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Phase transformation of fully lamellar γ-TiAl alloys in α + γ field①

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[Abstract] The isothermal phase transformation mechanisms in Ti-46.5Al-2Cr-1.5Nb-1V alloy were studied. The microstructures of the alloy annealed at 1 260 ℃ for different times (2 h, 4 h, 10 h) were observed by using optical microscopy, scanning electron microscopy and transmission electron microscopy. When the annealing time is up to 10 h, the primitive large lamellar grains (more than 600 μm) transform to small lamellar domains (about 50 μm). The small lamellar domains formed from one primitive grain have four kinds of fixed orientations and each orientation has a fixed angle. The lamellar spacing and composition of the small lamellar domains are different from those of the primitive lamellar grains.

[Key words] γ-TiAl alloy; phase transformation; microstructure
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1 INTRODUCTION

The mechanical properties of two-phase γ-TiAl intermetallic alloys are strongly dependent on microstructures[1]. There are four kinds of microstructures: near-gamma, duplex, near lamellae and fully lamellar. The best tensile properties of γ-TiAl intermetallic alloys result from duplex microstructure. The microstructure of fully lamellar exhibits the excellent fracture toughness and creep resistance[2~4]. But there is no optimum microstructure that can exhibit all the excellent room temperature ductility, fracture toughness and creep resistance. According to a lot of studies, the room temperature ductility is directly related to the morphology of α_2 phase and the volume fraction of γ phase, the grain size and the lamellae spacing are important factors for fracture toughness and creep resistance[5~7]. The different heat treatment can control these microstructure parameters. So it is very important to study the phase transformation in order to adjust the microstructure parameters. Because most of the engineering alloys have duplex microstructure, the phase transformation in α + γ field (the temperature between γ transformation temperature and eutectoid temperature, for Ti-48Al about 1 360 ℃ ~ 1 125 ℃) is more important[8,9]. But the details of phase transformation in this field are still not clear. In this paper, the isothermal microstructure transformation of Ti-46.5Al-1.5Nb-1Cr-1V alloy in α + γ field has been studied. The aim is to understand the mechanism of the transformation from γ to α and from γ to γ + α_2.

2 EXPERIMENTAL

The material used is Ti-46.5Al-1.5Nb-1Cr-1V (mass fraction) alloy. This alloy was prepared using the vacuum arc melting technology. The obtained ingot (approximately d30 mm × 250 mm) was HIP processed (1 260 ℃, 175 MPa, 3 h) to seal casting porosity. Samples were prepared for heat treatment by wrapping in Ta foil and sealing in quartz tubes filled with Ar to 33.25 kPa. The samples were heated in α phase field for 1 h then air-cooled to room temperature. After that, the samples were heated at 1 260 ℃ for 2 h, 4 h and 10 h, respectively, followed by air-cooling. Microstructures were examined by optical microscopy, SEM and TEM.

3 RESULTS AND DISCUSSION

Optical micrographs of Ti-46.5Al-1.5Nb-1Cr-1V alloy annealed at 1 260 ℃ for 2 h, 4 h and 10 h, respectively, are shown in Fig.1. A lot of small balls and small size lamellar domains can be observed when the sample was annealed for 2 h (Fig.1(a)). The size of the balls is about 2 ~ 8 μm, and the size of the lamellar domains is about 25 ~ 50 μm. The fraction of the small lamellar domains increases with the annealing time, e.g. for 4 h, as shown in Fig.1(b), but the size of the domains has no obvious change. When the annealing time increases to 10 h, almost all primitive large lamellar grains transform to small size lamellar domains (Fig.1(c)). The size of the domain is the same as that in the samples annealed for 2 h and 4 h, and the grain boundary of the primitive lamellar

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disappeared. The SEM backscattered electron image of the small lamellar domains is shown in Fig.2.

3.1 Initiation of small lamellar domains

The forming mechanism of the small lamellar domains can be obtained by analyzing the phase diagram. Although the alloy used in this paper is not

