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Effects of Cryogenic Treatment on the Thermal Physical Properties of TC4 Titanium Alloy

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Abstract: A cryogenic treatment test was carried on TC4 titanium alloy, and the effects of cryogenic treatment on the thermal physical properties of TC4 titanium under the temperature range of 25~600 °C were investigated through comparing the variation of the thermal conductivity and thermal expansion coefficient of the alloy before and after cryogenic treatment. The results show that the thermal conductivity of the cryogenic treated alloy is first less and then greater than that of the untreated alloy, however, its thermal expansion coefficient is first greater and then less than that of the untreated alloy with the increase of temperature. When the temperature is up to 600 °C, the thermal conductivity and thermal expansion coefficient of the cryogenic treated alloy are 7.24 $W \cdot m^{-1} \cdot K^{-1}$ and 11.71 × 10^{-6} $°C^{-1}$, and increased and decreased by 3.18% and 1.65% than that of the untreated alloy at the same temperature, respectively.

Key words: TC4 titanium alloy, cryogenic treatment, thermal conductivity, thermal expansion coefficient.

1. Introduction

TC4 titanium alloy attracts widely attention of some relative investigators as an important structural material, which was applied in aerospace and other fields [1-3]. With the increase of working temperature, it is practically important to study how to improve the heat stability of TC4 titanium alloy. Cryogenic treatment can improve the properties of metal materials and stabilize the size of the work piece [4, 5]. Currently, the applied researches about cryogenic treatment mainly focus on steel, hard alloy, aluminum alloy, copper alloy and etc. [6-8], while less on Titanium alloy. The thermal physical properties of metal materials influence components' size and mechanical properties under the condition of high temperature. In this study the thermal conductivity and thermal expansion coefficient of TC4 titanium alloy before and after cryogenic treatment are measured at the temperature range of 25 °C to 600 °C. The effect of the cryogenic treatment on the thermal physical properties of TC4 titanium alloy was also discussed. These results provide some reference data to the research and application of the cryogenic treatment to Titanium alloy.

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2. Experiments

The experimental material was as-annealed TC4 titanium alloy bar, which main chemical constituents (at.%) was 89.57Ti, 6.17Al, 3.84V, 0.25Fe, 0.17others. Doing cryogenic treatment on the as-annealed bar, the process system was that the samples were heated to 950 °C for 20 min, and then the samples were immersed in liquid nitrogen (-196 °C) for 30 min. The samples before and after cryogenic treatment were cut into φ 6 mm × 1.5 mm size specimens. From 25 °C to 600 °C, the thermal diffusion coefficient was measured by a TC-7000 thermal constant measurement test instrument with precision of ±7% and the heat capacity was measured by a STA449C thermal analysis instrument. According to the equation [9]: $\lambda = 100\alpha \cdot \rho \cdot Cp$, the thermal conductivity can be figured out. In the equation, λ was the thermal conductivity ($w \cdot m^{-1} \cdot K^{-1}$), α was the thermal diffusion coefficient ($cm^2 \cdot s^{-1}$), ρ was the density ($g \cdot cm^{-3}$), Cp was the heat capacity ($J \cdot g^{-1} \cdot K^{-1}$). From 25 °C to 900 °C, the thermal expansion coefficient of the alloy was measured by DIL402C tester with precision of ±3%, the specimen size was φ 6 mm × 25 mm referring to Al_2O_3. The structure character of the TC4 titanium alloy before and after cryogenic treatment was analyzed by Axiovert200MAT optical microscope and JEM-2010 transmission electron microscope.

3. Results and Discussion

3.1 Microstructure

Fig. 1 shows the microstructures of the TC4 titanium alloy before and after cryogenic treatment. It is seen that the original alloy structure consists of primary equiaxed crystal α and intergranular crystal β, and that the structure after cryogenic treatment consists of phases α and α′ which are unfused and massive. The TEM analysis (Fig. 2) shows that, the main component in the groundmass of the original alloy is thick primary phase α, while in the alloy after cryogenic treatment, there is plenty of needle phrase α′, and the size of primary phase α is smaller, the grain-boundary density is increasing obviously, and the amount of dislocations in the crystal grain is also increasing.

