EFFECT OF HOMOGENIZATION PROCESSING ON MICROSTRUCTURE AND PROPERTIES OF Ti-34Al-2Mn ALLOY[1]

Lei, Changming Qu, Xuanhui
Huang, Baiyun Xiong, Xiang
Powder Metallurgy Research Institute, Central South University of Technology, Changsha 410083, China

ABSTRACT

A γ-TiAl base alloy with the composition of Ti-34Al-2Mn(wt--%)was prepared by consumable electrode arc-melting technique. The effect of homogenization processing following arc-melting on its microstructure and mechanical properties was investigated. The emphases were placed on the microstructural evolution during solidification and homogenization, and the relationship between microstructure and ductility. It has been determined that the samples annealed at 900 ℃ for 20 h exhibit the best ductility compared with those treated at other temperatures up to 1 100 ℃, and they have a mixed structure of equiaxed grain of γ-TiAl single phase and some primary lamellar grains which include three types of interfaces, i. e., α_2/γ, γ/γ_R, γ/γ_T, maintaining specific orientaion relationships between both sides. The ductility improvement is believed to be associated with existence of suitable amount of α_2-Ti_3Al phase and the refinement of grains obtained at 900 ℃.

Key words: Ti-34Al-2Mn Alloy homogenization microstructure properties

1 INTRODUCTION

It has been known for a few decades that the intermetallic compound TiAl has attractive properties, which are suitable for space and aviation high-temperature structural components[1]. These benefits include low density, high melting point, high modulus, reasonable strength and corrosion resistance. One of the major problems limiting its use is poor room-temperature ductility. Mechanical properties of TiAl compounds are well known to be very sensitive to chemical composition and microstructure[2,3]. Single phase TiAl which has a composition on the Al-rich side of stoichiometry shows a brittle manner at room temperature, while two-phase TiAl with Ti-rich compositions shows higher strength and better ductility than the single phase TiAl[2,5]. It has also been reported that the third element addition, such as Mn, V or Cr, to TiAl can improve its ductility remarkably through enhancing the twinning process[2,3]. In the present work, the effect of homogenization processing properties of a TiAl+Mn ternary alloy are investigated in order to establish the

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relationship between microstructure and ductility of the TiAl-base alloys.

2 EXPERIMENTAL

The alloy used in this work has the following nominal composition: Ti-34Al-2Mn (wt.-%) and was prepared by consumable electrode arc-melting in an argon atmosphere. Three-point- bending specimens were spark eroded from the ingots, and then homogenized at temperatures up to 1 100 ℃ for 20 h, followed by furnace cooling. The heat-treated bars were mechanically polished to the final dimensions of 2 mm × 4 mm × 30 mm. Three to five specimens of each series were tested at room temperature. The span length of specimens was 25 mm and the cross head speed of the testing machine was controlled at 0. 2 mm/min. The metallographic samples were prepared in a standard fashion and etched with the Kroll solution. Alloy powders of −200 mesh were ground for X-ray diffracton to identify the existing phases. Disks of dia. 3 mm × 0. 3 mm for TEM examination were spark eroded from the broken bending specimens and then mechanically ground to 0. 1 mm in thichness. The final thinning was conducted by twin jets technique.

3 RESULTS AND DISCUSSION

3. 1 *Bending Properties*

Fig. 1 shows the typical recorded load-deflection curves from bending tests conducted at room temperature. The transverse rupture strength (TRS) and the plastic part of deflection (D_p) were used to represent the strength (TRS) and ductility (D_p) as a function of homogenization temperature are shown in Fig. 2. It can be seen that the strength of the alloy decreases monotonously

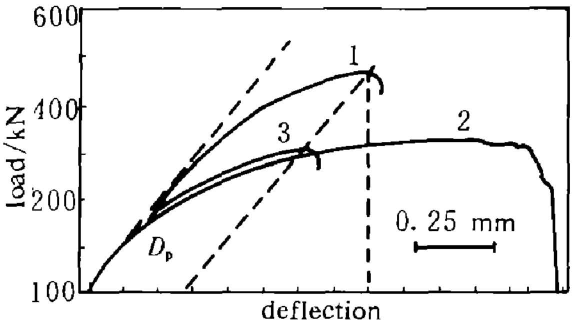

Fig. 1 Typical load-deflection curves from bending tests conducted at room temperature on Ti-34Al-2Mn alloy samples treated at different temperatures for 20 h

