

Effect of heat treatment on the mechanical properties of TiAl alloy

Jun Liu^{1,a}, Yulan Hu¹, Hongchao Qiao² and Jibin Zhao²

¹Shenyang Ligong University, Shenyang 110159, Liaoning, China

²Shenyang Institute of Automation, Chinese Academy of Sciences, Shenyang 110016, Liaoning, China

Abstract. Heat treatment can influence the microstructure and mechanical properties, in order to homogenize the composition and microstructure, improve the mechanical properties, Ti44Al6Nb0.9La alloy was heat treated at different temperatures and cooling conditions. The experimental results showed that macro-grains grew larger with the elevated temperature. The near-lamellar microstructure was obtained after heat treatment of 1200°C for 2 hours, which transformed into fully-lamellar microstructure as the temperature rose. In addition, linear and lumpish lanthanum compounds were located at inter-lamellae and the colony boundaries, which accumulated more with the accelerated temperature. Micro-hardness test indicated the value of micro-hardness increased differently and the value was the relative maximum when the temperature was 1270°C, as a result of solution strengthening of Nb and precipitation strengthening of La.

Keywords: TiAl alloy; heat treatment; grain refining; micro hardness; lanthanum.

1 Introduction

TiAl based alloys are potential high-temperature structural materials with low density, high specific strength and excellent creep resistance at elevated temperature[1], while the poor room ductility and toughness markedly restricts its comprehensive applications in aero-engine fabrication and automotive filed. Alloying is an efficient way to improve the mechanical properties of TiAl based alloys by adding elements with high melting point, such as Nb, which significantly enhances the strength, oxidation resistance and creep resistance at high temperature[2-3]. Moreover, B and Re addition can obviously suppress the growth of α grain [4-7] to refine the microstructure.

In addition, some studies [8-12] have reported that quenching, tempering and cyclic heat treatments do benefit to microstructure refinement and great performance of TiAl based alloys. It is reported by He [13] that the casting grain size of Ti48Al2Cr0.5Mo alloy is refined from 1000 μ m to 18~30 μ m by quenching and tempering treatments. According to Du H [14], the yield strength, fracture stress and ductility of as-cast structure is namely 330MPa, 415MPa and 0.7%, which is increased to 660MPa, 825MPa and 3.3% respectively via cyclic heat treatment. Malinov S [15] reported that Ti46Al2Cr2Nb alloy with fine fully lamellar microstructure by quenching, cyclic heat treatment and solution treatment successively, has an outstanding tensile stress of 707MPa.

^a Corresponding author : lj-mail-sut@163.com

Based on the above, this article mainly deals with the effect of heat treatment on the macro/microstructure and mechanical properties of Ti44Al6Nb0.9La alloy at different temperatures.

2 Experimental: materials, procedures and detection methods

The experimental alloy sample with a nominal composition of Ti44Al6Nb0.9La (at. %) was prepared by vacuum non-consumed electric arc melting. On the basis of related references, different heat-treatment processes were planned, namely of 1200°C for 2 hours/furnace cooling to 900°C /air cooling (HT1), 1270°C for 2 hours/furnace cooling to 900°C /air cooling (HT2), 1330°C for 2 hours/furnace cooling to 900°C /air cooling (HT3) with the heating rate of 10°C /s. In order to avert oxidization, samples were vacuum sealed and then put into the high-temperature vacuum furnace. After heat treatment macrostructure analysis was conducted with digital camera. The microstructure was characterized via scanning electron microscopy (SEM) employing back-scattered electron (BSE) imaging and optical microscopy (OM) after alloy sample surface being distilled water cleaned, wind dried, and etched in Kroll's reagent of 5 vol.% HF+5 vol.%HNO₃+90 vol.%H₂O. Besides, phase composition was determined via the energy spectrum analysis (EDS) and micro hardness test was also performed.

