SUPERPLASTIC BEHAVIOR OF HOT-FORGED TiAl-BASED ALLOY①

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ABSTRACT A γ-TiAl based material with a composition of Ti-33Al-3Cr-0.5Mo(mass fraction, %) was hot forged to produce fine-grained microstructure with good homogeneity. Samples of the hot-forged material were tested at strain rates ranging from $8\times10^{-5}s^{-1}$ to $8\times10^{-4}s^{-1}$ and temperatures between 1 000 ℃ and 1 075 ℃ to investigate its superplastic behavior. Results showed the occurrence of strain hardening and high m values which led to the good superplasticity of this alloy. Optimum superplastic forming conditions were at 1 075 ℃ and a strain rate of $8\times10^{-5}s^{-1}$. Under these conditions, the maximum elongation to fracture of 517% was achieved.

Key words TiAl deformation superplasticity strain rate

1 INTRODUCTION

TiAl-based alloys are considered the most favorable candidates as advanced structural materials for aerospace application because of their attractive elevated temperature strength induced by the ordered structure and low density[1]. However, the poor intermediate and room-temperature ductility of these materials make the conventional manufacturing techniques of these materials very difficult[2]. As a novel process, superplastic forming is an efficient way in the forming of hard-to-work materials (especially in the forming of parts with complicated shapes)[3]. For these reasons, the study of superplasticity in TiAl alloys is of great importance. The results have shown that TiAl alloys exhibit good superplastic characteristics, however, most researchers were focused on heat-treated materials and the test applied temperatures were relatively high (> 1 200 ℃)[4-6]. In the present work, the superplasticity of a Ti-33Al-3Cr-0.5Mo(mass fraction, %) alloy with a hot-forged microstructure was determined under executed temperature.

2 EXPERIMENTAL

The materials used in the present investigation with a nominal composition of Ti-33Al-3Cr-0.5Mo (mass fraction, %) were vacuum arc melted and cast. In order to reduce the inhomogeneity of chemical composition, a remelting technique and subsequent homogenization heat treatment at 1 040 ℃ were applied. Cylinders with a size of d85 × 100 mm were cut from the ingots and then HIPed at 1 250 ℃ to seal casting porosity. After forging to a total strain of 80%[7], the forged pancakes were cut into tensile specimens with a gauge section of 6 mm × 3 mm × 2 mm by electrical discharge machining. Tensile tests at elevated temperatures were performed with a Shimadzu AG-100KNA testing machine. The surface of each specimen was covered by special coating to prevent it from oxidizing.

Superplastic tensile tests were conducted at temperatures between 1 000 ℃ and 1 075 ℃ using strain rates of $8\times10^{-5}s^{-1}$, $2\times10^{-4}s^{-1}$ and $8\times10^{-4}s^{-1}$ respectively. A quasi-constant strain rate condition was created through continuous

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adjusting of the grip velocity. The value of m was measured by incremental strain rate tests. The microstructure of the alloy was examined using a Leica-Quantimet light microscope and specimens were etched by Kroll's reagent[8].

3 RESULTS

Treated by thermo-mechanical processing of canned forging, the initial coarse lamellar colonies were broken and significantly refined. The as-forged microstructure was shown in Fig. 1. It can be seen that a microstructure with good homogeneity was formed and the nominal mean grain size was about 1 μm.

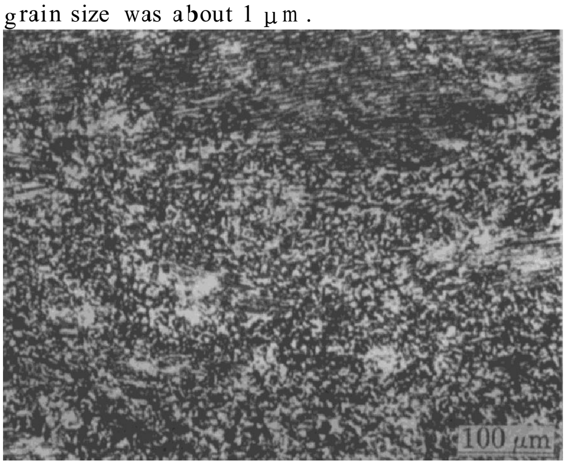

Fig.1 Microstructure of hot-forged TiAl alloy

The relative elongations were all above 300 % when the samples were tested under different conditions, and the maximum elongation of 517 % was achieved when tensile test was carried out at 1 075 ℃ with a strain rate of 8×10^{-5} s^{-1}. The results of tensile tests were shown in Table 1.

Table 1 Results of tensile tests

Temperature/ ℃	Strain rate/ s^{-1}	Elongation/ %
1 000	2×10^{-4}	467
1 025	2×10^{-4}	483
1 050	2×10^{-4}	500
1 050	8×10^{-4}	317
1 075	8×10^{-4}	333
1 075	8×10^{-5}	517

Fig.2 showed the true stress-strain curves of tensile tests at different temperatures with a constant strain rate of $2\times10^{-4}s^{-1}$. Strain hardening can be seen at three test temperatures and what should be noticed was that at 1 000 ℃ the flow stress was significantly raised.

