SUPERPLASTIC DEFORMATION OF TiAl BASED ALLOY①

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ABSTRACT The tensile properties of thermomechanically processed Ti-33Al-3Cr-0.5Mo (mass fraction, %) alloy were determined at 1000 ℃. In an initial strain rate range of $2.0\times10^{-4}\sim6.0\times10^{-4}s^{-1}$ superplastic deformation behaviour of fine grained specimens was observed, and the relative elongations ranging from 200%~305% were obtained. After deformation grain size became finer, a lot of dislocations were found. Combined with TEM observations, it was suggested that superplastic deformation was controlled by grain boundary sliding accomodated by movement of dislocation and dynamic recrystallization.

Key words superplastic deformation TiAl alloy dynamic recrystallization dislocation

1 INTRODUCTION

TiAl based alloys have considerable potential for application in aerospace industry because of their attractive elevated temperature strength and low density[1, 2]. However, one of the factors limiting structural applications of these materials is their poor workability. Recently, superplasticity has already been found in fine grained TiAl based alloys[3-6], therefore, superplastic forming will be a technological breakthrough to solve these problems and to promote these intermetallic alloys for structural applications. In fact, the superplastic forming tests of TiAl based alloy have been performed on a laboratory scale[7]. In this paper, the superplastic deformation of a fine grained TiAl based alloy with duplex microstructure was investigated, and the microstructure evolution of the deformed specimens was observed with optical microscope and transmission electron microscope (TEM).

2 EXPERIMENTAL

Alloy with the nominal composition of Ti-33Al-3Cr-0.5Mo (all composition reported in this paper are in mass percent) was prepared by consumable arc melting technique using commercial pure titanium, aluminium, chronium and molybdenum, and an ingot weighing 17 kg was obtained. The ingot was remelted two times to improve its homogeneity. After homogenization treatment was conducted at 1050 ℃ for 48 h in vacuum, the ingot was hot isostatic pressed (HIPped) at 1250 ℃ for 4 h under the pressure of 170 MPa. Then, a cylinder was cut out of the ingot and was thermomechanically treated to refine the as-cast microstructure[8]. The final heat treatment of the as-treated cake was carried out at 1250 ℃ for 7 h.

The tensile specimens with the gauge dimensions of d5 mm × 20 mm were prepared by electric sparking, and their surfaces were mechanically polished. Tensile tests were conducted in air on a WD-10D machine equipped with a furnace. The superplastic behaviour was examined in tension at 1000 ℃ in an initial strain rate range of $8.0\times10^{-5}s^{-1}$ to $7.0\times10^{-4}s^{-1}$. Samples for optical micrograph were etched in a Kroll

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solution. TEM samples of $d3.0\,mm \times 0.3\,mm$ discs were cut from tensile tested specimens, abraded to thickness of 0.06 mm and then electropolished on a double jet machine at − 30 ℃. TEM observations was performed on a H800 transmission electron microscope at an operating voltage of 175 kV.

3 RESULTS AND DISCUSSION

3.1 Tensile properties

Table 1 gives the tensile properties of Ti-33Al-3Cr-0.5Mo alloy at 1 000 ℃ at the strain rate range from $8.0\times10^{-5}s^{-1}$ to $7.0\times10^{-4}s^{-1}$. It can be seen that with strain rate increasing the elongation δ first increases and reaches its maxium (305%) under the strain rate of $3.6\times10^{-4}s^{-1}$, then gradually drops. It is evident that in the strain rate range from $2.0\times10^{-4}s^{-1}$ to $6.0\times10^{-4}s^{-1}$, the elongations are all above 200%. The peak flow stress (σ_p) in the true stress *vs* true strain curve increases with the rise of the strain rate. These results indicate the superplasticity in this alloy.

Table 1 Tensile property dependence of Ti-33Al-3Cr-0.5Mo alloy on strain rate at 1 000 ℃

Mechanical property	Initial strain rate/ $10^{-4}s^{-1}$						
	0.8	2.0	3.0	3.6	4.5	6.0	7.0
σ_p/MPa	55	78	100	117	130	162	175
δ/%	175	206	267	305	251	220	183

The true stress *vs* true strain curve was plotted from the test under the strain rate of $3.6\times10^{-4}s^{-1}$, and was shown in Fig. 1. It is clear that after yielding the flow stress decreases with increasing strain, that is, strain softening occurred in TiAl alloy during superplastic deformation. This owes to the tensile test with constant speed, because in this condition the true strain rate decreases with the increasing strain, and results in the drop of the flow stress according to Backofen's equation[9]. The strain softening of TiAl based alloy deformed at elevated temperature may also be related.

