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ARTICLE

# Isothermal Oxidation Behavior of TiAl-Nb-W-B-Y Alloys with Different Lamellar Colony Sizes

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**Abstract:** The oxidation behavior of full-lamellar Ti-42.5Al-8Nb-0.2W-0.2B-0.1Y alloys with different colony sizes was investigated by a thermogravimetric method at 900 °C for 100 h in air. The microstructure and composition of the alloy as well as the oxide scales were analyzed by OM, SEM, EDS and XRD. It is found that the oxidation kinetic of the present TiAl alloys accords with the parabolic law, and the alloy with larger lamellar colony has a better oxidation resistance than the one with smaller lamellar colony. The mass gain of the two samples with large and small lamellar colony after 100 h oxidation is 6.45 and 7.62 g/cm$^2$, respectively. And correspondingly the thickness of oxide scale is about 5 and 7 μm, respectively. Based on the analysis of oxidation kinetic and microstructure characterization, we conclude that the structural differences between the two samples which affect the diffusion rate of O element into the matrix result in different oxidation behavior.

**Key words:** TiAl alloys; full lamellar structure; lamellar colony; oxidation behavior

TiAl-based alloys have been used in aerospace, automotive and gas turbine industries due to their exceptional combination of light weight and mechanical properties and creep resistance at elevated temperatures[1-3]. However, the oxidation resistance of TiAl-based alloys is inadequate at high temperatures up to 600~900 °C [4]. The competitive oxidations of Ti and Al in the TiAl alloys made it difficult for the formation of a dense and continuous $Al_2O_3$ layer protecting the matrix from further oxidation[5,6].

Numerous researches on oxidation resistance of TiAl alloys have been made, but the published oxidation data show a large scatter[5, 7-10]. A great deal of research work has been undertaken to improve the oxidation behavior of TiAl alloys by adding ternary and quaternary elements. In view of the third element addition, niobium and several other elements have been reported to be effective in improving the oxidation resistance of TiAl in Ref. [11-13]. And the microstructure of TiAl alloy castings has a significant influence on the oxidation behavior[14-17]. In conclusion, the variation of oxidation resistance for TiAl alloys may be attributed to the alloy purity, alloying elements, differences in surface preparation, alloy microstructure and so on[11-16]. All of these reasons affected the oxidation resistance of the TiAl alloy but the mechanisms are not clearly elucidated. The generally accepted concept was that the continuous $Al_2O_3$ layer protected the alloys from further oxidation and efficiently improved oxidation resistance.

In the present paper, we have studied the oxidation behavior of the full-lamellar Ti-42.5Al-8Nb-0.2W-0.2B-0.1Y alloy at 900 °C in air to examine the effect of colony size on oxidation resistance. The oxidation kinetics has been analyzed, and the microstructure has been characterized in detail. The obtained experimental results are useful for understanding the oxidation mechanisms of TiAl-based alloys.

## 1 Experiment

The TiAl alloy for this study was prepared by vacuum arc remelting (VAR) with a nominal composition of Ti-42.5Al-8Nb-0.2W-0.2B-0.1Y (at%). The ingot was cut into 10 mm×10 mm×5 mm samples used for oxidation tests. In order to obtain full-lamellar structure and adjust the colony size, two different heat treatment processes were carried out, as shown in Table 1. The samples for oxidation tests were first polished using

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**Table 1 Heat treatments of the present alloy**

| Alloy composition/at% | Alloy | Heat treatment |
|---|---|---|
| Ti-42.5Al-8Nb-0.2W-0.2B-0.1Y | 1# | 1320 °C/15 min |
| | 2# | 1320 °C/5 h |

SiC paper and then cleaned in acetone solution. Isothermal oxidation tests were performed at 900 °C in a static air atmosphere in an electric furnace for oxidation. The total oxidation time was 100 h and each oxidized specimen was weighted using an electronic balance with 0.1 mg precision. Various techniques have been used to characterize the structure and thickness of the matrix and the oxide scale. X-ray diffraction (XRD) with Cu Kα radiation was applied for phase identification, and the SEM analysis was performed for the layer morphology examination as well as the thickness measurements of the oxidation layer.