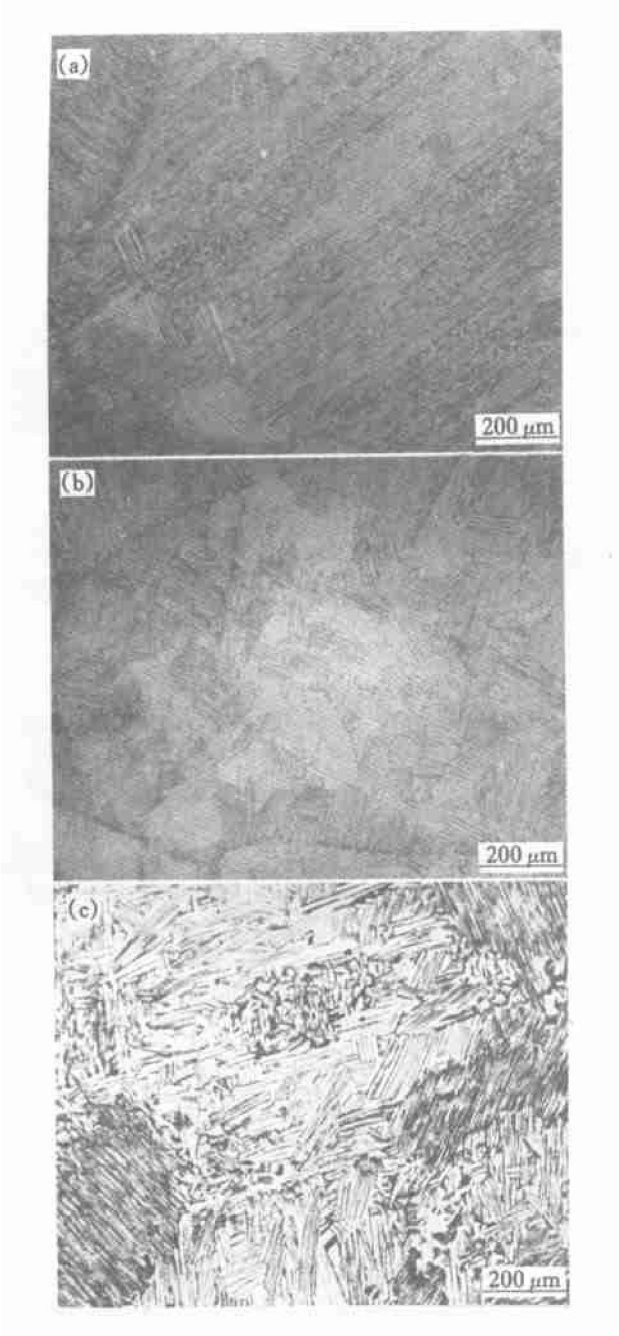

Fig.1 Optical micrographs of alloys annealed at 1 260 ℃ for different times
(a) —2 h; (b) —4 h; (c) —10 h

binary alloy, the binary phase diagram can be used to analyze this alloy. According to TiAl binary phase diagram(Fig.3)[8], the fully lamellar structure can be obtained after TiAl alloys are heated to the temperature of α field and hold for a period of time, then air-cooled to room temperature. At ambient temperature, the balance content of α_2 in this fully lamellar microstructure is C_1, about 36.8 %, that of γ is C_2, about 48.8 %. The volume fraction of γ and α_2 in the fully lamellar structure can be determined by the lever principle, and the volume fraction of α_2 is about 20 %. When the alloys were heated in $\alpha+\gamma$ field (1 260 ℃), the balance content of α_2 is B_1, about

