

Influence of Microstructures on Tensile Properties at 400°C of TC4 Titanium Alloy

Ren Yong Yang Nan Lei Jinwen Li Shaoqiang Du Yuxuan

Western Superconducting Technologies Co., Ltd, Xi'an 710018, China

Abstract: The effects of primary α phase volume fraction on the tensile properties at 400°C of TC4 titanium alloy was studied by different solution temperature (T_{β} -(10~80)°C). The effects of the thick of secondary α phase on the tensile properties at 400°C of TC4 titanium alloy was studied by different cooling speed after solution treatment (water quench, air cooling, furnace cooling). The results show that with the decrease of primary α phase, the tensile and yield strength increase up, but the ductility has a little change. The thick of secondary α phase increases with the decreases of cooling speed after solution treatment, highest tensile and yield strength by water quench, the tensile strength of air cooling and furnace cooling were basically the same, but the yield strength of furnace cooling was 40MPa lower than air cooling. Therefore, the influence of the primary α phase volume fraction on the tensile strength at 400°C was particularly obvious, we can control solution treatment and cooling way in combination with different requirements.

Key words: TC4 titanium, solution temperature, tensile properties at 400°C, microstructure

1 Introduction

Titanium alloy has the characteristics of low density, high specific strength, good corrosion resistance, low thermal conductivity, non-toxic and non-magnetic, weldable, good biocompatibility and strong surface decoration. It is a kind of lightweight and high strength resistant. Eclipsed structural materials have broad application prospects in weaponry and have been widely used in chemical, petroleum, electric power, medical, construction, sports and other fields [1]. The TC4 titanium alloy is a martensitic α - β titanium alloy containing 6% Al and 4% V, a nominal composition of an aluminum equivalent of 7.0, and a molybdenum equivalent of 2.9. The alloy with excellent comprehensive mechanical properties, excellent thermal plasticity and good welding performance, long-term use of temperature can reach 400 °C , and the cost is relatively low, is widely used in aerospace industry, such as aircraft engine fan and the compressor blade, disc parts, machine box, and beam in aircraft structures, joint and important bearing components such as the frame [2-6].

The tensile properties of alloys depend largely on the chemical composition of the alloys, the machining process and the heat treatment regime which determines the different microstructures [7-8]. At present, domestic and foreign scholars have studied the relationship between the microstructure and properties of TC4 titanium alloy under different heat treatment conditions. Liu wanying et al. studied the effects of solid solution temperature and aging temperature on the microstructure and properties of TC4 titanium alloy [9]. Niinomi M et al. preliminarily studied the relationship between the microstructure and properties of Ti-6Al-4V [10], and concluded that the primary phase was the channel for crack initiation and propagation, etc. However, the influence of heat treatment on microstructure and tensile strength at room temperature was studied in the above literatures, while the influence of heat treatment on high-temperature performance of aero-engine was rarely studied. In this paper, different microstructures were obtained by setting different solution temperature and cooling rate, and the influence of solution treatment system on the tensile properties at 400°C of TC4 titanium alloy was studied.

2 Materials and experimental

2.1 Materials

The material used in this test is a 5 tons ingot of TC4 titanium alloy produced by Western Superconducting Technology Co., Ltd. The macrostructure in the top and middle section of ingot have been shown in Fig. 1, Fig. 1 (a) and (b) show the macrostructure of the cross section of the head and the middle of the ingot respectively, it can be seen from the Fig. that the macrostructure of the head or the middle are uniform, it is typical alloy cast macrostructure.

The TC4 titanium alloy 5 ton ingot is forged into a Φ 300 mm bar after forging multiple times above the transformation point and below the transformation point. The uniform macrostructure in the top and middle section of bar have been shown in Fig. 2(a) and Fig. 2(b), it shows that the TC4 titanium alloy bar blank has obtained sufficient deformation during the preparation process. The forged microstructure of the TC4 titanium alloy Φ 300 mm rod blank is shown in Fig. 3. It can be seen from Fig. 3(a), (b) and (c) that the edge, R/2 and the center microstructures of the Φ 300mm bar are basically the same and relatively uniform, and the content of the primary α phase in the tissue is also basically equivalent, about 60%.

