MECHANICAL PROPERTIES IMPROVEMENT OF TiAl BY MICROSTRUCTURE REFINING[①]

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ABSTRACT A multi-step thermo-mechanical treatment (MSTMT) was developed to refine the microstructure of Ti-33Al-3Cr-0.5Mo(%) alloy. It was found that fine full lamellar structure can be obtained by appropriate procesing of MSTMT. Superior comprehensive mechanical properties can result from the full lamellar structure with homogeneous fine grain.

Key words intermetallic compounds mechanical properties microstructure

1 INTRODUCTION

Currently, intense attention has been paid to the study of TiAl-based alloys. Having the merits of low density and high strength at elevated-temperature, this kind of alloy is regarded as an ideal aerospace high-temperature structural material[1]. However, the practical application of this promising material is limited due to its brittleness at ambient temperature and poor hot-formability[2]. Previous studies[3-5] have shown that the microstructure is one of the most important factors which influence the mechanical properties of TiAl based alloys at ambient temperature. Fine and homogeneous duplex microstructure is helpful to improve its ductility at ambient temperature, while full-lamellar microstructure leads to the improvement of fracture strength, toughness and creep resistance. Favourable comprehensive mechanical properties can be obtained in the alloys with refined and homogeneous full-lamellar microstructure. Generally, hot working and subsequent heat treatment are adopted for the microstructural control. In this work, a multi-step thermo-mechanical processing has been developed. The effects of the processing parameters on the microstructure will be discussed.

2 EXPERIMENTAL PROCEDURE

The alloy with the nominal composition (Ti-33Al-3Cr)-0.5Mo(%) was prepared with consumable electrode arc melting technique in an argon atmosphere. In order to reduce composition inhomogenity, the alloy ingot was remelted, and afterwards vacuum annealed at 1 040 ℃ for 48 h. A cylindrical sample with the diameter of 40 mm and the height of 100 mm was spark eroded from the ingot and canned with metal capsule . The canned sample was heated to a given temperature and forged using a 500 t hydraulic press machine.

The metallographic samples were prepared in a standard fashion and etched with the kroll's solution. The microstructure was observed using POLYVAR optical microscope (OM) and X650 scanning electron microscope (SEM). The foils for transmission electron microscope were prepared by twin-jet technique using a solution consisting of 70 mL alcohol, 120 mL methanol, 100 mL butane-1-01 and 80 mL perchloric, at a voltage of ~45 V, current of 7 to 10 mA, and temperature of −40 ℃. Observation of the foils was conduct-

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ed in a CM12 transmission electron microscope (TEM) operated at 120 kV.

3 RESULTS

Fig. 1 shows the pictures of (Ti-33Al-3Cr)-0.5 Mo alloy forged under different stress states. Ingot A was forged with 40% deformation in unidirectional stress at 1 180 ℃. Many large, deep cracks have been observed on the surface of the disc. It was found that the cracks appeared even when the ingot was only pressed with 20% deformation. However, the thermoplasticity could be greatly improved if three dimensional stress was applied through the metal capsule. No crack was observed even with 80% deformation (Fig. 1*B*) in this canned case, which indicated that thermal forging under three dimensional stress would be a successful process for the thermo-mechanical treatment of TiAl alloys.

Fig. 1 The pictures of (Ti-33Al-3Cr)-0.5Mo alloy with 40% deformation in unidirectional stress (*A*) and with 80% deformation in three dimensional stress (*B*)

Fig. 2 shows the optical metallograph of (Ti-33Al-3Cr)-0.5Mo specimens forged at 1 180 ℃ with 60% deformation by using the latter forging process. Apparently, the microstructure was composed of three parts. The first part was the wave lines region where large deformation occurred obviously. Fig. 3 is the deformation substructure of this wave lines region. It is a typical lamellar colonies structure which comprised α_2 and γ lathes. There exists high density of dislocations and large amount of deformation twins in γ lathes. Furthermore, the twins intersected with α_2/γ or γ/γ phase boundaries. The second part was fine, equiaxial grains resulting from dynamic recrystallization. The third part was straight lines region with undeformed large lamellar grains. The TEM analysis of this third part found that in γ lathes there were deformation twins parallel to the existing lamellar laths (Fig. 4).

