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Effects of yttrium on microstructures and properties of Ti-17Al-27Nb alloy

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Abstract: The effects of rare earth yttrium on the microstructures and mechanical properties of Ti-17Al-27Nb alloy were studied. The as-cast microstructures of Ti-17Al-27Nb alloy with 0.85%Y(mole fraction) addition were refined and the tensile elongation also increased. Yttrium in the alloy exists as Y_2Al according to the EPMA, XRD analysis and electronegativity differences. Y_2Al distributes mainly on the grain boundary. Yttrium is found to improve the tensile strength of Ti-17Al-27Nb alloy due to the grain boundary strengthening. Furthermore, Y_2Al distributing in the grain boundary leads to grain refinement by pinning grain growth. This fracture mode has been changed from intergranular fracture for Ti-17Al-27Nb alloy to a mixture of intergranular fracture and transgranular fracture for Ti-17Al-27Nb-0.85Y alloy. The dimples were observed distinctly. Therefore, this yttrium containing alloy shows an excellent plasticity.

Key words: Ti-17Al-27Nb alloy; yttrium; intergranular fracture; trangranular fracture; microstructure; mechanical properties

1 Introduction

With the rapid development in aerospace technology, the aero engine components have to endure larger force and higher temperature due to speed increase of aero-craft. Therefore, more requisitions have to be presented when selecting materials for high-temperature applications in aero engines. Ti_3Al intermetallic compound has received more attentions as a candidate material for aerospace applications due to its low density, high specific elasticity modulus, high fracture toughness properties, and excellent oxidation resistance at elevated temperatures[1−4]. Nowadays, Ti_3Al based alloys were successfully applied in components of turbine for aerospace, astronautical turbine shell parts，satellite wave board and position engine parts[5, 6]. However, the room temperature plasticity and high-temperature properties of Ti_3Al based alloys are still unsatisfying. The β-stabilizing elements such as niobium has been added to Ti_3Al alloys to improve the room temperature plasticity and oxidation resistance at high temperature[7, 8]. In recent years, rare earth elements have been used in microalloying or alloying the metallic material, applying a pronounced effect on metallic microstructure. For example, rare earth elements may inhibit grain growth, hence, significantly refining the microstructure[9], which can significantly refine the microstructure of some metal materials such as Ti alloys and TiAl intermetallics[10]. At present, the references about rare earth elements effect microstructure of Ti_3Al based intermetallics are few. Therefore, in the present work, the effects of rare earth yttrium on microstructures and mechanical properties of Ti-17Al-27Nb alloy were studied to obtain new model and light high temperature resistant materials.

2 Experimental

The experiments were performed with two different alloys, Ti-17Al-27Nb alloy and Ti-17Al-27Nb-0.85Y alloy. The two different alloys were prepared by induction skull melting(ISM), starting with pure titanium (Purity ＞99.7%) and commercial Ti-Al-Nb master alloy, Nb-Al master alloy, Y-Al master alloy. Burning loss of aluminum was calculated in accordance with 30%(mass fraction) of aluminum content in material[11].

The microstructures and mechanical properties test

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specimens were cut from cast ingots using electrical discharge machining(EDM). The compositions of the cast ingots were analyzed using X-ray fluorescence (XRF). Microstructures and phases composing were analyzed using optical microscope(OM), X-ray diffraction(XRD), scanning electron microscope(SEM), and electro-probe microanalyses(EPMA). The metallographic samples were polished with Cr_2O_3 water solution, followed by etching in the Kroll reagent(V(HF):V(HNO_3):V(H_2O)=1:3:10).

Room tensile tests were conducted on an Instron-5569 universal electron tension tester with a crosshead speed of 0.01 mm/min (strain rate: 1.0×10^{-3} s^{-1}). The fracture surfaces were observed by scanning electron microscope(SEM) after tensile tests.

3 Results and discussion

3.1 Analysis of X-ray fluorescence(XRF)

The actual compositions of the cast ingots were examined by XRF, and the results of XRF are summarized in Table 1.