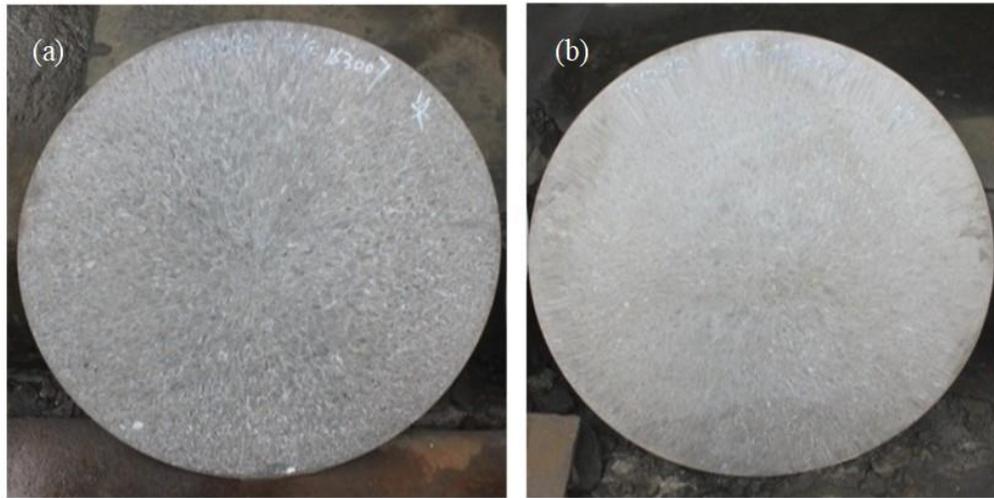


Fig.1 Macrostructures of TC4 titanium alloy 5-ton degree ingot: (a) Top; (b) middle.



Fig.2 Macrostructure of TC4 titanium alloy Φ 300mm bars: (a) Top; (b) middle.

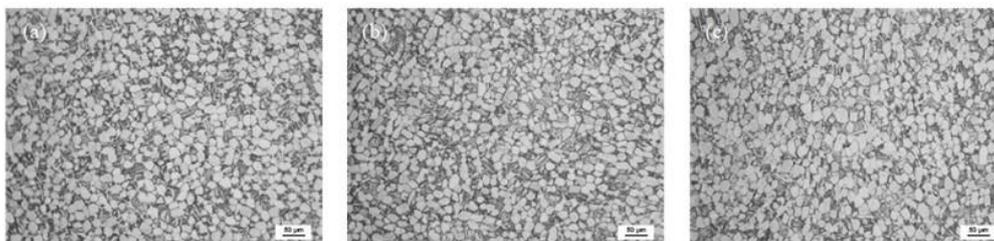


Fig.3 Microstructures of different positions on TC4 titanium alloy Φ 300mm bar: (a) Edge; (b) R/2; (c) center.

2.2 Experimental

Cutting a billet from the 70mm thickness TC4 titanium Φ 300mm sized bar without heat treatment, then cutting 10 sets of Φ 13mm \times 70mm samples by wire cutting perpendicular to the radial direction at 1/2 radius of the cross-section, and every set has 3 samples. 8 kinds of heat treatment in accordance with Table 1 in a different solution treatment temperature to obtain specimens with different levels of primary α , different secondary α phase morphology was obtained by different cooling methods at the same solution temperature. After heat treatment, the tensile properties at 400°C of 3 samples were tested in each set, and at the end of mechanical properties of the samples for metallographic specimen. The microstructure was observed and photographed by LEICA MEF4A inverted metallographic microscope. E45.305 machine was used to test the tensile properties at 400°C.

Table 1 Different heat treatments of TC4 titanium alloy

No.	Heat treatment
1#	T_{β} -10 °C/1h, WQ+780 °C/1h, AC
2#	T_{β} -20 °C /1h, WQ+780 °C/1h, AC
3#	T_{β} -30 °C/1h, WQ+780 °C/1h, AC
4#	T_{β} -40 °C/1h, WQ+780 °C/1h, AC
5#	T_{β} -50 °C/1h, WQ+780 °C/1h, AC
6#	T_{β} -60 °C/1h, WQ+780 °C/1h, AC
7#	T_{β} -70 °C/1h, WQ+780 °C/1h, AC
8#	T_{β} -80 °C/1h, WQ+780 °C/1h, AC
9#	T_{β} -50 °C/1h, AC+780 °C/1h, AC
10#	T_{β} -50 °C/1h, FC to 780 °C/1h, AC