3 Results and discussion

3.1 The influence of heat treatment on the macrostructure of Ti44Al6Nb0.9La alloy

Fig.1 showed the as-cast macrostructure and the macrostructure after heat treatment of Ti44Al6Nb0.9La alloy. Fine and uniform equiaxed grains were obtained in the as-casting condition and grains grew significantly with the tendency of tiny grains being swallowed up after heat treatment. As shown in Table 1, the grain size of Ti44Al6Nb0.9La alloy augmented dramatically and the homogeneity of macrostructure deteriorated with the solution temperature rising because of simultaneous augmentation for colonies and grain size.

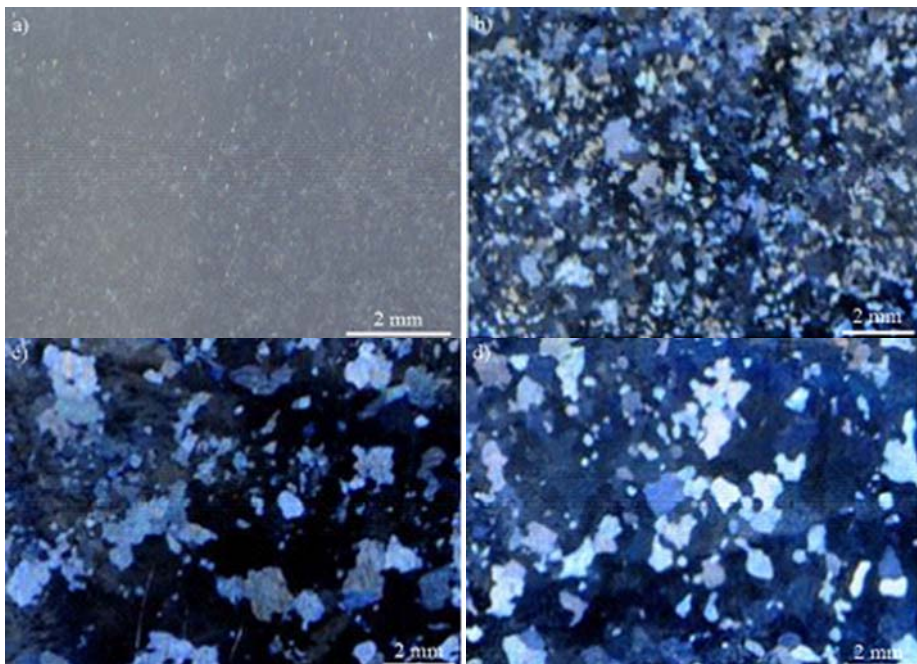
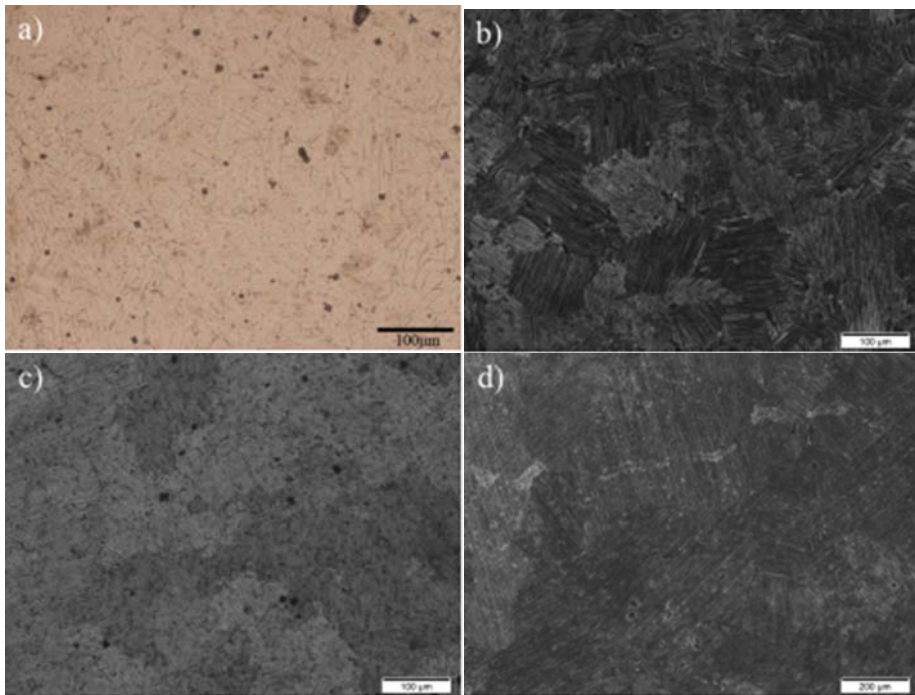


