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Tensile and creep properties of Ti-600 alloy

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Abstract: Ti-600 is one of the high performance titanium alloys used at 600 ℃, which was developed in Northwest Institute for Nonferrous Metal Research (NIN) in China. The tensile and creep properties of Ti-600 alloy with different thermal treatment conditions were investigated. The results indicate that Ti-600 alloy possesses favorite comprehensive properties solution-treated at 1 020 ℃ for 1 h, then air-cool, and aged at 650 ℃ for 8 h, finally air-cooling, especially possesses quite good creep resistance. The residual deformation is less than 0.1% for the alloy exposed at 600 ℃ for 100 h with the stress of 150 MPa, and the bimodal microstructures of the alloy are almost the same as that of the alloy treated by duplex thermal treatment, only needle primary α phases became relatively thicker and coarsened. The ultimate strength and the elongation of the alloy tested at ambient temperature are 1 080 MPa and 12%, respectively; while at 600 ℃, they are 690 MPa and 16%, respectively. The ductility of the alloy tested at room temperature is no less than 5% after thermal exposing at 600 ℃ for 100 h.

Key words: Ti-600 alloy; high temperature titanium alloy; tensile property; creep resistance

1 Introduction

Titanium and titanium alloys, with the combination of high strength-to-mass ratio, excellent mechanical properties, and corrosion resistance, have found many critical applications in aerospace, energy, and chemical industries, etc[1−7]. More and more Ti alloys are used for static and rotating gas turbine engine components, most of which were used at severe environments[4,7].

The most widely used Ti alloy is Ti-6Al-4V alpha-beta alloy, and its application temperature is normally below 400 ℃. Owing to the requirements for the aerospace industry for increased performances and higher using temperatures, new types of advanced Ti alloys are under development[1−7], including high temperature Ti alloys, high strength Ti alloys, corrosion resistant Ti alloys, Ti alloys used for shipbuilding, functional Ti alloys and medical Ti alloys. And the development of high temperature Ti alloys has contributed significantly to the spectacular progress in thrust-to-mass ratio of the aero gas turbines. When considering the phase equilibrium and microstructure stability, the use of conventional titanium alloys have restricted to below 600 ℃. Titanium alloys, when exposed in air at elevated temperatures, normally when higher than 500 ℃, readily absorb oxygen leading to alpha-case formation which has been shown to severely limit the high-temperature capability of alloys in terms of mechanical properties[8]. So, the application threshold temperature for titanium alloys is 600 ℃ at present.

Several kinds of high performance titanium alloys, e.g. Ti-1100, IMI834, BT36 and Ti-600, etc, have been developed and many have found practical applications at 600 ℃ for long period[7, 9−11]. A near α type titanium alloy, Ti-600 (Ti-A1-Sn-Zr-Mo-Si＋Y) was exploited by Northwest Institute for Nonferrous Metal Research in China[10−11]. In the present work, tensile properties at ambient temperature and at 600 ℃, and creep properties at 600℃ of Ti-600 alloy was investigated.

2 Experimental procedure

A 200 kg ingot was produced by electrode consumption

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vacuum arc furnace. The α/β transition temperature for the alloy is about 1 010 ℃. The ingot was conventionally forged to produce diameter 35 mm bars. The forging was then rolled to diameter 14 mm bar at temperatures below 1 000 ℃. The relatively low temperature range for rolling was selected to obtain fine grains. The tensile and creep samples were cut from the rolling bars and solution treated from 995 ℃ to 1 060 ℃, and then aged at 650 ℃ for 8 h, air cooling.

The gauge diameter of the tensile and creep specimens was both 5 mm, and the gauge length for them was 25 mm and 48 mm, respectively. The creep experiments were made on KD-2 apparatus, and the specimens were exposed at 600 ℃ for 100 h with the stress of 150 MPa. Microstructures of the alloy were observed using Olympus PMG3 optical microscope and JSM 6460 scanning electron microscope, respectively.

3 Results and discussion

3.1 Tensile and creep properties of Ti-600 alloy

Table 1 shows the tensile properties of Ti-600 alloy tested at three temperatures (ambient temperature, 600 ℃ and 650 ℃). From Table 1, it can be seen that after appropriate thermal treatment, the alloy possesses favorite tensile strength and elongation. The ultimate strength for the alloy tested at ambient temperature is almost the same for the alloy solution treated whether below or above the β transus temperature. The yield strength, elongation and reduction of area all have the same variation tendency as the ultimate strength for the alloy tested at ambient temperature. While at 600 ℃ and 650 ℃, the alloy still possesses good mechanical properties. The ultimate strength for the alloy is 690 MPa and 665 MPa, respectively. From the results, it can be seen that the alloy can be easily used at 600 ℃ with quite favorite combination of tensile strength and elongation.