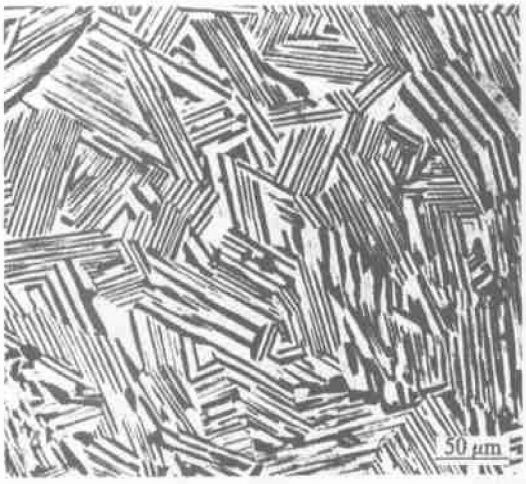

Fig.2 SEM backscattered electron image of small lamellar domains

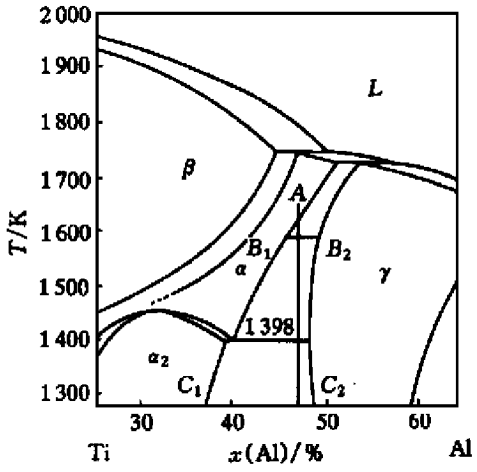

Fig.3 TiAl binary phase diagram

43.8 %, that of γ is B_2, about 49.8 %. The volume fraction of α_2 is about 60 %. The phase transformation begins from the reaction, $\gamma\rightarrow\alpha$, because there is difference between the volume fraction of α_2 of 1 260 ℃ and that of the room temperature ($\varphi(\alpha_2)_{1\,260\,℃} > \varphi(\alpha_2)_{25\,℃}$). The γ lamellae begin to break and dissolve, and the α phase begins to precipitate (as shown in Fig.4). Fig.5 shows the TEM electron image of γ balls, which is produced after γ lamellae break and dissolve. The massive α phases precipitate from the ordered domain boundaries of α lamellae, and grow. The content of α phase increases with the increase of the annealing time. In the cool-

ing process, the γ phase precipitates from α phase, and the phase transformation process is $\alpha \rightarrow \alpha_2 \rightarrow \alpha_2 + \gamma$ or $\alpha \rightarrow \alpha_2 + \gamma$[9]. The initiation of the small lamellar domains is during the process of cooling.

3.2 Orientation of small lamellar domain

There are four kinds of orientations for the small lamellar domains in one primitive lamellar grain. And each has a defined angle (as shown in Fig.6). The γ phase has an FCC structure which has four {111} close packed planes, and the α phase has an HCP structure which has only one close packed planes: (0001). When the alloys were heated at 1 260 ℃, α phase began to precipitate from four kinds of oriented γ phase, and there is a determined crystallographic relationship between α phase and γ phase, i.e. $\{111\}_\gamma \parallel (0001)_\alpha$[9]. During the cooling process, the volume fraction of γ phase increases when the temperature decreases from 1 260 ℃ to room temperature, at this period γ phase begin to precipitate from α_2 phase, and there is only one direction of γ phase in one α_2 domain because α_2 phase has one close packed plane. After that, small size lamellar domains form. The orientation of the small lamellar domains is defined by the orientation of the close packed plane of α phase precipitated from γ phase. Fig.7(a) shows the orientations of four close packed planes of γ phase, which like a tetrahedron. The orientation of the small lamellar domains is parallel to them. The projection of tetrahedron is a quadrangle (Fig.7(b)). Fig.6 shows the optical micrograph for the orientation of the small lamellar domains, which is the same as the quadrangle in Fig.7(b).