3. Results

3.1 Effects of solution temperature and cooling rates on microstructure

The microstructure of TC4 titanium alloy samples after heat treatment is shown in Fig. 4. Fig. 4 (a) and (b), (c), (d), (e), (f), (g) and (h) shown the microstructure of solid solution temperature form 10°C to 80°C below the phase transform temperature respectively. As can be seen from Fig. 4, after the solution treatment, the microstructure of TC4 titanium alloy changed significantly, the primary α content decreases significantly with increasing solid solution temperature. And the size and shape uniformity of the phase were good in the same metallographic field, so we only need to pay attention to the difference between the initial α content and the size. The content of the primary α phase of Fig. 4 (a) is about 6.0%, and the average size of the equiaxed α phase is 16 μ m; The content of the primary α phase of Fig. 4 (b) is about 13.9%, and the average size of the equiaxed α phase is 16.7 μ m; The content of the primary α phase of Fig. 4 (c) is about 17.8%, and the average size of the equiaxed α phase is 19.6 μ m; In Fig. 4 (d), the content of the primary α phase is about 28.6%, and the average size of the equiaxed α phase is 21.2 μ m; In Fig. 4 (e), the content of the primary α phase is about 38.0%, and the average size of the equiaxed α phase is 23.1 μ m; Fig. 4 (g) and (h) was very close to the microstructure, the primary content of α were 53.2% and 57.6% respectively, in the same optical field within the size and shape of the primary α are uniformity, primary α phase has fully equiaxed, such as the average size of α phase were 24.3 μ m and 25.5 μ m, it shows that when the solution temperature drops to a certain extent (T_{β} -70 °C and T_{β} -80 °C), the influence on the microstructure is weakened. Fig. 4 (i) and Fig. 4 (j) are the microstructures obtained by air cooling and furnace cooling after the TC4 titanium alloy is solid solution at T_{β} -50 °C. With the decrease of the cooling rate after solid solution, the size of the primary α phase becomes larger, and the secondary α phase increases. Under the furnace cooling, the primary α phase and the secondary α phase are basically connected together and cannot be distinguished.