Table 1 Chemical compositions of experimental alloys after ISM (mole fraction, %)

Alloy	Al	Nb	Y	Ti
Ti-17Al-27Nb	16.85	27.30	-	Bal.
Ti-17Al-27Nb-1Y	17.16	26.71	0.85	Bal.

It is found that the measured compositions of the cast alloys are very close to the nominal compositions. In this paper, the measured, instead of nominal yttrium composition was employed to study its effect on the microstructures and mechanical properties of Ti-17Al-27Nb alloy. Therefore, the chemical compositions of two alloys are Ti-17Al-27Nb and Ti-17Al-27Nb-0.85Y.

3.2 Microstructures of alloys and phases analysis

The influence of yttrium on microstructure of Ti-17Al-27Nb alloy and Ti-17Al-27Nb-0.85Y alloy is shown in Fig.1. It is revealed that the morphologies of both alloys are equiaxed structure. However, it is shown that the addition of yttium refines the equiaxed grains. SEM images of both Ti-17Al-27Nb alloy and Ti-17Al-27Nb-0.85Y alloy are shown in Fig.2. From Fig.2, it is found that the precipitates along grain boundaries decrease greatly.

Niobium is a β-stabilizing element, which improves the room temperature plasticity of Ti_3Al alloys. Martensite transformation takes place in both binary alloys and ternary alloys when rapid cooling from β-phase. However, the martensite transformation is restrained with increasing niobium content, β-phase or

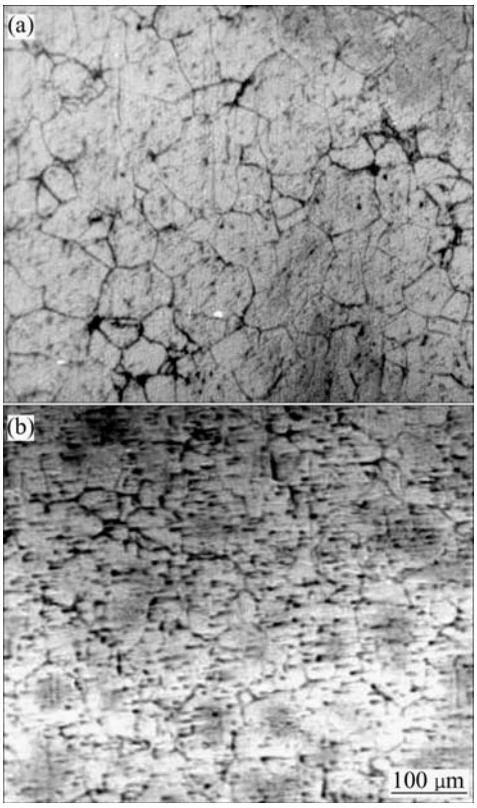

Fig.1 Optical microstructures of Ti-17Al-27Nb alloy(a) and Ti-17Al-27Nb-0.85Y alloy(b)

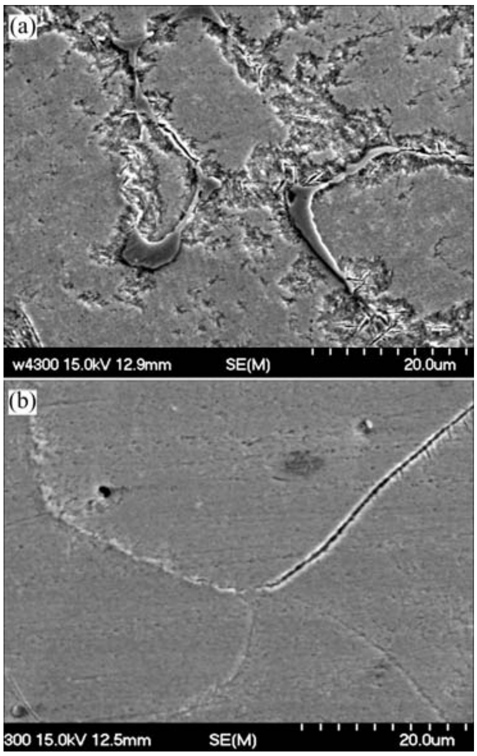

Fig.2 SEM images of Ti-17Al-27Nb alloy(a) and Ti-17Al-27Nb-0.85Y alloy(b)

B_2-phase can retain to room temperature[12]. The aluminum atoms in the B_2-phase play an important role in ordering during disorder(β-phase)-order(B_2-phase) transformation. An aluminum content greater than 12% is premise to the formation of an ordered B_2-phase[13].