Nowadays, more and more attention has been put on the high temperature creep property of conventional high temperature titanium alloys[1,4]. Table 2 shows the thermal stability and creep properties of Ti-600 alloy at 600 ℃. The results indicate that the alloy possesses quite good thermal stability property and creep resistance. After exposed at 600 ℃ for 100 h, the elongation for the alloy tested at ambient temperature is not less than 5%, which makes the alloy can be easily found practical engineering application. After exposed at 600 ℃ for 100 h with the stress of 150 MPa, the residual deformation is not excess 0.1% for the alloy thermal treated at the five conditions mentioned in this paper. The best creep resistance can be got for the alloy solution treated with the highest temperature (1 060 ℃), which is only 0.068%.

3.2 Microstructure of Ti-600 alloy

The relationships between microstructures and mechanical properties have been studied extensively. The morphologies of Ti-600 bars treated by duplex treatment

Table 1 Tensile properties of Ti-600 alloy at different testing temperatures

Testing temperature/℃	Treatment condition	Ultimate tensile strength/MPa	Yield strength/MPa	Elongation/%	Reduction area/%
RT	800 ℃, 1 h, AC	1 030	955	13	34.0
	1 008 ℃, 2 h, AC+aging	1 070	965	14	25.0
	1 020 ℃, 1 h, AC+ aging	1 080	985	12	23.0
	1 060 ℃, 1 h, AC+ aging	1 070	995	12	14.5
600	1 020 ℃, 1 h, AC+ aging	690	565	16	37.0
650	1 020 ℃, 2 h, AC+ aging	665	535	19	47.0

Aging condition: 650 ℃/8 h, air cooling.

Table 2 Thermal stability and creep property of Ti-600 alloy treated under different conditions

Condition	Thermal stability 1)			$\varepsilon_{residual}$ 2)/%
	Ultimate tensile strength/MPa	Elongation/%	Reduction area/%	
995 ℃/2 h AC+aging	1 180	8	14	0.099
1 005 ℃/2 h AC+aging	1 150	7.5	12	0.085
1 020 ℃/1 h AC+aging	1 090	6.0	13	0.081
1 020 ℃/2 h AC+aging	1 070	8.5	17	0.072
1 060 ℃/1 h AC+aging	1 150	5	9	0.068

1) Specimens were exposed at 600 ℃ for 100 h, then the tensile tests were made at ambient temperature; 2) Specimens were creep exposed at 600 ℃ for 100 h with stress of 150 MPa; Aging condition is 650 ℃, 8 h, air cooling.

were investigated, as shown in Fig.1. When solution treated below the β transus temperature (i.e. 1 008 ℃), bimodal microstructure can be got for the alloy, and very fine needle primary α can be found, as shown in Fig.1(a). When the solution treatment temperature increases to above the β transus temperature (i.e. 1 020 ℃), evenly distributed needle α can be found in the alloy, and the microstructure for the alloy is needle primary α and fine lamellar α plus β, as shown in Fig.1(b). The relatively thicker needle primary α can be found in Fig.1(b), the reason is that the origin β grains are bigger when the alloy solution treated at 1 020 ℃.

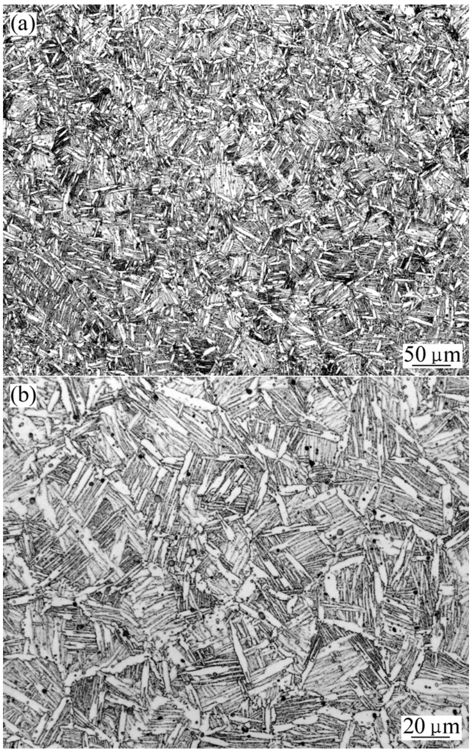

Fig.1 Microstructures of Ti-600 alloy bars treated at different condition: (a) Solution treated at 1 008 ℃ for 2 h, AC, then aged at 650 ℃ for 8 h, AC; (b) Solution treated at 1 020 ℃ for 1 h, AC, then aged at 650 ℃ for 8 h, AC

Fig.2 shows the microstructures of the alloy after creep experiment. The morphologies of the alloy are almost the same as that of the alloy only treated by duplex treatment, no essence difference between them. The short primary α grains grows up, which is benefit to the creep properties.