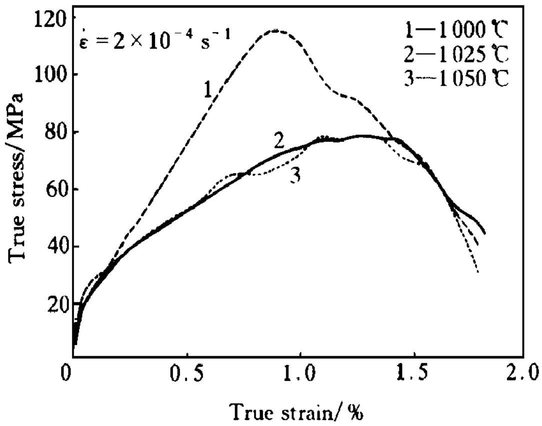

Fig.2 True stress-strain curves of hot-forged TiAl alloy

The elongation versus temperature curve showed that at a given strain rate the elongation value increased with the increasing temperature. Although tensile test at a higher temperature was not practiced because of the limitation by the furnace, higher superplastic elongation can be expected from the results showed in Fig.3.

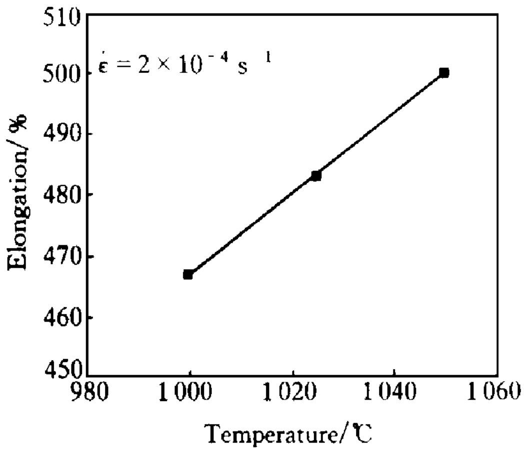

Fig.3 Temperature-elongation curve of hot-forged TiAl alloy

Fig.4 shows stress - strain curves gained in incremental strain rate change test. As can be seen, the deformation behavior of this material showed an apparent transformation from area II (superplastic deformation) to area III (plastic deformation) with the increasing of strain rate.

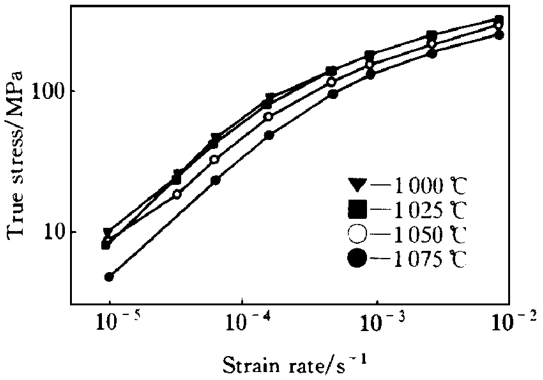

Fig.4 Stress - strain curves of hot-forged TiAl alloy

4 DISCUSSION

Lee W B[5] found that TiAl-based alloys would exhibit better superplasticity if strain hardening occurred. However, strain softening was observed in their research when test temperature decreased to 1 250 ℃ and the elongation value also decreased. The results in Fig.2 indicate that the material used in this study was strain hardened and showed high elongations even at a temperature as low as 1 000 ℃. Since the hot-forged TiAl alloy was not heat treated prior to test, the high density of dislocations was preserved and led to the strain hardening phenomenon. Dynamic recrystallization was hindered at the initial stage of deformation because of the low temperature and this made the strain hardening procedure which could prevent the development of necking last to great strain.

The good superplasticity achieved in the present study can also be attributed to the high strain rate sensitivity of hot-forged TiAl alloy. Through strain rate change test the m value of this refined material at a strain rate of 2×10^{-4} s^{-1} were calculated to be 0.4 ~ 0.5 in the temperature interval of 1 000 ~ 1 075 ℃. In material with such a high strain rate sensitivity, the transferring of necking area was promoted and thus the metastable deformation stage was prolonged which at last led to a high elongation.

The data illustrated in Fig.4 was analysed by Zener-Holloman equation:

$$\dot{\varepsilon} = K\sigma^n \exp(-Q/RT)$$

in which $\dot{\varepsilon}$, σ were strain rate and true stress respectively, K was a constant, n was stress parameter, Q was activation energy of the process. The activation energy was calculated to be about 250 kJ/mol, which was lower than the results of other researches (~400 kJ/mol).

5 CONCLUSIONS

(1) Hot-forged TiAl-based alloy displays good superplasticity in 1 000 ~ 1 075 ℃, the maximum elongation of 517 % has achieved at 1 075 ℃ and a strain rate of $8 \times 10^{-5} s^{-1}$.

(2) The high density of dislocations in this material causes strain hardening in the initial stage of deformation and thus prevent the development of local necking.

(3) The tested material is strain rate sensitive and this is also beneficial to the transferring of necking area. The m values calculated by strain rate change test are 0.4 to 0.5.

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