1—as-cast; 2—900 ℃, 20 h; 3—1 100 ℃, 20 h

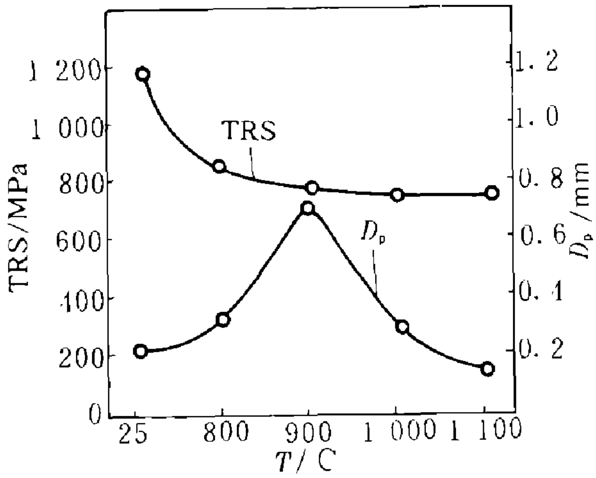

Fig. 2 Changes of strength (TRS) and ductility (D_p) as a function of homogenization temperature

with increasing temperature, while the ductility increases with temperature and reaches a maximum value at 900 ℃.

3. 2 *Phase Constitution*

The X-ray diffraction spectra for samples treated at different temperatures are presented in Fig. 3. It has been determined that all tested samples are composed of an ordered γ-TiAl phase with a $L1_0$ structure and an ordered α_2-Ti_3Al phase with a $D0_{19}$ structure. However the content of the α_2-Ti_3Al phase decreases with increasing homogenization temperature.

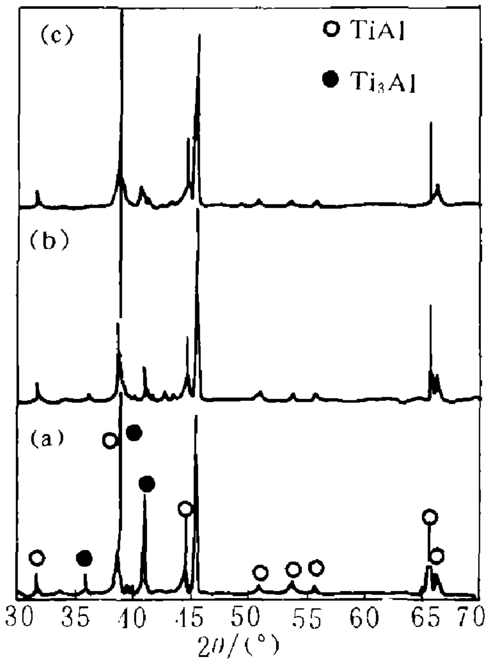

Fig. 3 X-ray diffraction spectra for samples treated at different temperatures for 20 h
(a)—as-cast; (b)—900 ℃; (c)—1 100 ℃

3.3 *Microstructure*

Fig. 4 shows the metallographic structures of Ti-34Al-2Mn alloy heat-treated at different temperatures followed by furnace cooling. The as-cast alloy has a full lamellar structure. The TEM analysis shows that the lamellar grains consist of γ and α_2 phaes and the alternate γ/α_2 plates have a definite crystallographic orientation relationship, $\{111\}_\gamma // \{0001\}_{\alpha_2}$ and $\langle 1\bar{1}0]_\gamma // \langle 11\bar{2}0]_{\alpha_2}$, as observed previously[6]. In the samples homogenized at 800 ℃ for 20 h, some new finer equiaxed grains of single phase occurred at the primary grain boundary. With increasing temperature, both the number and size of these newly formed grains increase at the expense of the primary lamellar grains, and in the primary lamellar grains some of the γ plates contact with each other directly. Selected area electron diffraction analysis conducted across the γ/γ interfaces indicates that some of the adjacent γ plates share the same diffraction patterns and only do the Kikuchi lines move to some distance[7]. This suggests that both sides of the interface have very little orientation difference as two column-like subgrains. However between some other adjacent γ plates, there exist twin-like orientation relationships (Fig. 5).

4 DISCUSSION

4.1 *Microstructural Evolution*

The equilibrium solidificatin of Ti-34Al-2Mn alloy starts with the formation of a disordered *bcc* phase (β-Ti) as shown in Fig. 6.