The forming tendency of disordered α-phase in the Ti_3Al base alloys is less. When rapid cooling from high-temperature and the martensite transformation is hindered, only α-phase can form. Once ageing is completed, the ordered α_2 phase forms. The XRD results of both alloys are given in Fig.3. It is shown that the main phases are B_2 and α_2. According to Fig.2, the matrix is B_2-phase with equiaxed grains, α_2 phase precipitates along the grain boundaries. But Ti-17Al-27Nb-0.85Y alloy shows a three-phases (B_2+α_2+Y_2Al) microstructure. Similarly, the matrix is B_2-phase with equiaxed grains, α_2-phase precipitated on the grain boundary. Fig.4 shows the backscattered electron (BSE) images and the distribution of yttrium element (white parts in Fig.4) in the Ti-17Al-27Nb-0.85Y alloy. Y_2Al phase is found to distribute mainly on grain boundaries.

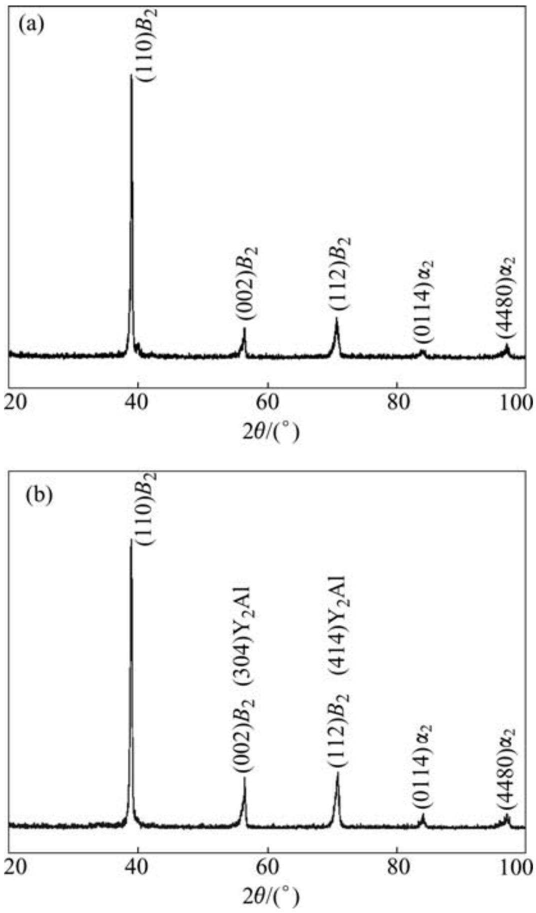

Fig.3 X-ray diffraction patterns of Ti-17Al-27Nb alloy(a) and Ti-17Al-27Nb-0.85Y alloy(b)

Fig.5 and Table 2 show that energy dispersive spectrum(EDS) analysis and the measured compositions of yttrium-rich phases for Ti-17Al-27Nb-0.85Y alloy, respectively. The EDS spectrum clearly shows the existence of Y element. The mole ratio of Y and Al

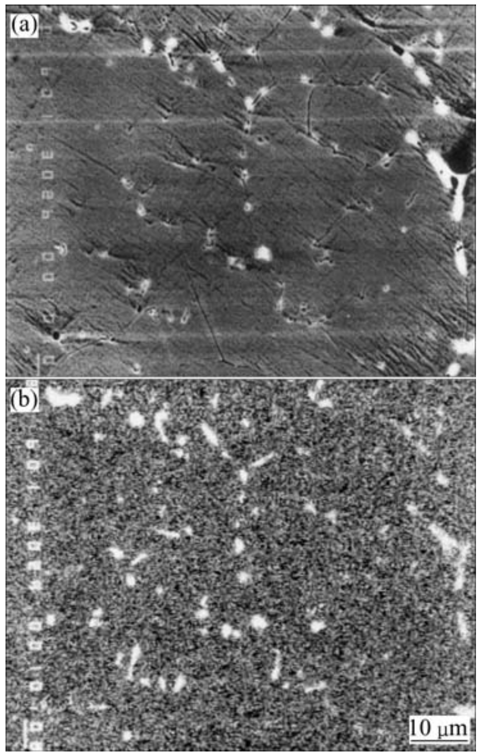

Fig.4 EPMA images showing distributions of yttrium element for Ti-17Al-27Nb-0.85Y alloy: (a) Backscattered electron (BSE); (b) Facial distribution of yttrium element

