Effect of Cooling Rate on Microstructure of Two Kinds of High Nb Containing Tial Alloys

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Abstract. In this paper, high Nb-TiAl alloys with Cr and W additions were prepared by Vacuum induction melting method, and then were heat treated under three different cooling rates of slow cooling, furnace cooling and air cooling. The phase composition of the alloy was analyzed by X ray diffraction, and the microstructure of the alloy was observed by optical microscope (OM), scanning electron microscope (SEM) and energy dispersive analyzer. The results show that the microstructure of Ti45Al8Nb0.2Cr and Ti45Al8Nb0.2W are fully lamellar structure with the main phase composition of $\alpha+\gamma$ after 3 different heat treatment conditions. The grain size of the two alloys decreases with decreasing of cooling rate, and the grain size of the alloyed with Cr alloy is smaller than that of the alloyed with W alloy. Most of the original massive $\beta$ phase at grain boundaries and lamellar interfaces dissolved after heat treatment, and the transformation of $\beta$ phase is easier for Ti45Al8Nb0.2Cr.

1. Introduction

TiAl alloys are attractive for application on aircraft and automotive for their excellent high temperature specific strength, especially the alloy with high Nb content[1-2]. $\beta$ phase stabilized elements such as W, Mo, Cr, Ta were used to improve the mechanical properties[3-4]. $\beta$ phase segregation on the grain boundaries was thought to be unbeneffited to the mechanical properties of high Nb containing TiAl alloys due to the brittle characters of $\beta$(B2) phase at room temperature and even lower the brittle-to-ductile transition temperature. It has been observed that microcracks at interface of $\beta$ and matrix occurring after tensile test. And $\beta$ also reduce the creep resistance at higher temperature[5-8]. It has been reported that heat treatment in the $\alpha+\gamma$ phase field, such as Ti-45Al-7Nb-0.4W-0.15B (at%) alloy heated in the temperature of 1220-1260ºC for 8-36h can eliminate the $\beta$ phase. Increasing the heat treatment temperature will reduce the holding time, and impede grain coarsening [9]. In the earlier work, it has been found that the transformation of $\beta$ phase was related with the cooling rate[10]. So it is necessary to study the dynamics of $\beta$ phase transformation. In the present work, two alloys with compositions of Ti45Al8Nb0.2Cr and Ti45Al8Nb0.2W (at%) were used to investigate the effect of cooling rate on $\beta$ phase dissolution during heat treatment in $\alpha+\gamma$ phase field.

2. Experimental

Two alloy ingots with nominal compositions of Ti-45Al-8Nb-0.2Cr and Ti-45Al-8Nb-0.2Cr (at%) were prepared by vacuum induction skull melting furnace. Then small pieces with dimension of 10mm*10mm*10mm were cut of the ingot for heat treatment. The specimens were heat treated under vacuum at the temperature of 1300ºC (about 60ºC below the $T_{\alpha}$), which is in the $\alpha+\gamma$ phase field, held for 10min then cooled at different cooling rates. Three cooling rates were selected, such as controlled slow cooling in furnace (about 5-6ºC/min), furnace cooling (about 20 ºC/min), and air cooling (100-200 ºC/min). The X-ray diffraction measurements were performed on a Bruker AXS D/MAX-3C
using Cu-Kα radiation. The SEM measurement was carried out on FEI QUANTA FEG 650 equipped with Energy Dispersive X-ray Detector (EDX). The specimens for SEM observation were electron-polished in a solution of methanol, 2-Butoxyethanol and perchloric acid at room temperature and 40 kV for 15 s.

3. Results and discussion

3.1. Phase constitution of Ti45Al8Nb0.2Cr alloy and Ti45Al8Nb0.2W alloy

The XRD patterns of Ti45Al8Nb0.2Cr and Ti45Al8Nb0.2W alloys at different cooling rates are shown in figure 1, which indicates that the main phases of the two alloys are γ and α2 phase, and the content of α2 phase decreases with decreasing cooling rates. The reason is that α2 phase transformed to γ phase directly and the eutectoid reaction α→α2+γ was inhibited at higher cooling rate, thus the content of α2 phase in the alloy at air cooling condition is lower than that of the alloy at furnace cool and the alloy at controlled slow cooling rate shows the highest owing to the sufficient transformation of α2 phase.

