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Effect of aging on the tensile properties and microstructures of a near-alpha titanium alloy

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ABSTRACT

The effect of aging temperature between 650 °C and 750 °C for different aging times on the tensile properties and microstructures of Ti60 alloy were studied. The results show that the strength of the alloy increases first and then decreases with the aging temperature increases from 650 °C to 750 °C. The reduction of area of the alloy is more sensitive to the aging time than elongation. With increasing aging temperature and time, the volume fracture and grain size of silicides and α_2 phase increase gradually. The silicides have the strengthen effect on the Ti60 alloy, but the effect weakens when the silicides grow up. The loss of ductility is mainly attributed to the precipitation of α_2 phase after aging treatment.

1. Introduction

With the requirement of aircraft construction integrity, reliability and durability, near-α titanium alloy which can be serviced at 600 °C, have been explored competitively all over the world [1]. The characteristic of this kind of alloy is the addition of the silicon to improve the high-temperature tensile and creep properties. The superiority of the alloys is most pronounced in the solution-treated and aged (STA) condition with a precipitation hardened microstructure. However, the practical application of these alloys has been limited by their ductility. A few possibilities have been proposed for the loss of ductility in these alloy systems including the precipitation of intermetallic phases (Ti_3Al) and silicides, and formation of the oxides on the surface of the alloy [2–4]. Donlon et al. [5] pointed out that the α_2 (Ti_3Al) precipitates significantly decrease the ductility of titanium alloys, and this effect is further exacerbated by the precipitation of silicides. Cai et al. [6] also found that α_2 phase can decrease the ductility of TG6 titanium alloy. Neal and Fox [7] have shown that reduction in ductility of IMI834 alloy is essentially due to silicides. Several investigations have shown that the oxidation layer can modify the mechanical properties of titanium alloy due to the formation of surface cracks [3,6,8]. Meanwhile, a large amount of reports indicated that the mechanical properties of the titanium alloy are strongly influenced by the volume fraction, grain size, morphology and distribution of the precipitation which in turn depends on the composition, hot working processing and heat treatment of the alloy [9,10].

Ti60 alloy, the alloy of present investigation, is a new high-temperature titanium alloy developed in China. It belongs to Ti–Al–Sn–Zr–Mo–Si series titanium alloy, which is similar to IMI834 alloy. Compared with IMI834 alloy, more silicon element is added to improve its creep performance at high temperature. In addition, a small amount of tantalum and carbon elements are added in the alloy to improve its heat-resistant and widen the processing window, respectively [11]. Several investigations have been performed to characterize the constitutive relationship, the hot deformation behavior and the heat treatment of Ti60 alloy [12–14]. Our previous researches found that two instable processing fields should be avoided due to the flow localization during the hot deformation of Ti60 alloy [13]. Cai et al. [15] have researched the effect of solution treatment on the creep properties of Ti60 alloy forged in the (α + β) phase field. The results showed that the excellent creep properties were obtained for the specimens with lamellar structure which obtained by solution treated above the β transus following air cooling. Meanwhile, for the specimen solution treated under the β transus, the primary α phase decreases with increasing of solution temperature which can improve the creep properties of the alloy with equiaxed structure. Hao et al. [16] have researched the influence of aging on the creep properties of Ti60 alloy. They found that the aging temperature of the alloy should be in the range of 740–760 °C to improve its creep properties. The aging time cannot exceed 2 h at 750 °C because the long

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time aging will results in the precipitation of silicides, and thus the content of Si in the solution state is decreased, then the creep properties is decreased. Wang et al. [17] have investigated the influence of forging processes on microstructure and mechanical properties of Ti60 alloy. The results indicated that the bimodal microstructure was obtained after near-β forging which have excellent properties.

The heat treatment variables are time and temperature of solution treatment, cooling rate, and aging temperature and time. The present paper is concerned with the influence of aging temperature and time on the microstructure and properties of Ti60 alloy. This work is part of a wider study being carried out with the aim of developing thermal and thermo-mechanical treatments for optimum mechanical properties in the high temperature titanium alloy Ti60.

2. Experimental details

Ti60 alloy used in the present work was received in bar form with a diameter of 270 mm. Its chemical composition is presented in Table 1. The β transus temperature (T_β) of the alloy was identified as 1050 °C using metallographic analysis method by the heating test, in which four specimens with the same size of Φ10 mm × 10 mm were heated at 1040, 1045, 1050 and 1055 °C, held for 40 min and then quenched immediately, respectively, and consequently the volume fraction of α phase of the specimen heated at 1050 °C was nearly disappeared. To obtain the desired microstructure, the as-received Ti60 alloy bar had been subjected to a large number of hot forging which is carried out through open die forging in the α + β region, with sequential deformations in lengthwise and radial directions. This process was repeated for three times, with reheating stages in between. Finally, a homogenous bimodal microstructure was obtained which consisted of equiaxed α phase within a fine transformed β matrix, as shown in Fig. 1.