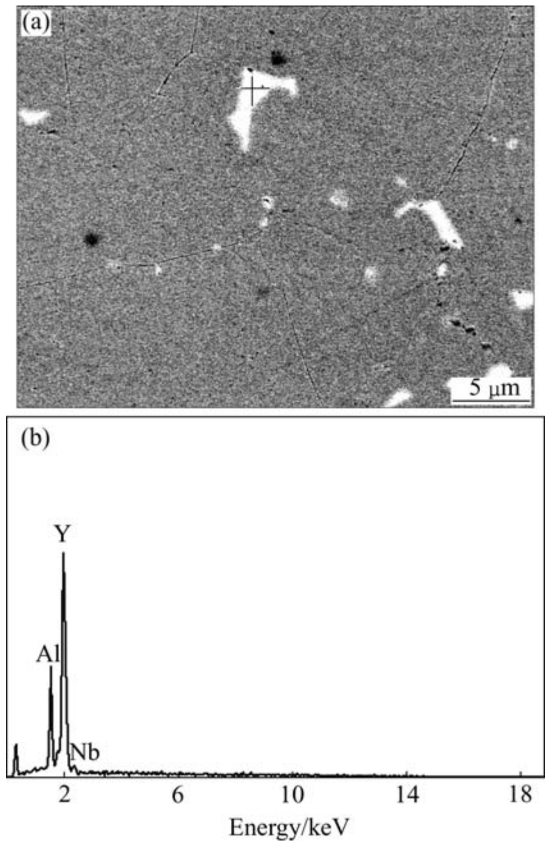

Fig.5 SEM image(a) and corresponding EDS analysis of yttrium-rich phases for Ti-17Al-27Nb-0.85Y alloy(b)

Table 2 Compositions of yttrium-rich phases for Ti-17Al-27Nb-0.85Y alloy

Element	w/%	x/%
Al	14.59	36.02
Nb	0	0
Ti	0	0
Y	85.41	63.98

elements is measured to be about 2:1 in the alloys, which proves that the yttrium-rich phases are Y_2Al.

Generally, the rare earth elements can react with many elements to form compound due to their active chemical properties. In the present research, the reactivity of yttrium with titanium, aluminum, and niobium can be judged according to electronegativity. The binding force between atoms increases with increasing electronegativity difference.

The data of electronegativity of yttrium and electronegativity differences with other elements in the alloy are given in Table 3. Table 3 shows that the electronegativity difference of aluminum with yttrium is the largest, which indicates that they are the easiest to form compound. Combined with the analytical results of X-ray diffraction (XRD) and electro-probe microanalyses(EPMA), the formations mechanism of yttrium-rich phases can be shown as

$$2Y+Al \rightarrow Y_2Al \tag{1}$$

Table 3 Electrnegativity and electronegativity differences with Y of elements in alloy[14]

Element	Electronegativity	Electronegativity difference with Y
Ti	3.65	0.45
Al	4.20	1.00
Nb	4.00	0.80
Y	3.20	0

Fig.4 shows the backscattered electron(BSE) images and distribution of yttrium in Ti-17Al-27Nb-0.85Y alloy. It is seen that a lot of Y_2Al phases distributed on grain boundaries. The Y_2Al phase plays an important pinning role in grain boundary migration, thus the grain growth tendency is restrained. At the same time, α_2-phase precipitating on the grain boundary is also restrained. Therefore, fairly fine equiaxed grains are formed and α_2-phase precipitating on grain boundary decreases greatly with the addition of yttrium.