As the temperature goes through the peritectic reaction, $\beta + L \rightarrow \alpha$, β-Ti transforms into α-Ti which is a disordered *hcp* phase maintaining the morphology of the primary β-Ti grains. Solid state cooling causes the β-Ti phase to transform to γ-TiAl with an ordered $L1_0$ structure. During the phase transformation, the γ plates nucleate on the base plane (0001) of the α phase and become thicker at the expense of supersaturated α phase. so that all the plates in a grain are aligned parallel regardless of their nucleation sites, with the orientation relationship of $\{111\}_\gamma // \{0001\}_{\alpha_2}$ and $\langle 1\bar{1}0]_\gamma // \langle 11\bar{2}0\rangle_{\alpha}$ Further cooling to 1 125 ℃ gives rise to the decomposition of the remaining disordered α-Ti phase into an ordered α_2-Ti_3Al phase and an ordered γ-TiAl phase. To lower the interfacial energy, the colse-packed plane of the γ phase will keep parallel to the colse-packed of the α_2 phase and the colse-packed direction of γ phase will also be to the colse-packed direction of the α_2 phase, therefore, the orientation relationship of $\{111\}_\gamma\{0001\}_{\alpha_2}$ and $\langle 1\bar{1}0\rangle_\gamma // \langle 11\bar{2}0\rangle_{\alpha_2}$ is