(Ti-33Al-3Cr)-0.5Mo alloy specimens

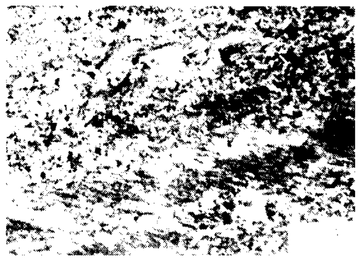

Fig. 2 Optical micrograph of (Ti-33Al-3Cr)-0.5Mo alloy after thermo-forged with 60% deformation at 1 180 ℃

Fig. 3 Lamellar grains in wave lines region of (Ti-33Al-3Cr)-0.5Mo alloy forged at 1 180 ℃ with 60% deformaition

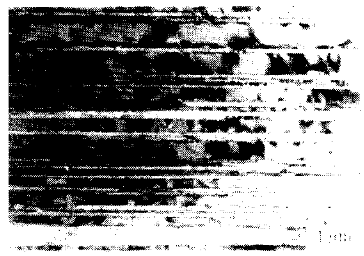

Fig. 4 TEM analysis of undeformed lamellar colonies in (Ti-33Al-3Cr) -0. 5Mo alloy forged at 1 180 ℃ with 60% deformation

forged at 1 180 ℃ with 60% deformation were annealed between 1 250 ℃ and 1 310 ℃. Microstructure changes could be observed in these annealed specimens. Recrystallization of the deformed large lamellar (part 2) resulted in fine structures. However the undeformed large lamellar grains in the straight lines region showed high thermal stability with little change even if annealed for long time. Fig. 5 is the optical microstructure of forged specimens annealed at 1 250 ℃ for 4 h.

The above mentioned experimental results indicate that one-step thermomechanical process (thermal forging plus heat treatment) could not eliminate unrecrystallized large lamellar grains. In order to obtain homogeneous, fine microstructure, one more extra hot forging was adopted.

Fig. 5 OM of (Ti-33Al-3Cr)-0. 5Mo alloy after 1 180 ℃, 60% deformation and 1 250 ℃, 4 h annealing

Fig. 6 OM of (Ti-33Al-3Cr) -0. 5Mo alloy after 1 180 ℃, 60% deformation, 1 250 ℃, 7 h HT and 1 040 ℃, 50% deformation

The (Ti-33Al-3Cr)-0. 5Mo alloy sample which had been forged at 1 180 ℃ with 60% deformation and annealed at 1 250 ℃ for 7 h, was forged again at 1 040 ℃ with 50% further deformation. Fig. 6 shows the again deformed microstructure. There was no more original undeformed large lamellar grains in specimen, showing a homogeneous microstructure without straight lines region. Fig. 7 shows three different microstructures of the specimens after two steps deformation at three different heat treatment temperatures of 1 250, 1 280 and 1 310 ℃. Very fine and homogeneous microstructure is obtained in these specimens. Duplex microstructure was obtained for the samples annealed at 1 250 ℃ for 4 h, and the average grain size was 10 to 20 μm (Fig. 7a). Annealing at 1 280 ℃ resulted in near-lamellar structure sized 15 μm (Fig. 7b) Increasing annealing temperature to 1 310 ℃, i. e. higher than T_α(T_α = 1 305 ℃), a homogeneous and fine full-lameller structure sized 20 to 30 μm(Fig. 7c) have been produced.

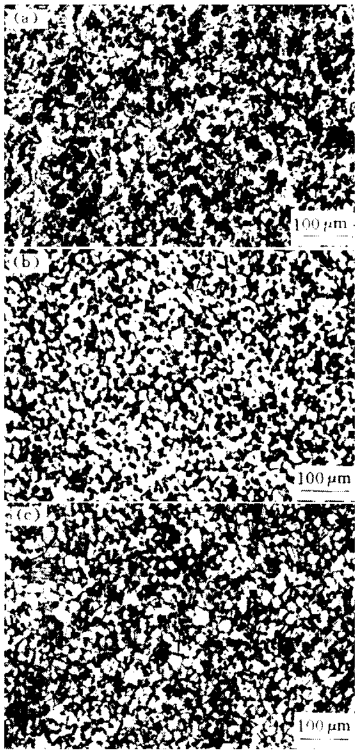

Fig. 7 OM of (Ti-33Al-3Cr)-0.5Mo alloy after 1 180 ℃, 60% deformation, 1 250 ℃, 7 h HT, and 1 040 ℃, 50% deformation and 1 250 ℃, 4 h(a), 1 280 ℃, 3.5 h(b) and 1 310 ℃, 2.5 h(c)HT

