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Tensile and creep properties of thermomechanically processed boron modified Timetal 834 titanium alloy

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ABSTRACT

The effect of addition of 0.2 wt.% B on the tensile and creep properties of Timetal 834 alloy was studied in the thermomechanically processed condition after subjecting it to different heat treatments. The 0.2% YS and UTS of the boron modified alloy was found to be higher than that of the base alloy irrespective of the heat treatment employed. The creep strain for 100 h as well as the steady state creep rate at a temperature of 600 °C and initial stress of 150 MPa stress was also significantly lower for the B modified alloy. The results were explained on the basis of load sharing by the TiB whiskers.

1. Introduction

Boron (B) modified titanium alloys containing B < 1.5 wt.% B have attracted considerable interest in recent years because of their increased strength with comparable or marginally better ductility, superior fatigue resistance as well as higher wear resistance as compared to the matrix alloys [1–9]. Most of these studies have been carried out on induction skull melted ingots in the as-cast condition [1–5] or using the powder metallurgy route [6–8]. However, most conventional titanium alloys for aeronautical applications are processed using vacuum arc melting route followed by high temperature forging and rolling. Thus the processing of boron modified titanium alloys by the above route assumes considerable significance given that this route is well established, inexpensive and offers potential for scale-up. In a recent study, Chandravanshi et al. [9] have investigated the effect of minor addition of B on the tensile properties of vacuum arc melted Timetal 685 alloy in the as-cast and as-cast + heat treated condition. They observed that the addition of boron refines the as-cast microstructure of Timetal 685 alloy. However, they found that the addition of B results in only a marginal increase in yield and ultimate tensile strength at room temperature with an appreciable drop in ductility. On the other hand, Chandravanshi et al. [10] have found that addition of 0.2 wt.% B results in an increase in yield and ultimate tensile strength both at room temperature and 600 °C in Ti-1100 alloy fabricated by vacuum arc melting followed by high temperature forging and rolling. Thus it would be interesting to know if minor additions of boron have a beneficial effect in other titanium alloys in the thermomechanically processed condition.

In light of the above, the effect of minor addition of B (0.2 wt.%) on tensile and creep properties of near α Timetal 834 titanium alloy fabricated by vacuum arc melting followed by high temperature forging and rolling was investigated in the present study. Timetal 834 was chosen because it has a higher temperature capability (~600 °C) than Timetal 685 (~480 °C) and has applications in compressor disks, blades and housings in modern aeroengines [11–14].

2. Experimental procedure

Nominal chemical composition of the melted alloys is shown in Table 1. The alloys were prepared by consumable vacuum arc melting. While Ti, Al, Zr, Sn, Si, and B were added in elemental form, Mo and Nb were added as Mo/Al and Nb/Al master alloys. The raw materials were blended and compacted to 50 × 50 × 500 mm^3 rectangular compacts (each weighing 5 kg) using a 1000 ton hydraulic press. Two such compacts welded together inside the furnace, formed the electrode for primary melting, which was carried out in a water cooled copper crucible under a dynamic vacuum of 10^{-3} mbar to obtain an ingot of 110 mm diameter weighing about 10 kg. The ingots were machined to remove the contaminated layer. Further, the top and bottom portions of the ingot which were usually defective were also cut. Two primary ingots were welded for secondary melting, which yielded a 140 mm diameter ingot weighing about 20 kg. The ingot was skin machined and radiographed to locate and discard the defective portions. Beta transus tem-

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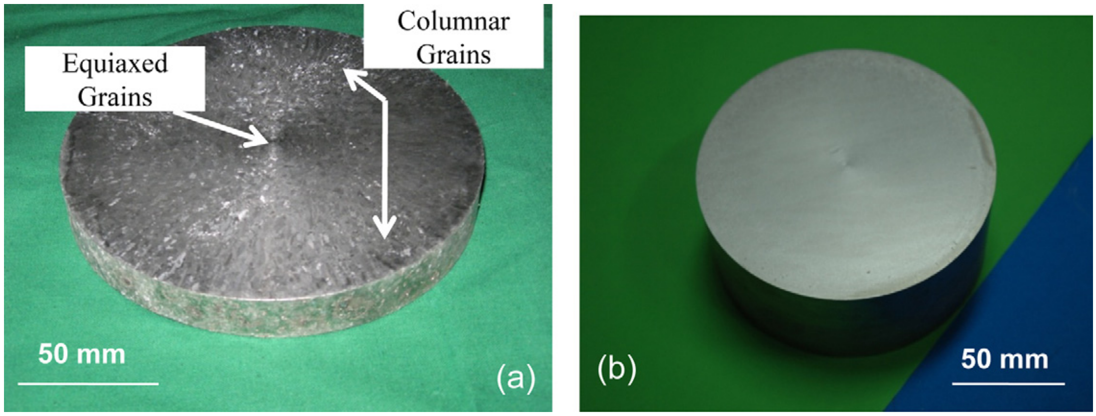

Fig. 1. Macrostructures of as-cast ingots of Timetal 834 (a) base alloy and (b) B modified alloy.

perature (β_T) of the alloys were determined by solution treating specimens in a range of temperature from (975–1105 °C) followed by oil quenching and examination of the microstructure and the β_T of the base alloy and the boron modified alloy were determined to be 1045 °C and 1075 °C, respectively. Tamiriskandala et al. [15] have reported similar increase in β_T in B modified titanium alloy.