Different heat treatments were given to the material, as shown in Table 2. First, all the specimens were solution treated (ST) at 1010 °C for 2 h following oil cooling (OC), and then the specimens were aged at 650 °C, 700 °C and 750 °C for different times, separately. Cylindrical tensile specimens with a gauge length of 25 mm and a diameter of 5 mm were employed. The tensile tests were conducted per ISO 6892 standard [18]. The properties results were the mean values obtained from three tested specimens. Microstructures of the specimens were analyzed by an optical microscope (OM) Leica DFC320. TEM specimens with a thickness of 0.3 mm were prepared by cutting in the tensile specimens and mechanically thinned to 40–50 μm in thickness. After jet polishing by a double-jet polisher at −30 °C, specimens were observed in HITACHI H-800 transmission electron microscope at 175 kV.

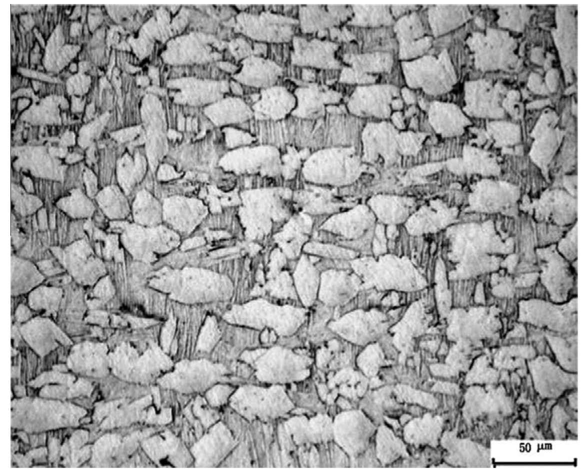

Fig. 1. Initial microstructure of Ti60 alloy.

Table 2
Heat treatment given to Ti60 alloy.

Solution treatment (°C)	Aging temperature (°C)	Aging time (h)	Cooling way
1010	650	0/2/4/8/16	Air cooling
	700	0/2/4/8/16/24/48	
	750	0/2/4/8/16	

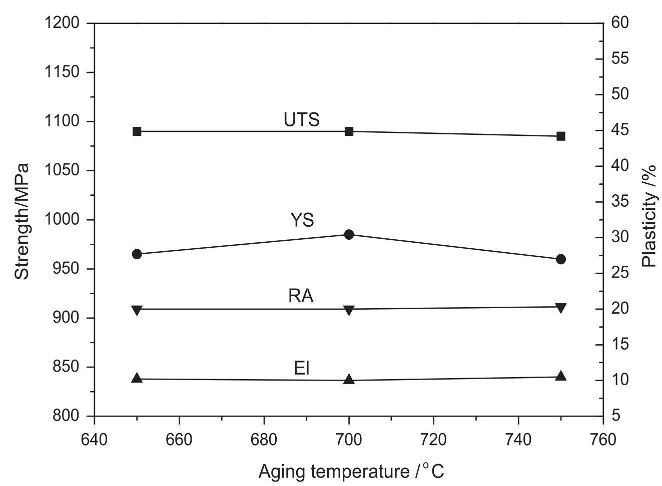

Fig. 2. Effect of aging temperature on the tensile properties of Ti60 alloy.

3. Results

3.1. Tensile properties

The room-temperature tensile properties of Ti60 alloy after aging at 650 °C, 700 °C and 750 °C for 2 h are shown in Fig. 2. It can be seen that the reduction of area (RA) and elongation (El) of the specimens have a little change with increasing aging temperature. It is suggested that the ductility of the alloy is not sensitive to the aging temperature under the condition of short aging time. The yielding strength of the alloy increases when the aging temperature increasing from 650 °C to 700 °C. However, when the aging temperature increases to 750 °C, the yielding strength decreases obviously and the value even lower than that of specimens aged at 650 °C. The results suggested that the change of internal microstructures may make the alloy strengthened with increasing the aging temperature, but the strengthening effect decreases with the aging temperature further increasing.

Fig. 3 shows the tensile properties of Ti60 alloy after aging at 650 °C, 700 °C and 750 °C for different times. Compared with the specimens without aging, the strength increases slightly while the ductility decreases obviously for all the specimens after aging for 2 h, especially the decreases of RA is more pronounced than that of elongation. It is suggested that the RA is more sensitive to the aging time than the El of the alloy. The RA decreases gradually

Table 1
Chemical composition of Ti60 alloy (wt%).

Al	Sn	Zr	Mo	Nb	Ta	Si	C	Ti
5.8	4.0	3.5	0.4	0.4	1.0	0.4	0.06	Balance