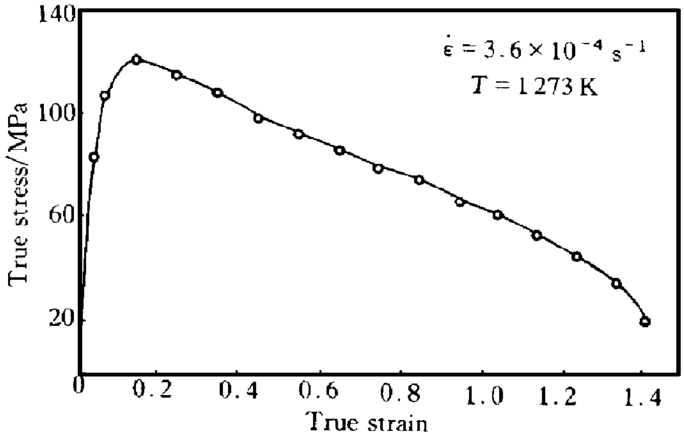

Fig. 1 True stress *vs* true strain curve for Ti-33Al-3Cr-0.5Mo alloy at 1 000 ℃ at an initial strain rate of $3.6\times10^{-4}s^{-1}$

3.2 Microstructure

The original microstructure of the tensile specimens is shown in Fig. 2, which is a homogeneously fine-grained duplex microstructure with a mean grain size of 10 μm. The microstructure of the specimen head and that of the specimen neck after superplastic deformation at 1 000 ℃ at the strain rate of $3.6\times10^{-4}s^{-1}$ and a strain level of 305%, is shown in Fig. 3(a~c), respectively. It can be seen from Fig. 3(a) and Fig. 3(b) that the microstructure in the head is coarser than the original and that in the neck, furthermore, the grains in the specimen neck are remarkably finer and more equiaxial, with the grain size range from 4 μm to 8 μm, and the finest microstructure can be found nearby the fracture area, as shown in Fig. 3(c). The coarser grains in the undeformed specimen owe to the heat treatment during the test, while the refinement of the grains in the specimen neck is resulted from dynamic recrystallization, which is a specific feature of TiAl under superplasticity conditions[3, 10, 11], and is one of the reasons why the flow stress decreases with the increasing strain shown in Fig. 1. The easiness of dynamic recrystallization in TiAl is probably due to lower mobility of dislocations in it as compared to metals[12, 13]. During the superplastic deformation of TiAl, dynamic recrystallization can result in refinement of coarse grains and relaxes the stress concentration caused by the grain boundary sliding, therefore, the dynamic recrystallization in TiAl may provide for the enhancement of its superplasticity. However, in the last stage of superplastic deformation, acts of dynamic recrystallization may not occur regularly in the whole microstructure and probably result in further refining of the microstructure in some fine-grained regions, in which the strength of the alloy decreases and strain concentration takes place, finally, fracture may occur in one of the regions.

Cavitation can be found in the specimens after deformation, and the voids are shown in Fig. 3(c), marked by *A*, *B* and *C*. The volume percentage of the voids in the specimen decreases with the distance from the fracture tip, in which the voids are connected each other and arranged along the tensile direction. The coalescence and conjunction of the voids during deformation can lead to the specimen failure.

TEM observations show that individual dislocations prevail in TiAl under superplastic deformation, but some of the grains display dislocation pile-up and nets. In Fig. 4, a row of dislocations is moving towards a grain boundary and is piled up before the grain boundary, in which dislocation nets are formed. It is noticeable that dislocation nets can also be found within gamma grains, as shown in Fig. 5, and some of the dislocations were obviously originated from the grain boundary. It was established that grain boundary sliding occurred in superplastically deformed TiAl[14], so the motion of dislocations mentioned above can be related to the grain boundary sliding during superplastic deformation. On the one hand, when the grain boundary sliding was hindered by an obstacle grain, the strain hardening would be aroused, which can be relaxed by emitting dislocations. Some of the dislocations can travel through the grain to the opposite grain boundary and interact with each other, as a result, a lot of mobile grain boundary dislocations can be produced, which can enhance the development of grain boundany sliding and the migration of the grain boundaries.