## 2 Results and Discussion

### 2.1 Initial microstructure

The microstructures of the Ti-42.5Al-8Nb-0.2W-0.2B-0.1Y alloy with different lamellar colony sizes before oxidation are shown in Fig.1. From the OM images in Fig.1a and Fig.1b, one can note that both the alloys have fully lamellar microstructure. However, the colony size in the two alloys is quite different due to the different heat treatment processes. When the alloy is treated for 15 min at 1320 °C (labeled as 1#), the colony size is much smaller, whereas the colony size in the 2# alloy (heat treated at 1320 °C for 5 h) is much larger. Fig.1c and Fig.1d show the SEM images of the alloys at higher magnification, and it is found that the lamellar spacing in the 2# alloy is comparable with that of the 1# alloy.

It was reported that the TiAl alloys with fine fully lamellar microstructure possesses the best high temperature performance[18]. High Nb containing TiAl alloys without B and Y element generally produce coarse microstructure. B and Y addition can not only improve the high temperature oxidation of alloys but also enhance the mechanical properties by refining the microstructure.

The histogram of the colony sizes of the present TiAl alloys are shown in Fig.2. One can observe that the colony size in 1# alloy is in the range of 20~160 μm, and yields an average value of about 85 μm. In contrast, the colony size is 50~350 μm for 2# alloy with an average value of about 195 μm. In addition, one can notice that the colony size is increased with the holding time in *α* phase, which is in accordance with the Baker equation[19].

### 2.2 Oxidation kinetics

Fig.3 shows the mass gain curves. The results indicate that the two microstructures show similar oxidation kinetics at 900 °C. A review of earlier investigations on oxidation kinetics of the TiAl based alloys revealed that the parabolic rate law was considered as the basis of data processing and interpretation of the mass gain vs. time data[20]. In order to understand whether a simple kinetics law can apply, the curves can be fitted by an equation model as:

$$\Delta M_n = k_n t \quad (1)$$

where $\Delta M$ is mass grain per unit surface area of specimen, $t$ is exposure time and $k_n$ is the rate constant. The rate constant $k_n$ and exponent $n$ were evaluated from the linear regression fitting of $\ln(\Delta M)$ vs. $\ln t$ data. And the relationship of the two data is as follows:

$$\ln(\Delta M) = \frac{1}{n}\ln t + \frac{1}{n}\ln k_n \quad (2)$$

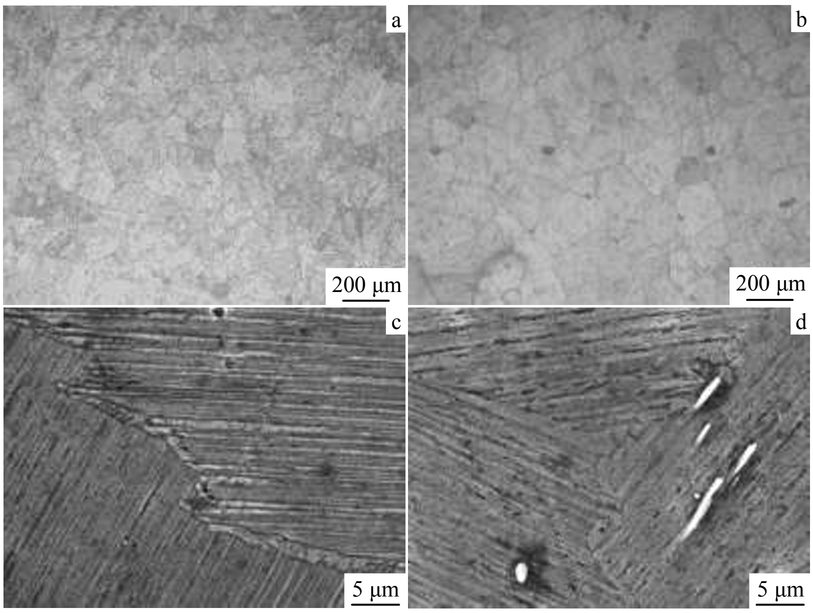


Fig.1 OM (a, b) and SEM (c, d) of microstructures of TiAl alloys: (a, c) small lamellar colony and (b, d) large lamellar colony