Figure 1. The macrostructure of Ti44Al6Nb0.9La: a) as cast, b) 1200°C, c) 1270°C, d) 1330°C

Table 1. Average colonies size of Ti44Al6Nb0.9La alloy

Temperature(°C)	Grain size (μm)	Colonies size (μm)
1200	380~460	40~90
1270	640~950	70~150
1330	850~1100	180~300

3.2 Effect of heat treatment on the microstructure of Ti44Al6Nb0.9La alloy

**Figure 2.** The microstructure of Ti44Al6Nb0.9La by OM: a) as cast, b) 1200°C, c) 1270°C, d) 1330°C

A typical duplex microstructure, consisting of primary γ grains and $(\alpha_2+\gamma)$ lamellae, was observed in the as-casting Ti44Al6Nb0.9La alloy (Figure 2(a)), and a near-lamellar microstructure of about 380μm to 460μm in colony size was found after HT1 (Figure 2(b)). With the solution temperature elevated, the microstructure was transformed into a fully lamellar structure of 640μm to 950μm at 1270°C and 850μm to 1100μm at 1330°C in colony size. It was also observed that linear and lumpish black precipitations were distributed irregularly at inter-lamellae and the colony boundaries. In brief, the lamellar colonies and the amount of precipitation grew obviously with the solution temperature rising.

As shown in the Fig.3, lots of strip light phase appeared in the as-cast microstructure and then disappeared after heat treatment, which was proved as the segregation of Nb via EDS. Fig.4 and Table 2 show that Nb was dissolved sufficiently into the matrix after heat treatment of 1330°C for 2 hours, which was in accordance with previous studies [16] that the segregation of Nb was removed by heat treatment. A large amount of granular, clubbed and lump light phase dispersed erratically and accumulated with the solution temperature increasing. EDS results replied that La was found free in

the matrix and existed in the form of lanthanum compound, which exhibited lump, clubbed and granular shape and white contrast in BSE images.