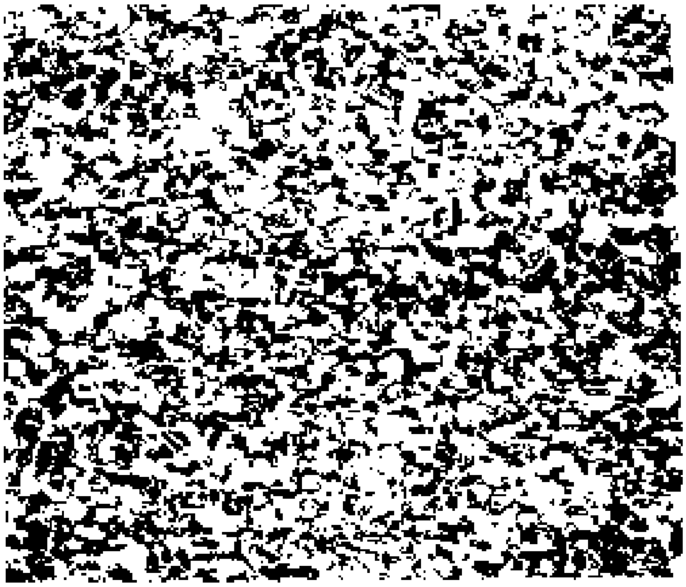

Fig. 2 Orignal microstructure of Ti-33Al-3Cr-0.5Mo alloy before deformation, × 100

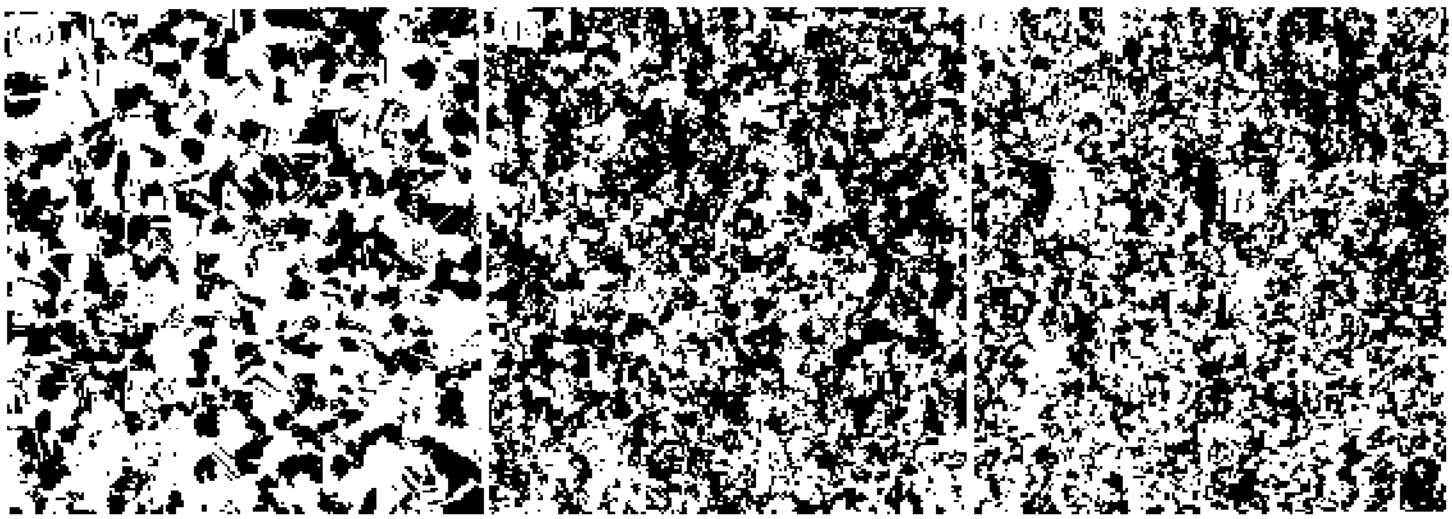

Fig. 3 Optical micrograph of TiAl alloy after 305% **superplastic deformation,** × 100