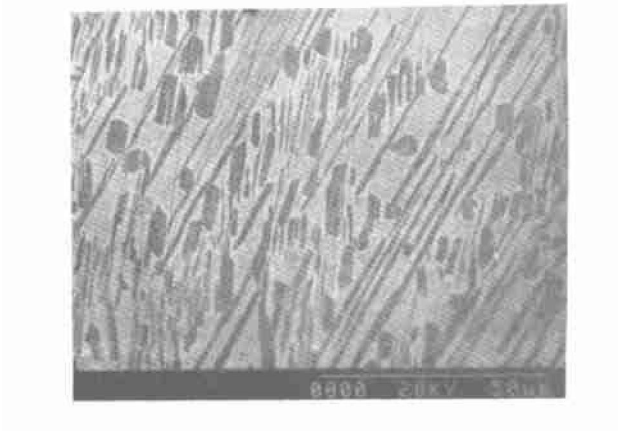

Fig.4 SEM backscattered electron image for solubilization of γ lamellae

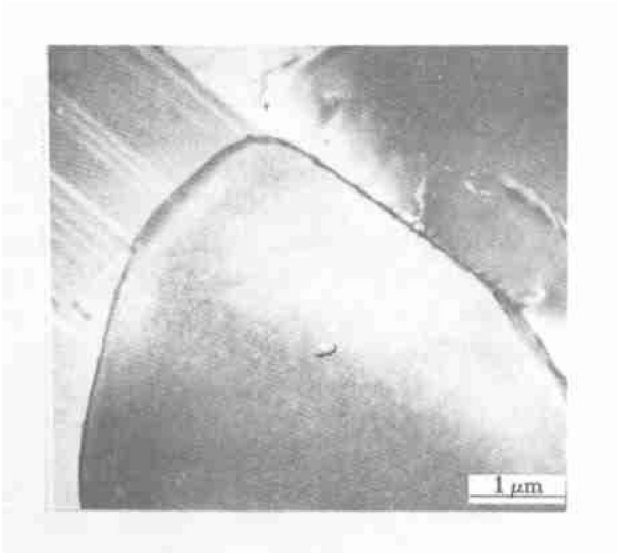

Fig.5 TEM electron image for solubilization of γ lamellae

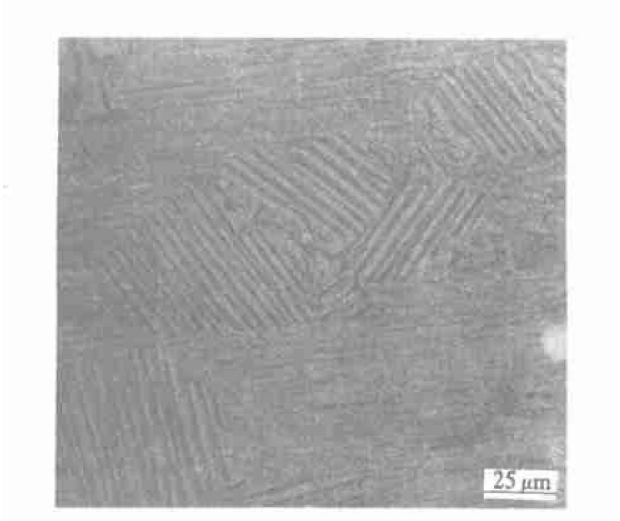

Fig.6 Optical micrograph for orientations of small lamellar domains formed from one grain

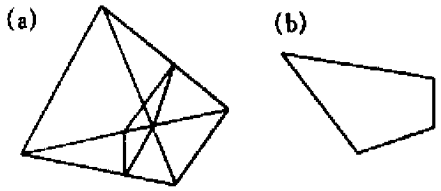

Fig.7 Schematic diagram for orientation of small lamellar domains
(a) —Orientations of four close packed planes of γ phase;
(b) —Projection for orientations of four close packed planes

This process can be confirmed by the microstructure of the samples quenched from γ+α field. When the rate of cooling process is so fast that the precipitation of γ from α_2 is depressed, the massive α_2 can be observed in the microstructure of the quenching samples. And the size of the massive α_2 is identical to small lamellar domains.

3.3 Lamellar spacing of small lamellar domains

The lamellar spacing of small lamellar domains is larger than that of the primitive lamellar grains. This is because Al content of α (B_1 in Fig.3) in γ+α field is lower than the average composition (A in Fig.3), and the temperature is lower than that of α field. The

phase transformation driving force is lower than that of the cooling process from α field. So the nucleation rate of γ decreased during the cooling process from $\gamma + \alpha$ field. This leads to the larger lamellar spacing. Fig.8 shows the TEM images of lamellar spacing of the small lamellar domains and the primitive lamellar grains.

3.4 Composition of small lamellar domains

There is a difference between the composition of small lamellar domains and the large primitive lamellar grains, mainly because of the content of α_2 phase. Fig.9 shows the SEM (back scatter) image of the microstructure in the transformation process. The right bottom of Fig.9 shows the small lamellar domains, and its left top shows the large primitive lamellar grains.

In the small lamellar domains, the amount of α_2 increases obviously. This is because when air-cooling from α phase, the Al content of the lamellar microstructure is close to nominal composition, about 46.5%. The content of α_2 is about 20% and the content of γ is about 80%.

After annealed at 1 260 ℃ for a period of time, the composition of γ phase and α phase begin to close the balance composition. According to the binary phase diagram, the content of α_2 phase is about 60% and that of γ is about 80%. So the volume fraction of α_2 phase increases obviously.

3.5 Size of small lamellar domains

Through enough annealing at 1 260 ℃, α phase extensively nucleates in the large primitive lamellar grains and then grow. Finally, the large primitive lamellar grains almost transform to small lamellar domains. The grains' size decreases obviously. The size of the large primitive lamellar grains is more than 600 μm, but the small lamellar domain size is only about 50 μm. So this process can decrease the grain size effectively.

The size of the small lamellar domains is determined by the grain size of α precipitates from γ. During the annealing process, α precipitated from γ, and grow. This process led to an increase in total grain boundary energy. Such increased energy may be compensated by decreasing the number of lamellar interfaces of γ/γ, γ/α_2[9]. When the free energy reduced by decreasing of the number of lamellar interface could not compensate the increase of α grain boundary energy, the growth of α grain stops. This is the reason why the small lamellar domain could not grow to a larger one.