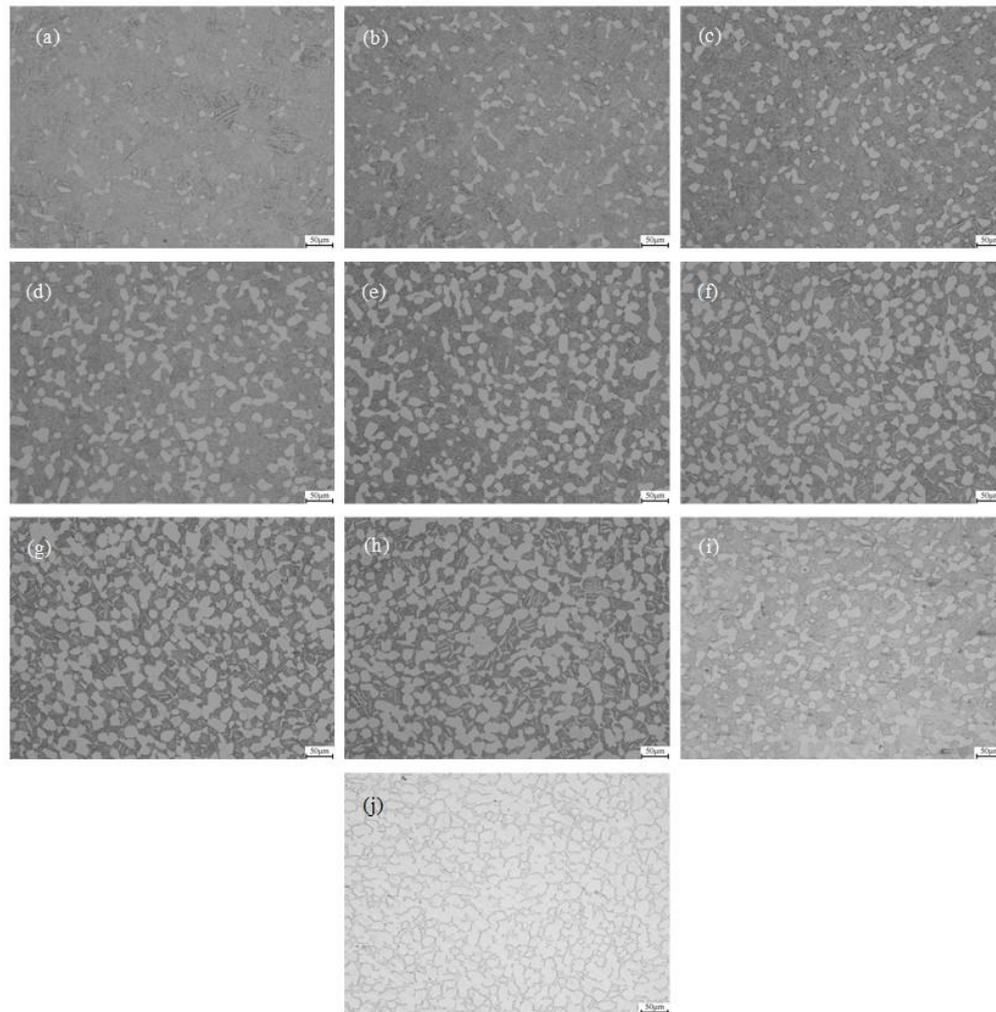


Fig.4 Microstructures of TC4 titanium alloy treated with different solution temperature and different cooling rates

(a) T β -10°C/1h, WQ; (b) T β -20°C/1h, WQ; (c) T β -30°C/1h, WQ; (d) T β -40°C/1h, WQ; (e) T β -50°C/1h, WQ;
(f) T β -60°C/1h, WQ; (h) T β -70°C/1h, WQ; (a) T β -80°C/1h, WQ; (i) T β -50°C/1h, AC; (j) T β -50°C/1h, FC

3.2 Influence of solution temperature and cooling rates on tensile properties

The tensile properties at 400°C of TC4 titanium alloy treated by different heat treatments are shown in Table 2. (Repeat 3 samples of data for each condition and average). As can be seen from Table 2 and Fig. 5, as the solution temperature decreases, the tensile strength at 400°C drops significantly, and the plasticity index does not change much. When the solution temperature is between $T_{\beta}-20^{\circ}\text{C}$ and $T_{\beta}-60^{\circ}\text{C}$, the strength decline trend is most obvious. After the temperature is lower than $T_{\beta}-60^{\circ}\text{C}$, the strength dropped slowly.

Table 2 Tensile properties at 400°C of TC4 titanium alloy treated by different heat treatments

No.	Rm/ MPa	Rp0.2/ MPa	A/ %	Z/ %
1#	805	681	14.0	62.8
2#	798	671	15.0	63.8
3#	777	645	17.5	65.1
4#	747	619	15.5	63.8
5#	730	602	17.0	64.2
6#	703	575	16.5	62.9
7#	700	569	17.0	62.4
8#	685	555	17.0	59.9
9#	687	543	16	59.3
10#	682	502	20	57

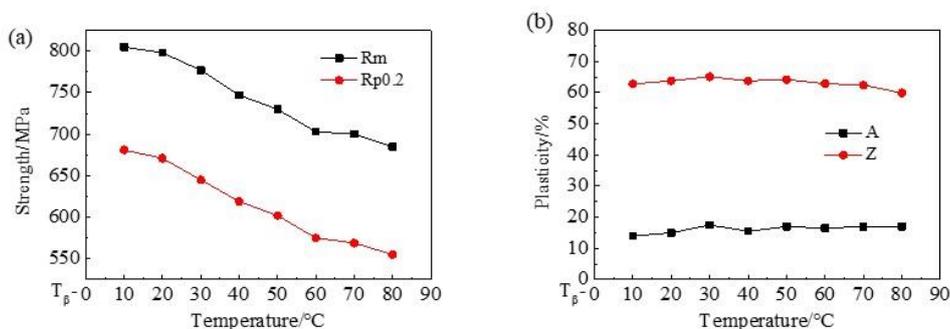


Fig.5 Tensile properties on 400°C of TC4 titanium alloy treated by different heat treatments: (a) Strength; (b) plasticity