(a) —Specimen head; (b) —Specimen neck; (c) —Area near fracture

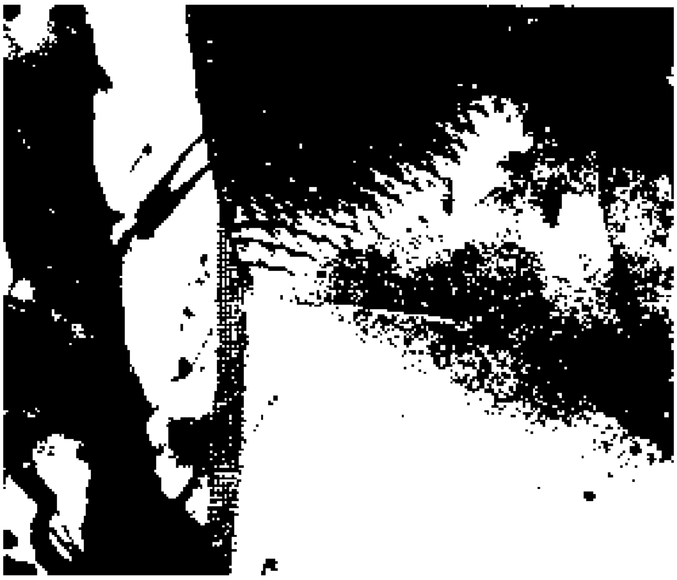

Fig. 4　Dislocations pile-up before a grain boundary, ×30 000

Fig. 5　Dislocation nets within a gamma grain, ×25 000

On the other hand, it is difficult for some of the dislocations in TiAl alloy to slip and transit from one plane to another by means of cross-slip and climbing[12, 13], consequently, a density of dislocations sufficient for the start of dynamic recrystallization is created, especially in coarse grains, and this process can account for the refining of grains shown in Fig. 3. It is quite certain that the superplastic deformation in TiAl alloy is closely related to the movement of dislocations and dynamic recrystallization, and grain boundary sliding accomodated by the dislocation motion and dynamic recrystallization is the superplasticity mechanism in TiAl alloy.

3　CONCLUSIONS

(1) Fine-grained Ti-33Al-3Cr-0.5Mo alloy with duplex microstructure displays superplasticity at 1 000 ℃ and in initial strain rate range from $2.0\times10^{-4}s^{-1}$ to $6.0\times10^{-4}s^{-1}$, with the largest elongation of 305%.

(2) Dynamic recrystallization occurs during the superplastic deformation, and results in the refinement of the microstructure.

(3) A lot of dislocations were found in some grains of TiAl alloy under deformation, and grain boundary sliding accomodated by the dislocation motion and dynamic recrystallization is the superplasticity mechanism in TiAl alloy.

REFERENCES

1　Kim Y W. JOM, 1994, 46(7): 30.

2　Yamaguchi M and Inui H. In: Darolia R, Lewandowski J, Liu C T *et al* eds. Structural Intermetallics, TMS, Warrendale, PA, 1993: 127.

3　Imayev R M, Kaibyshev O A and Salishchev G A. Acta Metall Mater, 1992, 40(3): 581.

4　Wajata T *et al*. ISIJ Intern, 1993, 33(8): 884.

5　Nobuki M, Vanderschueren D and Nakamura M. Acta Metall Mater, 1994, 42(8): 2623.

6　Lee W B, Yang H S and Mukherjee A K. Mater Sci Eng, 1995, A192/193: 733.

7　Koeppe C, Bartels A, Clemens H, Schretter P and Gataz W. Mater Sci Eng, 1995, A201: 182.

8　Huang Baiyun, He Yuehui, Zhou Kechao and Qu Xuanhui. Mater Sci Eng, 1997, A239-240: 709

9　Backofen W A, Turner I R and Avery D H. Trans ASM, 1964, 57: 980-990.

10　Imayev R M and Imayev V M. Scripta Metall Mater, 1991, 25: 2041.

11　Salishchev G, Imayev R M, Imayev V M and Shagiev M. In: Kim Y W, Wagner R and Yamaguchi M ed, Gamma Titanium Aluminides, TMS, Warrendale, PA, 1995: 95.

12　Greenberg B A *et al*. Scripta Metall, 1988, 22: 859.

13　Hug G, Loiseau A and Vryssiere P. Phil Mag A, 1988, 57: 499.

14　Zelin M G, Lee W B and Mukherjeee A K. J Mater Res, 1994, 10: 2467.

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