As compressor disc and blade for high ratio aero-engines, higher creep resistance are required for high temperature Ti alloys used at 600 ℃. Creep resistance has great relation with the volume fraction of β transus phases. Better creep property can be got with more and more lamellar phases. The best creep resistance can be got with 100% β transus microstructure in theory. But the thermal stability has the reverse tendency with creep resistance, which means, the plasticity will decrease with the increase of lamellar phases for the alloy exposed at 600 ℃ for 100 h. The ductility and the thermal stability would be improved abruptly for the alloy with a certain amount of primary α phases.

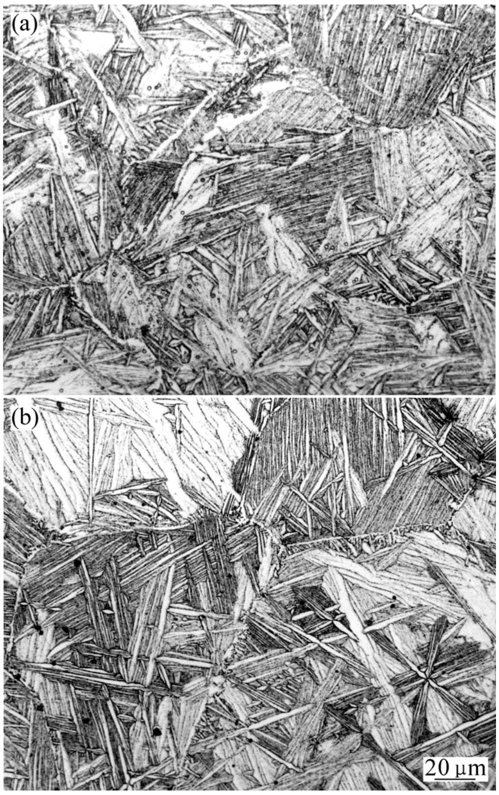

Fig.2 Microstructures of Ti-600 alloy after creep experiments: (a) Solution treated at 1 020 ℃ for 1 h, AC, then aged at 650 ℃ for 8 h, AC; (b) Solution treated at 1 060 ℃ for 1 h, AC, then aged at 650 ℃ for 8 h, AC

Ti-600 alloy was solution treated at 1 020 ℃ (former) and 1 060 ℃ (latter), respectively, and then the creep experiments were made, their microstructures are shown in Fig.2. The origin β grains of the alloy in Fig.2(b) are bigger that of in Fig.2(a), the secondary α phases precipitated from the β transus phases are also coarsened. As shown in Table 2, the creep resistance for the former is not as good as the latter. Transgranular strength and grain boundary strength will both decrease at high temperature, but the strength decreased faster at the grain boundary, the transgranular strength has the main effect on the alloy. The creep resistance will be much better with coarse phases, for the relative slip of boundary phases are weakened. But, the ductility for the former is better, as shown in Table 1. Since small quantities of element yttrium has been added into the Ti-600 alloy, fine grains can be found in the microstructures of the alloy, as shown in Fig.1 and Fig.2. So, the ductility and the thermal stability for the alloy are improved, and at the same time, the high temperature instant strength and the creep rupture strength are also enhanced.

In a word, the alloy possess favorite comprehensive properties (an optimal combination of ductility at ambient temperature and at 600 ℃, thermal stability and creep property) when solution treated at 1 020 ℃.

4 Conclusions

1) Ti-600 alloy possess favorite comprehensive properties solution treated at 1 020 ℃ for 1 h, air cooling, then aged at 650 ℃ for 8 h, air cooling.

2) The ultimate strength and elongation of the alloy at ambient temperature are 1 080 MPa and 12%, respectively; while at 600 ℃, they are 690 MPa and 16%, respectively.

3) The residual deformation is 0.081% for the alloy exposed at 600 ℃ for 100 h with the stress of 150 MPa.

4) The ductility for the alloy exposed at 600 ℃ for 100 h is no less than 5%.

5) The morphologies of the alloy creep ruptured at 600 ℃ for 100 h with the stress of 150 MPa are almost the same as that of the alloy only treated by duplex treatment, only primary α phases are coarsened.

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