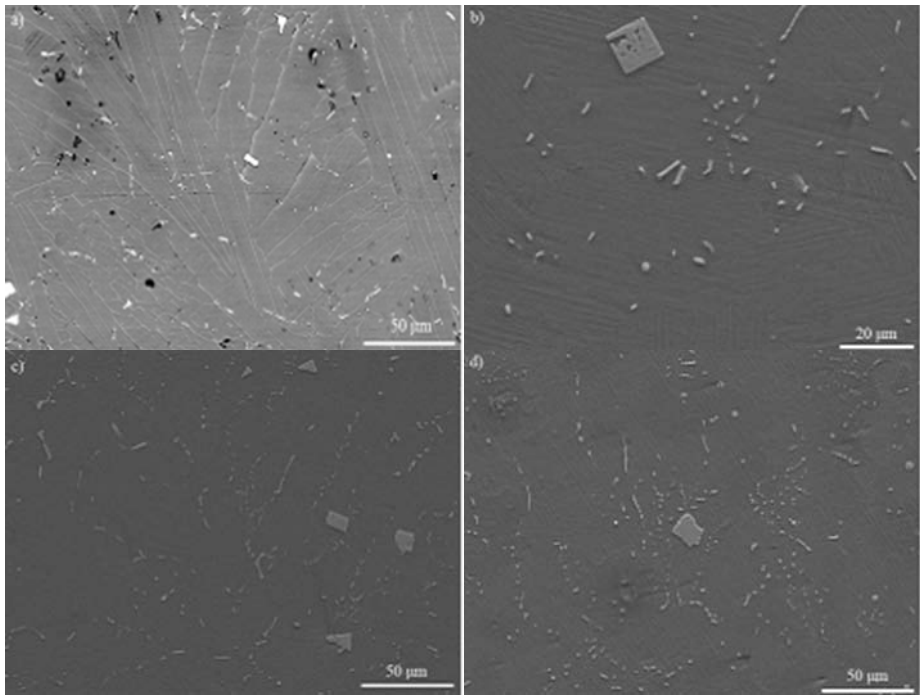


Figure 3. The microstructure of Ti44Al6Nb0.9La alloy by SEM a) as cast b) 1200°C c) 1270°C d) 1330°C

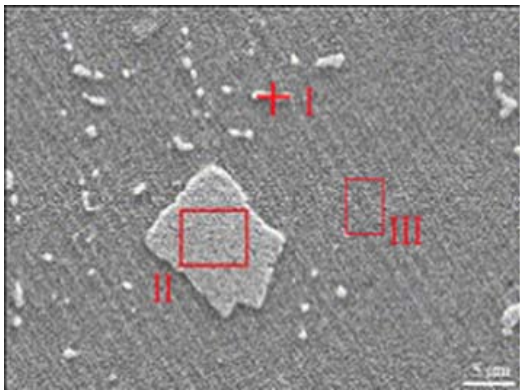


Figure 4. BSE image of Ti44Al6Nb0.9La alloy after heat treatment of 1330°C

Table 2. Spectrum analysis of Ti44Al6Nb0.9La alloy at 1330°C

Position (at. %)	Ti	Al	Nb	La	O
I	17.63	53.08	02.93	26.35	—
II	06.37	21.26	00.37	22.11	49.89
III	48.61	44.78	06.16	00.45	—

3.3 Effect of heat treatment on mechanical properties of Ti44Al6Nb0.9La alloy

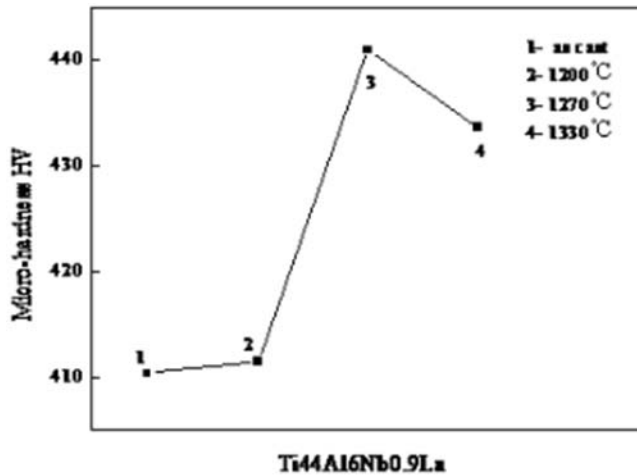


Figure 5. The micro-hardness of Ti44Al6Nb0.9La alloy

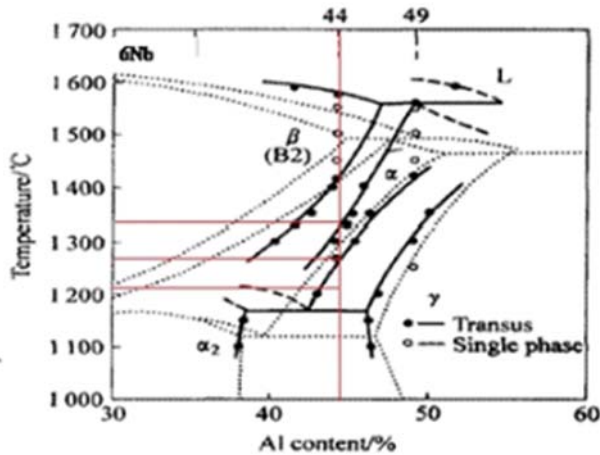


Figure 6. Binary phase diagram of Ti-Al-6Nb alloy

It was evident that the micro-hardness value improved differently after heat treatment as shown in Fig.5. Specifically, the micro-hardness increased slightly at 1200°C and the value increased significantly with the solution temperature rising and the micro-hardness value reached to the relative maximum at 1270°C.