4 Discussion

Analysis of tensile strength at 400 °C by combining different primary α contents of samples (see Fig. 5), it can be found that the tensile strength of TC4 titanium alloy gradually decreases with the increase of the content of primary α . When the content of primary α is more than 50%, the decreasing trend of strength is gradually slowed down. The properties of a α - β titanium alloy are related to the chemical composition of the alloy and many other factors (chemical composition of the phase and its stability, volume fraction of the phase and its strength ratio, and microscopic morphology of the phase) [11-13]. As the solid solution temperature is higher, the less the primary α phase, the more the transformed β phase. The volume of the transformed β phase increases, and in the case where the thickness of the α -sheet is substantially close, the interface between the α -sheets increases, resulting in difficulty in sliding, resulting in an increase in strength. With the increase of cooling rate, the tensile strength and yield strength at 400 °C of TC4 titanium alloy are increasing. This is mainly because the faster the cooling rate after solution treatment, the more the small and narrow supercooled β phase (Martensite α') that is too late to undergo an equilibrium transition. Since the interior of the martensite α' contains a large number of dislocations, as the content of martensite increases, the strength increases and the plasticity decreases. In addition, when the solid solution temperature is the same as $T_{\beta}-50^{\circ}\text{C}$, the slower the cooling rate, the more the secondary α phase is precipitated in the transformed β phase. When the cooling rate is slow to a certain extent, the secondary α phase will spheroidize [14-15]. Thereby reducing the strength of the alloy.

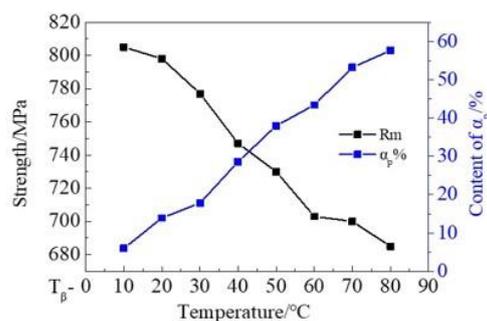


Fig.6 Relationship between tensile strength and primary α contents

5 Conclusion

1) Below the phase transition point, with the increase of solid solution temperature, the content of primary α phase of TC4 titanium alloy decreased gradually, and the content of β -transformed phase increased significantly. As the cooling rate increases, the martensite α' content increases, and the primary α and the secondary α are connected together after furnace cooling.

2) Below the phase transition point, as the solution temperature increases, the tensile strength at 400°C of TC4 titanium alloy increases a, and the plasticity changes little; as the cooling rate increases, the strength of the material increases, the difference of plasticity is also not obvious.

References

- [1] Huang Xu, Zhu Zhishou, Wang Honghong. Advanced Aeronautical Titanium Alloy and Applications [M]. Beijing: National Defense Industry Press, 2012: 47.
- [2] Zhou Lian. Rare Metal Materials and Engineering [J], 2003, 32(8): 577-584.
- [3] Huang Zhanghong, Qu Henglei, Deng Chao, et al. Material Review[J], 2011, 25(1): 102-107.
- [4] Boyer R R. Materials Science and Engineering [J], 1996, A213(1): 103-114.
- [5] Zhu Zhishou, Wang Xinnan, Tong Lu, et al. Material China[J], 2010, 29(5): 14-17.
- [6] Zhao Yongqing. Material China [J], 2014, 33(7): 398-404.
- [7] Ding R, Guo Z X, Wilson A et al. Mater Sci Eng A[J], 2002, 327(2): 233.
- [8] Seshacaryulu T, Medeiros S C, Morgan J T et al. Mater Sci Eng A[J], 2000, 279: 289.
- [9] Liu Wanying, Zhu Yike, Shi Taihe et al. Hot Working Technology[J], 2013, 42(18): 141.
- [10] Niinomi M, Kobayashi T. Mater Sci Eng[J], 1988, 100: 45.
- [11] Ankem S, Margolin H. Metall Trans A[J], 1986, 17(12): 2209.
- [12] Movchan B A, Lemkey F D. Mater Sci Eng A[J], 1997, 224: 36.
- [13] Ankem S. Thesis for Doctorate[D]. New York: Polytechnic Institute of New York, 1980.
- [14] Zhang Yaowu, Zeng Weidong, Shi Chunling et al. The Chinese Journal of Nonferrous Metals [J], 2011, 21(11): 2781.