips XL30 FEG) and the electron back scattered diffraction (EBSD, HKL Nordlys).

3. Results and discussion
3.1. Tensile properties and stress-strain curves
Figure 1 shows the tensile properties of samples. As shown in Figure 1(a), they were untensile samples, tensile formed samples at 880 °C/0.001 s⁻¹, 880 °C/0.0125 s⁻¹ and 1000 °C/0.001 s⁻¹, respectively. When deformed at 880 °C, only slight plastic deformation occurs. However, when the temperature reached 1000 °C, the specimen experienced obvious plastic deformation. Figure 1 (b) shows the stress-strain curves of specimens under different deformation conditions. The blue and red curves show that the samples undergo slight plastic deformation and then fracture occurs. Therefore, brittle fracture is observed at 880 °C/0.001 s⁻¹ and 880 °C/0.0125 s⁻¹. It can be seen from the yellow curve that the elastic phase, the inconspicuous yield phase and the necking phase appear in the tensile process under the deformation condition of 1000 °C/0.001 s, indicating that the sample underwent obvious plastic deformation. Table 1 shows the tensile properties of samples under different deformation conditions. The sample deformed at 1000 °C/0.001 s⁻¹ shows the largest elongation (24%).

Table 1. Tensile properties of samples under different deformation conditions.

| Deformation condition | Tensile strength (MPa) | Elongation (%) |
|-----------------------|------------------------|----------------|
| 880°C/0.001s          | 472                    | 12.8           |
| 880°C/0.0125s         | 540                    | 8.4            |
| 1000°C/0.001s         | 370                    | 24.0           |
3.2. Tensile properties and stress-strain curves

Figure 2 shows the fracture morphology of TiAl-based alloys after high temperature tensile under different deformation conditions. According to Figure 2 (a-d), the fracture surfaces were mostly intergranular fracture, and a small number of ruptures occurred across lamellae, which were the characteristics of typical brittle fracture [10]. The fracture surface showed a stair-step shape, which was related to the poor coordination deformation ability of lamellae. When crack propagated across lamellae, it was easy to produce stress concentration, and the lamellae became instability and fractured. In Figure 2 (e) and (f), the fracture surface was generally composed of lamellae and dimples, and shear planes could be seen locally on the fracture surface, indicating that brittle and plastic mixed fracture occurred in the sample under this condition.

Figure 3 shows EBSD maps of microstructure near the fracture of the alloys deformed at 880 °C/0.0125 s\(^{-1}\) and 1000 °C/0.001 s\(^{-1}\). The lamellae fractured and fragmented, and some α\(_2\) phase spheroidized, forming a large number of recrystallized grains. The volume fraction of γ phase, α\(_2\) phase and β phase were about 97.7%, 1.71% and 0.59%, respectively. The content of γ phase and β phase increased by 6.7% and 190.2%, respectively, compared with those at 880 °C/0.0125 s\(^{-1}\). Additionally, the recrystallized grains formed were generally γ phase, as shown in Figure 3 (a) and (c).
In addition, Figure 3 (b) and (d) show the grain boundary distribution of the alloy under the deformation conditions of 880 °C/0.0125 s\(^{-1}\) and 1000 °C/0.001 s\(^{-1}\), respectively. The grain boundary rotation angle less than 15° is represented by white lines, while the grain boundary rotation angle greater than or equal to 15° is represented by black lines. The microstructure under the two deformation conditions was dominated by high angle grain boundaries. By contrast, the sample deformed at 1000 °C/0.001 s\(^{-1}\) possessed less high angle grain boundaries than that deformed at 880 °C/0.0125 s\(^{-1}\), because more plastic deformation was triggered in the former leading to dislocation rearrangement.

Figure 3. EBSD maps of microstructure near the fracture of the alloys deformed at (a, b) 880 °C / 0.0125 s\(^{-1}\) and (c, d) 1000 °C / 0.001 s\(^{-1}\).

Figure 4 shows the grain size distribution of TiAl-based alloy after high temperature tension. Under the deformation conditions, the grain size range of \(\alpha_2\) phase was 1-4.5 μm, and the grain size range of \(\gamma\) phase was 1-2.5 μm. When the deformation temperature was 880 °C, the average size of \(\gamma\) and \(\alpha_2\) grains were about 1.356 μm and 2.152 μm, respectively. While the temperature was raised to 1000 °C, the average size of \(\gamma\) and \(\alpha_2\) grains were about 1.127 μm and 1.821 μm, respectively, which were reduced by 16.89% and 15.38%, respectively. Deformed at 1000 °C/0.001 s\(^{-1}\), numbers of lamellae were decomposed, which belonged to a kind of dynamic recrystallization [11]. So, \(\gamma\) and \(\alpha_2\) grains were finer than those deformed at 880 °C/0.0125 s\(^{-1}\), respectively.

Figure 4. The grain size distribution of TiAl-based alloy after high temperature drawing: (a) \(\alpha_2\); (b) \(\gamma\)
4. Conclusion

(1) For the high temperature tensile test, the TiAl-based alloy undergoes brittle fracture under the deformation conditions of 880 °C/0.001 s and 880 °C/0.0125 s. When the deformation temperature was 1000 °C and the strain rate was 0.001 s⁻¹, the TiAl-based alloy exhibits more plastic deformation, and brittle and plastic mixed fracture occurs.

(2) When deformed at 1000 °C/0.001 s⁻¹, the volume fractions of γ phase, α₂ phase and B₂ phase are about 97.7%, 1.71% and 0.59%, respectively. The contents of γ phase and B₂ phase increase by 6.7% and 190.2%, respectively, compared with that deformed at 880 °C/0.0125 s⁻¹.

(3) With the increase of deformation temperature and the decrease of strain rate, the degree of lamellar fragmentation, spheroidization and dynamic recrystallization grains were enhanced, resulting in a large number of fine grains in the alloy.

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