The initial breakdown of the cast ingot is always carried out in β region because of lower forging loads, hence as-cast ingots were subsequently forged at 1100 °C to 32 mm thick billets. The ingots were subsequently rolled in the α–β region at a temperature of (β_T − 25 °C) to 16 mm thick plates. A series of heat treatments, involving solution treatment and aging, were employed for the evaluation of mechanical properties. Samples were first solutionized at 1100 °C for 2 h followed by furnace cooling to room temperature and subsequently solution treated at β_T − 100 °C, β_T − 50 °C, β_T − 20 °C and β_T + 10 °C for 2 h, oil quenched and aged at 700 °C for 2 h and air cooled.

The microstructures after heat treatment were examined using a FEI quanta 400 scanning electron microscope (SEM). Volume fraction of primary elongated α was measured using quantitative image analysis using 10 traces in each condition. The microstructure for one of the heat treatments was also examined using a transmission electron microscope (TEM, FEI Tecnai G^2) to study the effect of B addition on α—lath size. The heat treated samples were used to fabricate specimens for the tensile testing at room temperature as well as creep testing at 600 °C. High temperature creep is one of the prime requirements of near α Timetal 834 titanium alloy since the alloy is targeted for application at about 600 °C. High temperature tensile tests at 600 °C were also carried out for one solution treated condition, i.e., β_T − 20 °C. The tensile test was carried out as per ASTM standard E – 8 M [16] on a screw driven Walter + Bai Ag testing machine at a nominal strain rate of $6.7 \times 10^{-4}\ s^{-1}$. The creep tests were carried out on a constant load creep testing machine at 600 °C and initial stress of 150 MPa. During creep testing, temperature was controlled within ±2 °C.

The fracture surfaces of the tensile specimens were examined under the SEM. The dislocation sub-structure in as-tensile tested specimens was studied using a FEI Tecnai G^2 TEM. Sample preparation for TEM studied involved sectioning of thin discs from the middle portion of the gauge length of the interrupted crept specimens and near the fracture end of tensile tested specimens. The thin discs thus obtained were mechanically polished to 100 μm thickness using a SiC paper and electropolished in twin jet electropolisher (Fischione Instruments). Electropolishing was done using 5% H_2SO_4 and methanol as electrolyte at −50 °C and the voltage was maintained at 20 V.

3. Results

3.1. Macrostructure and microstructure

The macrostructures of 140 mm diameter secondary ingots of the base and B modified alloy are shown in Fig. 1. Coarse grained structure is observed in the case of base alloy Timetal 834. Two distinct regions comprising of columnar grains (at the periphery) and equiaxed grains (at the center) are visible in the case of base alloy. The average grain size of the equiaxed grains is 1190 μm. The columnar grains region is absent in the case of B modified alloy (Fig. 1b). Considerable grain refinement is also seen and the average grain size is 206 μm.

The low magnification micrograph taken from different locations of the rolled plate containing 0.2 wt.% B is shown in Fig. 2. This figure shows that the borides have a tendency of aligning themselves longitudinally along the rolling direction. Microstructures of Timetal 834 alloy under different heat treatment conditions are shown in Fig. 3. While the base alloy exhibits elongated α in a transformed β matrix in α–β heat treated condition, a fully transformed β structure is seen in β heat treated condition. The microstructural parameters including α lath thickness, volume fraction of elongated α and prior β grain size are listed in Table 2. It can also be observed that increase in the solution treatment temperature leads to decrease in the volume fraction of elongated α. Also, the prior β grain size increases with increase in solution treatment temperature whereas α lath spacing remains more or less unchanged. The microstructure of the processed 0.2 wt.% B containing Timetal 834 alloy in different heat treatment condition are shown in Fig. 4. It can be observed that the microstructures are similar to the base alloy for comparable heat treatments, other than for the presence of elongated white precipitates. The representative higher magnification SEM micrograph showing these precipitates for one of the heat treatment is given in Fig. 5. EDS analysis has confirmed that these precipitates contain Ti and B.

Table 1
Nominal chemical composition of base and B modified Timetal 834 alloy (wt.%).

Alloy/elements	Al	Sn	Zr	Mo	Nb	Si	B	O	N	C
Base	5.78	4.01	3.71	0.72	0.55	0.30	–	0.09	0.007	<0.06
Modified	5.80	3.98	3.74	0.71	0.57	0.28	0.19	0.08	0.008	<0.06