3.2 Thermal Properties

Fig. 3 shows the changing curves of the thermal conductivity of the TC4 titanium alloy with temperature before and after cryogenic treatment. It can be seen that, from 25 °C to 600 °C, with the temperature's increasing, the thermal conductivity of the alloy after cryogenic treated is less at the beginning and greater after comparing with the original alloy. At 100 °C, the thermal conductivity of the alloy after cryogenic treatment is 7.21 $W \cdot m^{-1} \cdot K^{-1}$, decreasing by 2.22% than that of the original alloy at the same temperature. But at 600 °C, the thermal conductivity of the alloy is 7.24 $W \cdot m^{-1} \cdot K^{-1}$ after cryogenic treatment increasing by 3.18% than the that of the original alloy at the same temperature.

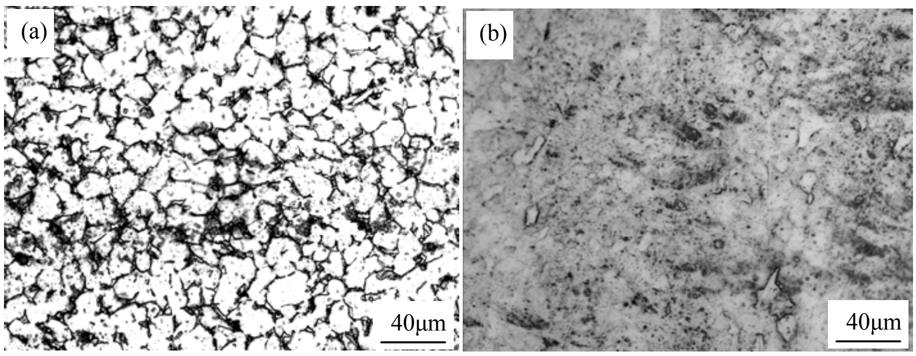

Fig. 1 Microstructure of TC4 titanium alloy: (a) original; (b) cryogenic treatment.

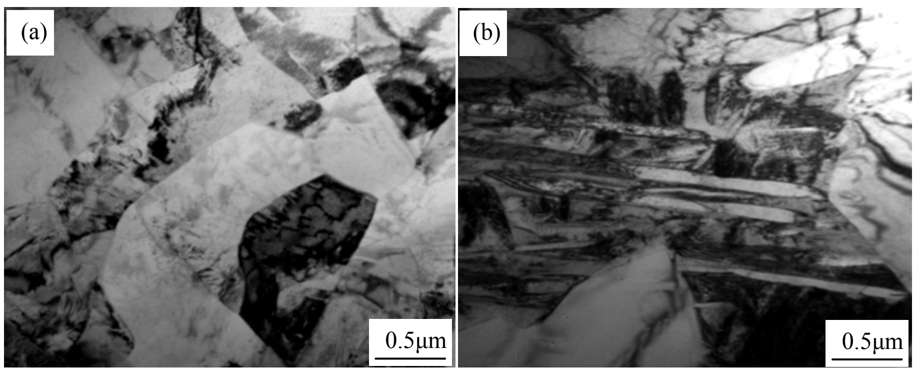

Fig. 2 TEM images of TC4 titanium alloy: (a) original; (b) cryogenic treatment.

There is needle phrase α′ in the TC4 titanium alloy after cryogenic treatment causing the increase of the grain-boundary density, and at the same time due to volume shrinkage there are stress, attice distortion and dislocations, so it increases the scattering process of electronic and the resistance to move [10, 11], decreases the thermal properties of the alloy. Furthermore, the original alloy structure consists of phrases α and β, and the structure after cryogenic treatment consists of phases α and α′ which both are hexagonal close packed lattice, while phase β is body-centered cubic lattice. Diffusion coefficient in phase β is bigger than in α because of the smaller lattice density, so at the cold condition, the thermal property of TC4 titanium alloy after cryogenic treatment is worse than that before cryogenic treatment. With the increase of temperature, the stress and dislocation due to cryogenic treatment are removed, the scattering effect of electronic is decreased, the thermal resistance of materials is decreased, and the unstable phase α′ is resolved to promote the atomics' diffusion and the alloy's thermal property. On the other hand, because pores of the material inside deteriorate the thermal properties of the material [12], the volume of the TC4 titanium alloy shrinks during cryogenic treatment, deducing some pores close, reducing pore content in the materials and improving the thermal property. Thus, the thermal conductivity of the TC4 titanium alloy after cryogenic treatment can be increased when the temperature reaches a certain value.