The properties of the TiAl alloys have close relations with the grain size and the lamellar spacing[10,11]. Because annealing process decreases the grain size at the same time increases the lamellae spacing, whether this process can improve the properties of the alloys or not need further studies. And the next step is to take some methods to decrease the lamellar spacing of the lamellae domains.

4 CONCLUSIONS

1) The small lamellar domains are produced during the cooling process.

2) During annealing at 1 260 ℃ for a period of time, a large fully lamellar microstructure is almost transformed to a small lamellar microstructure. The grain size is obviously reduced from 600 μm to about 50 μm.

3) The small lamellar domains in one primitive large lamellar grain have four orientations, and each orientation has a fixed angle.

4) The lamellar spacing of small lamellar domains is much larger than that of primitive grains.

5) The volume fraction of α_2 in small lamellar

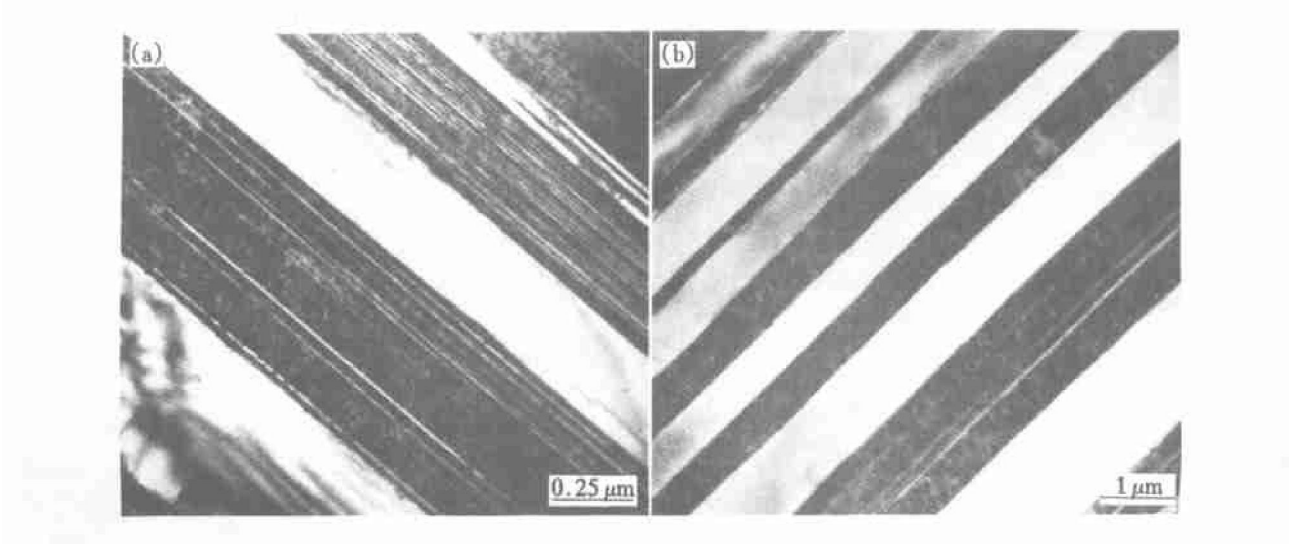

Fig.8 TEM images of lamellar spacing
(a) —Small lamellar domains; (b) —Primitive lamellar grains

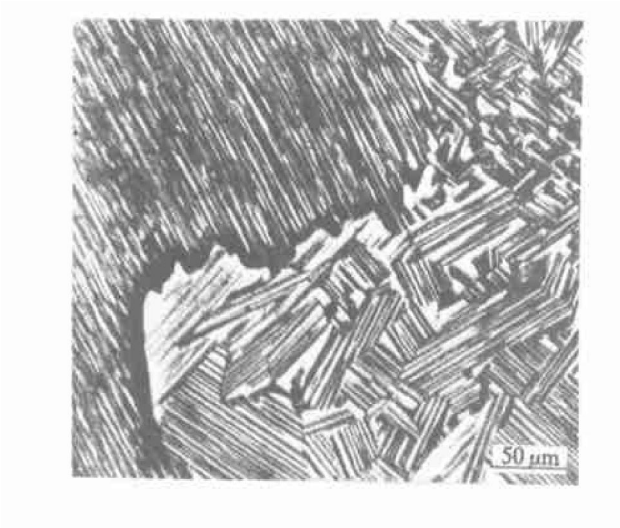

Fig .9 SEM backscattered electron image for microstructure of transformation process

domain is much higher than that in primitive grains. The volume fraction of α_2 in small lamellar domains is about 80 %, and the volume fraction of α_2 in primitive grains is about 20 %.

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