4 DISCUSSION

Because of their poor high temperature deformability, TiAl based alloys can not be deformed with the normal hot working process. Even if the sample was isothermally forged at high temperature and at very low strain rate, the deformation without capsule still resulted in deep cracks on the sample surface. However, at three dimensional stress state through the cannister the plasticity of TiAl-based alloy has been enhanced so remarkably that thermal forging can be conducted even at relatively high strain rate. No cracking was found on the surface of the sample, as shown in Fig. 1*B*.

The room-temperature mechanical behaviour of TiAl-based alloy strongly depends on the microstructure. Many investigators have shown that homogeneous and fine duplex microstructure can yield better ductility and fine fully-lamellar microstructure may exhibit high strength, reasonable ductility, and high fracture toughness. But it is difficult to obtain fine microstructure from casting TiAl-based alloy by general processing. In comparision of Fig. 5 and Fig. 6, it is easy to see that the second deformation(i. e. 1 040 ℃, 50% deformation) is very important for fine microstructure. As shown in Fig. 6, after second deformation the straight line region in Fig. 5 was eliminated. The straight line region in Fig. 5 was changed to wave lines region in Fig. 6. It is necessary to mention that the heat treatment of 1 250 ℃, 4 h annealing in Fig. 5 is also very improtant. When the sample of 1 180 ℃, 60% deformattion was heat treated in ($\alpha + \gamma$) phase field fine equiaxed grains formed surround the straight lines region. Thus, the coarse lamellar colonies in these straight lines region can be more easily rotated and totally smashed during the second thermal forging, as shown in Fig. 6. We name the whole process mentioned above MSTMT, which includes two steps of thermal forging and the following heat treatment. By means of MSTMT process different types of fine homogenous microstructure can be easily obtained in TiAl-based alloy. It is well worth noticing that superior comprehensive mechanical properties have been obtained for the alloys with homogeneous and fine fully-lamellar microstructure, as listed in Table 1.

Table 1 Mechanical properties of (Ti-33Al-3Cr) -0. 5Mo alloy with homogeneous and fine full-lamellar microstructure

Temperature	σ_b /MPa	σ_s /MPa	δ /%	K_{IC} /MPa m$^{1/2}$
RT	650	494	2.4	20.0
900 ℃	430	329	113	

5 CONCLUSIONS

(1) It is difficult to remove the coarse lamellar colonies in cast TiAl-based alloy with one-step hot working process.

(2) The thermal deformation ability of TiAl-based alloy can be enhanced in the presence of three dimensional compressive stresses.

(3) The fine full lamellar structure obtained from MSTMT can result in very superior combined mechanical properties.

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(*From page 72*) and bigger; thus the rate of SO_2 loss into the gaseous effluent increases with roasting time. When roasting time retains 1 h at 700 ℃, 97% of the sulfur can be retained.

As mentioned above, the optimized roasting conditions are as follows: temperature 700 ℃, time 1h, α 1. 1. Correspondingly, the sulfur retention and extractions of gold and silver can reach 97%, 91. 3%~93% and 83%, respectively. If stoichiometry ratio (α) reduces to 0. 95, the consumption of sulfuric acid in the leaching will be decreased, and gold and silver recovered is almost constant.

5 CONCLUSIONS

(1) The oxidation of pyrite in the presence of hydrated lime will tend to pass through an intermediated pyrrhotite stage. The behavior of silver during lime-roasting of the concentrate needs further investigation.

(2) Roasting temperature and residence time have in general favourable effects on sulfur retention and decarbonation as well as gold and silver extraction.

(3) Under the optimized conditions, the sulfur retention and leaching extractions of gold and silver in calcine can gain 97%, 93 % and 83%, respectively.

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