3.3 Thermal Expansion

Fig. 3 shows the relationship curves between the thermal expansion coefficients of the TC4 titanium alloy before and after cryogenic treatment with heating temperature. It can be seen that, in the range of 25 °C to 600 °C, the variation trends of the thermal expansion coefficient and length of the two kinds of states are the same. With the increase of temperature, the thermal diffusion coefficient of the alloy after cryogenic treatment first is higher than the alloy before cryogenic treatment and then lower. At 100 °C and 600 °C, the thermal diffusion coefficients of the TC4 titanium alloy after cryogenic treatment are 8.19 × 10^{-6} °C^{1} and 11.71 × 10^{-6} °C^{-1} respectively, and compared to the alloy before cryogenic treatment, the former increases 2.63% while the latter decreases 1.65%.

Because there are plenty of dislocations and vacancies in phase α′ in the TC4 titanium alloy after cryogenic treatment, which weakens the cohesion between atoms [13], the alloy is easy to expend when heated. With the increase of temperature, phase α′ will be resolved and the concentration of dislocations and vacancies will be decreased. There is no phase α′ in the TC4 titanium alloy before cryogenic treatment. It

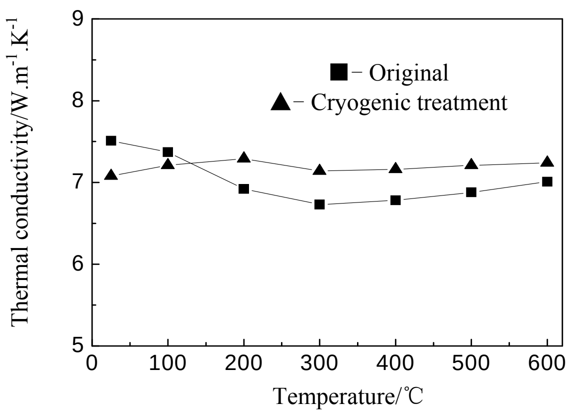

Fig. 3 Relationship between the temperature and the thermal conductivity of TC4 titanium alloy.

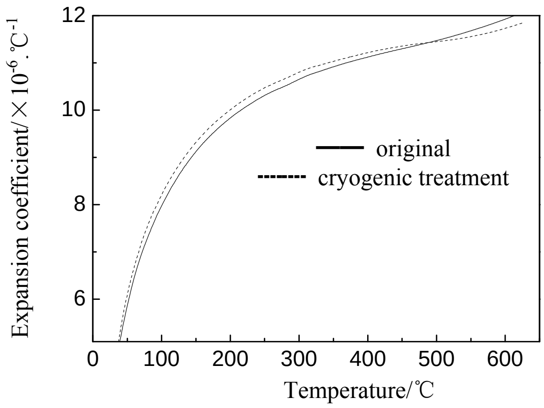

Fig. 4 The expansion curves of TC4 titanium alloy.

may be the main reason of Fig.4 in which the thermal diffusion coefficient of the TC4 titanium alloy before and after cryogenic treatment changes when heated.

4. Conclusions

(1) In the range of 25 °C to 600 °C, thermal conductivity of the TC4 titanium alloy after cryogenic treatment first is lower than the alloy before cryogenic treatment and then higher, while thermal expansion coefficient is on the contrary. But cryogenic treatment does not change the change trend of the t thermal expansion coefficients with heating temperature.

(2) At 100 °C, the thermal conductivity and the thermal expansion coefficient of the alloy after cryogenic treatment are 7.21 $W \cdot m^{-1} \cdot K^{-1}$ and 8.21 × 10^{-6} $°C^{-1}$ respectively, compared to the alloy before cryogenic treatment, the former decreases 2.22% while the latter increases 2.63%. At 600 °C, the thermal conductivity and the thermal expansion coefficient of the alloy after cryogenic treatment are 7.24 $W \cdot m^{-1} \cdot K^{-1}$ and 11.732 × 10^{-6} $°C^{-1}$ respectively, compared to the alloy before cryogenic treatment, the former increases 3.18% while the latter decreases 1.65%.

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