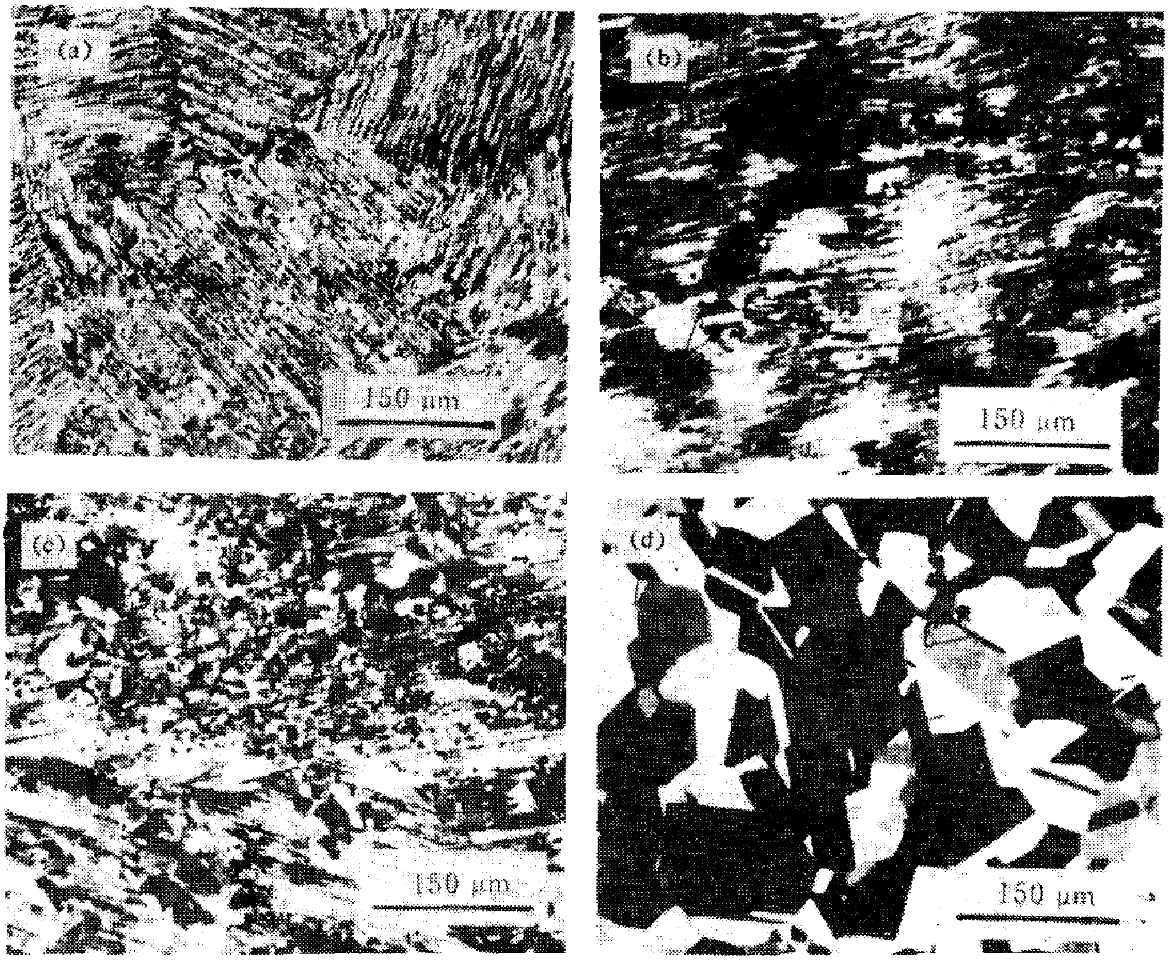

Fig. 4 Metallographic structures of Ti-34Al-2Mn samples treated at different temperatures for 20 h
(a)—as-cast; (b)—800 ℃; (c)—900 ℃; (d)—1 100 ℃

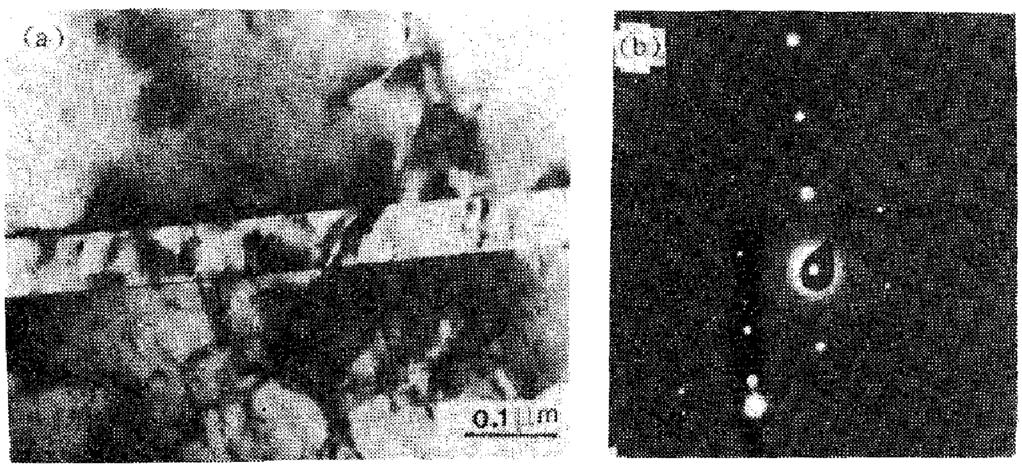

Fig. 5 TEM image of a lamellar grain consisting of alternate γ plates, showing a twin-related orientation relationship between two adjacent γ plates

strictly obeyed between the precipitated γ plate and the α_2 matrix. This orinetation relationship results in six possible orientation variants of $\langle 110 \rangle_\gamma$ with respect to $\langle 11\bar{2}0 \rangle_{\alpha_2}$, i.e.

$$A: [110]_\gamma // [11\bar{2}0]_{\alpha_2},$$

B: $[110]_\gamma // [1120]_{\alpha_2}$,
C: $[101]_\gamma // [1120]_{\alpha_2}$,
D: $[101]_\gamma // [1120]_{\alpha_2}$,
E: $[011]_\gamma // [1120]_{\alpha_2}$,
F: $[011]_\gamma // [1120]_{\alpha_2}$.

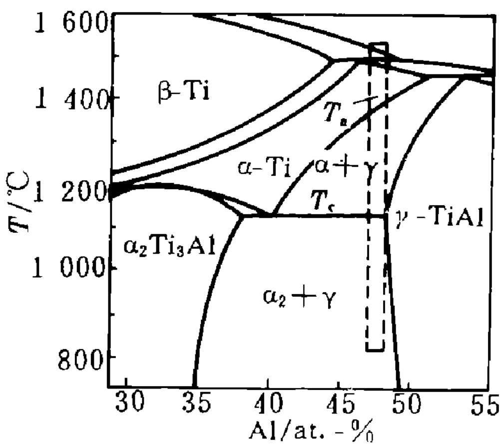

Fig. 6 The central portion of the recently refined TiAl phase diagram[2]