![XRD patterns of two alloys at different cooling rates](image)

**Figure 1.** XRD patterns of two alloys at different cooling rates, (a) Ti45Al8Nb0.2Cr, (b) Ti45Al8Nb0.2W

3.2. Microstructure of Ti45Al8Nb0.2Cr alloy

The microstructure of Ti45Al8Nb0.2Cr alloy after different cooling rate is shown in figure 2 and figure 3. The microstructure of casting ingot also shows here for comparison, which presents near lamellar microstructure with massive β phase located at the grain boundaries and the α/γ interphase. After heat treatment the alloys show near fully lamellar microstructure, and the grain size increases with increasing the cooling rate. However the lamellar spacing decreases with increasing the cooling rate. The alloy after air cool shows massive α2 phase at grain boundaries. EDX analysis (Table 1.) shows that the light gray contrast area contains less Al content and higher Nb content, but the dark area contains higher Al content and less Nb content, which are α2 phase and γ phase respectively based on the result of XRD. The partition coefficient of Nb between α and γ phases is corresponding to the results of R. Kainuma[11]. After heat treatment the β phase transformed to α2 and γ phase.
Figure 3. SEM images of Ti45Al8Nb0.2Cr alloy at different cooling rates (a) casting ingot, (b) controlled slow cooling rate, (c) furnace cool, (d) air cool, (e) locations for EDX analysis of the alloy under furnace cool.

Table 1. EDX analysis of Ti45Al8Nb0.2Cr alloy under furnace cool condition.

| Test Locations | Element Content (at%) |
|---------------|------------------------|
|               | Ti  | Al  | Nb  | Cr  |
| 1             | 52.79 | 38.50 | 8.46 | 0.25 |
| 2             | 45.95 | 45.61 | 8.44 |       |
| 3             | 45.78 | 46.02 | 8.01 |       |
3.3. Microstructure of Ti45Al8Nb0.2W alloy

The microstructure of Ti45Al8Nb0.2W alloy are shown in figure 4, figure 5 and Table 2. Similar to Ti45Al8Nb0.2Cr alloy, the Ti45Al8Nb0.2W alloy also has near lamellar microstructure, with grain size decreasing as decreasing the cooling rate. The main phases are \( \alpha_2 + \gamma \). But some white contrast phases are found at the grain boundaries, especially in the alloy under air cool condition, which contains less Al content and higher Nb and W content by EDX analysis. They are untransformed \( \beta \) phase comparing to the microstructure of casting ingot.

**Figure 4.** Optical images of Ti45Al8Nb0.2Cr alloy at different cooling rates (a) controlled slow cooling rate, (b) furnace cool, (c) air cool, (d) grain size vs cooling condition.

**Figure 5.** SEM images of Ti45Al8Nb0.2W alloy at different cooling rates (a) casting ingot, (b)controlled slow cooling rate, (c) furnace cool, (d) air cool, (e) locations for EDX analysis of the alloy under furnace cool.
Comparing the two alloys, the grain size of Ti45Al8Nb0.2Cr alloy is smaller and the transformation of β phase is easier than that of Ti45Al8Nb0.2W alloy. The reason is maybe that the diffusion of W is difficult, the eutectoid reaction of α→α_2+γ and the reaction of β→α+γ needs more time, so the nucleation and growth of subgrain of α_2+γ is difficult at the same condition.

The above results indicate that heat treatment in the α+γ area for short time can dissolve the original massive β phase of the two alloys, but the transformation extent depends on the cooling rate. The dissolution of β phase is a diffusion controlled transformation. Holding at the higher temperature gives the driving force to break through the energy barrier for elements diffusion. The accomplishment of the diffusion is occurred during the cooling process. The element has sufficient time for diffusion at controlled cooling rate, so the β phase transformed completely, but at the higher cooling condition, such as the air cool, only part of β phase transformed to α and γ phase. So heating at higher temperature and slow cooling can effectively dissolve the β phase.

4. Conclusions
The microstructures of Ti45Al8Nb0.2Cr and Ti45Al8Nb0.2W alloy cooling from the α+γ phase field at three different cooling rates were investigated. The main conclusions are drawn below.

The main microstructure of Ti45Al8Nb0.2Cr and Ti45Al8Nb0.2W alloys are fully lamellar structure, with grain size decreases as decreasing the cooling rate. Comparing the two alloys, Ti45Al8Nb0.2Cr shows smaller grain size and than that of Ti45Al8Nb0.2W alloy.

In the two alloys, most of β phases transformed to α and γ phases except the Ti45Al8Nb0.2W alloy at air cool condition. And the dissolution of β phase is easier in Ti45Al8Nb0.2Cr than that of Ti45Al8Nb0.2W alloy.

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