3.3 Effect of rare earth yttrium on properties of alloys

BOEHLERT[15] has ever studied the mechanical property of single B_2-phase, β-phase and O+B_2-phase in Ti-Al-Nb system. Ti-12Al-38Nb alloy, which shows β-phase for lower Al and higher Nb, reveals a higher room temperature elongation and workability than Ti_2AlNb with an $O+B_2$-phase microstructure. The Ti_2AlNb alloy with $O+B_2$-phase has better combined properties. On the other hand, Ti_2AlNb alloy with pure B_2-phase shows a higher strength than the Ti-12Al-38Nb alloy with pure β-phase. However, its tensile elongation is very low. So the coarse-grained single B_2-phase alloy has a fairly high brittleness.

In this study, the as-cast Ti-17Al-27Nb alloy shows a B_2-phase matrix with coarse equiaxed grains. The mechanical properties results of the as-cast Ti-17Al-27Nb and Ti-17Al-27Nb-0.85Y alloys are listed in Table 4.

Table 4 Mechanical properties of as cast alloys

Alloy	σ_b/MPa	δ/%
Ti-17Al-27Nb	534.81	0.35
Ti-17Al-27Nb-0.85Y	577.65	1.20

It can be seen from Table 4 that the strength and plasticity of alloys are enhanced with the addition of yttrium. Analysis show that equiaxed grains refining which results in grain boundaries strengthening arouses the strength increasing of the alloy. In addition, the decreasing precipitates on grain boundary and equiaxed grains refining with the addition of Y are believed to be the reasons of plasticity improving of the alloy.

The tensile fractographies of alloys are shown in Fig.6. It is found that Ti-17Al-27Nb alloy fails along

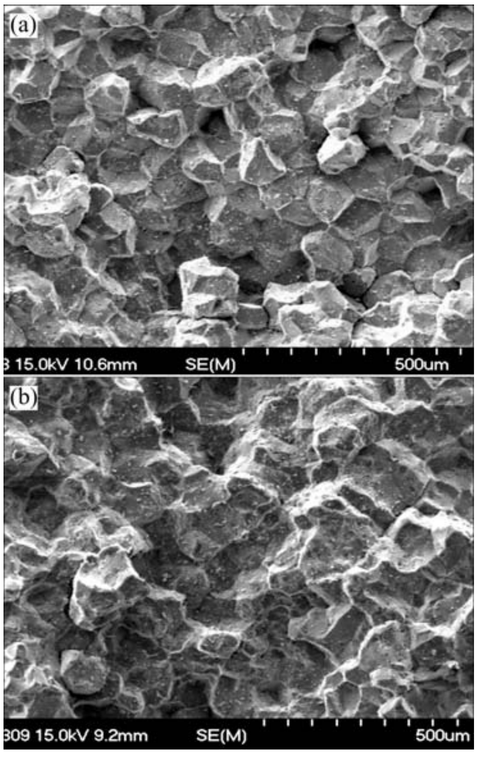

Fig.6 Tensile fracture surface of Ti-17Al-27Nb alloy(a) and Ti-17Al-27Nb-0.85Y alloy(b)

grain boundaries that reveals its brittleness. In contrast, Ti-17Al-27Nb-0.85Y alloy with the addition of yttrium shows both cracks along grain boundaries and transgranular cracking. Moreover, the dimples are clearly distinguished. Therefore, this alloy shows better plasticity.

4 Conclusions

1) Compared with the as-cast Ti-17Al-27Nb alloy, the Ti-17Al-27Nb alloy with addition of 0.85%Y yttrium shows a refined equiaxed grain microstructure, and the precipitates on grain boundaries are less.

2) Y is found to exist as Y_2Al phases in the Ti-17Al-27Nb-0.85Y alloy. Y_2Al phases distribute mainly on the grain boundaries, which results in grain boundaries strengthening and arouses the strength increasing of the alloy. In addition, Y_2Al phases distribute mainly on grain boundaries preventing grain growth is also the dominant reason of equiaxed grains refining.

3) The tensile elongation increases with addition of yttrium that causes finer microstructure. The addition of yttrium also changes the fracture mode from intergranular fracture for the Ti-17Al-27Nb alloy to a mixture of intergranular fracture and transgranular fracture.

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