However, because variants C and F are identical to variants D and E respectively from the selected area diffraction patterns (SADP), only four distinguishable orientation variants of $\langle 110]_\gamma$ with respect to $\langle 1120]_{\alpha_2}$ can be obtained from the SADP. It is known that diffusion of atoms in ordered phase is generally slow, thus the diffusion-related solid-state phases transformations $\alpha \rightarrow \gamma$ and $\alpha \rightarrow \alpha_2 + \gamma$, may be restrained if the cooling rate is high. Therefore, the content of α_2 phase in as-cast alloy is usually higher than the equilibrium content as a result of non-equilibrium solidification. When the alloy is homogenized at elevated temperatures, it tends to an equilibrium phase constitution, so that additional γ phase precipitates from the supersaturated α_2 phase. Independent growth of γ plates during homogenization causes their direct contact with each other. If two adjacent γ plates with different orientations grow into direct contact with each other, they will show a twin-related orientation relationship, and if two γ plates with the same orientation are brought into contact, they will combine into one thicker plate or form two column-like subgrains when some interfacial dislocations exist at the interface. On the other hand, some new lamella-free equiaxed grains nucleate at the primary grain boundaries and grow by gradual consumption of the lamellar matrix during homogenization. The process is believed to be driven by the interfacial energy difference between the resulted lamella-free grains and the matrix lamellar grains. Because the nucleation and the growth of these new grains generally depend on the migration of atoms, the number and the size of the new grains will increase with temperature for certain time.

4.2 *Relationship between Microstructure and Ductility*

As mentioned above, heat treatment has a strong effect on the microstructure and mechanical properties of TiAl alloy. It has been proposed that interstitial elements, primarily nitrogen and oxygen, deteriorate the ductility of TiAl phase by increasing the Peierls stress of dislocations[8]. These elements have a much higer solubility in α_2-Ti_3Al phase than in γ-TiAl phase so that they will segregate strongly to the α_2-Ti_3Al region in two-phase samples, leaving the γ-TiAl phase essentially free interstitials. In view of this point, the existence of α_2-Ti_3Al phase in TiAl-base alloy is beneficial to its plastic deformation. However, as a more brittle second phase, too much α_2-Ti_3Al which acts as a fracture source, will cause the alloy more brittle. Therefore, an optimum content of α_2-phase may exist for ductility of two-phase TiAl-base alloys. This content for the alloy studied in this work probably corresponds to that obtained at 900 C. Another possible factor is the effect of grain size. Fractography showed that the fracture mode in TiAl alloys was mainly of the transgranular type at room temperature, namely, cleavage fracture with rather flat planes. It seems that the dislocation pile-ups caused transgranular fracture. Therefore, decrease in grain size will shorten the length of dislocation pile- ups, and decrease the stress concentration near the front of the dis-loction pile-ups. This allows the samples to undertake larger deformation before fracture. At 900 C, the finest grains are produced, therefore, this alloy should show better ductility which is consistent with the experimental results.

5 CONCLUSIONS

(1)The arc-melted Ti-34Al-2Mn alloy homogenized at 900 C for 20h has the best ductility compared with those treated at other temperatures up to 1100 C.

(2) The alloys with better ductility have a structure composed of fine equiaxed grains of single γ phase and some primary lamellar grains.

(3)In the lamellar grains, three types of interfaces are identified, i. e. , γ/α_2, γ/γ_s (subgrain boundary)and γ/γ_T (twin-related boundary).

REFERENCES

1 Lipsitt, H A. In: Koch, C C; Liu, C T; Stoloff N S(ed). High Temperature Ordered Intermetallic Alloys, I, MRS Symp Proc, Vol. 31 Pittsburgh, PA: MRS, 1985, 351—361.

2 Kim,Y W; Dimduk.D M. J of Metals,1991, 43(8): 10.

3 Kim, Y W. J of Metals, 1989,41(7):21

4 Qu, X H *et al*. In: Sun, W C; Chui,I P (Ed). Titanium Science and Engineering, Proceedings of 7th National Conference on Titanium and Its Alloys, Vol. 1, Changsha, Press of CSUT,1990. 319.

5 Huang, S C; Hall, E L. Matall Trans, A 1991,22A(2):427.

6 Shechtiman, M J; Lipsitt, H A. Metall Trans, A 1974, 5A(6):1373.

7 Qu, X H *et al*. Effects of Composition and Annealing on the Microstrucetures and Mechanical Properties of TiAl- based Alloys. (Paper Presented at Inter Symp on Heat Treatment and Annealing on Ordered Alloys. Materials Week'1990. Cobo Hall, Detroit, Michigan, USA, Oct. 8—11 1990),14.

8 Aindow, M *et al*. Scripta Metall, 1990, 24 (6): 1150.