Owing to the segregation eliminated, Nb dissolved fully in the matrix after heat treatment and the solution strengthening was more significant at the elevated temperature with the result of high value of micro-hardness. After heat treatment of 1270°C for 2 hours, large quantity of Lanthanum compounds were located at the colony boundaries, which effectively suppressed the growth of lamellar colonies. As a result, the inter-crystalline strengthening of fine lamellar colonies had much to do with the highest micro-hardness. As depicted in the Binary phase diagram of Ti-Al-6Nb alloy (Fig.6), the heat treatment of 1330°C was located in the solid phase region of (α + β) close to the single phase region of α , in which α grain grew dramatically. In conclusion, the coarse lamellar colonies decreased the micro-hardness relatively at 1330°C. In a word, the micro-hardness improved after heat treatment with the comprehensive result of the solution strengthening of Nb and precipitation strengthening of La.

4 Conclusions

(1) The grain size increased and the homogeneity of Ti44Al6Nb0.9La alloy deteriorated when the temperature was 1330°C.

(2) Duplex transformed into NL by means of heat treatment of 1200°C, while ($\alpha_2+\gamma$) FL was finally obtained after the heat treatment at 1270°C and 1330°C, lump, clubbed and granular lanthanum compounds were found at inter-lamellar and the colony boundaries. With increasing of temperature, the amount of precipitation increased and the segregation of Nb was eliminated.

(3) In contrast with the as-cast structure, the micro-hardness values of Ti44Al6Nb0.9La alloy after different heat treatment processes were improved differently and the value reached to the relative maximum at 1270°C, which was the comprehensive effect of solution strengthening of Nb and precipitation strengthening of La.

Acknowledgements

The authors are grateful to Prof. Hao Bo for his helpful discussions and advices. We would also like to thank the anonymous reviewers for their critical and constructive reviews of this paper. This study was co-supported by the National High Technology Research and Development Program of China (Grant No. 2012AA041310), the National Natural Science Foundation of China (Grant No: 61170146) and the Natural Science Foundation of Liaoning Province of China (Grant No. 2015020032).

References

1. K. Uenishi, K. F. Kobayashi, *Intermetallics*, **4**, S95 (1996)
2. D. Hu, *Intermetallics*, **9**, 1037 (2001)
3. Y.H. Wang, J.P. Lin, Y.H. He, *Rare Metals*, **25**(4), 349 (2006)
4. U. Hecht, V. Witusiewicz, A. Drevermann, J. Zollinger, *Intermetallics*, **16**, 969 (2008)
5. W.D. Wang, Y.C. Ma and B.Chen, *J. Mater. Sci. Technol.*, **26**(7), 639 (2010)
6. C.M. Liu, H.J. Li, *Chinese Journal of Materials Research*, **13**(4), 395 (1999)
7. H.P. Qua, P. Li and S.Q. Zhang, *Materials and Design*, **31**, 2201 (2010)
8. X.F. Ding, J.P. Lin, L.Q. Zhang, *Trans. Nonferrous Met. Soc. China*, **21**, 26 (2011)
9. H. P. Qu, P. Li, S. Q. Zhang, A. Li, *Materials and Design*, **31**, 2201 (2010)
10. J. Sienkiewicz, S. Kuroda, R. M. Molak, *Intermetallics*, **49**, 57 (2014)
11. C. M. Liu, H. M. Wang, X. J. Tian, *Materials Science & Engineering A*, **604**, 176 (2014)
12. S.Z. He, Y.H. He, B.Y. Huang, *Journal of Aero Nautical Materials*, **3**(23), 5 (2003)
13. D. Hu, R. R. Botten, *Intermetallics*, **10**(7), 701 (2002)
14. S. MALINOV, W. SHA, *Material Science and Engineering A*, **365**(2), 202 (2004)
15. W. Wang, W.D. Zeng, C. Xue, *Intermetallics*, **45**, 29 (2014)