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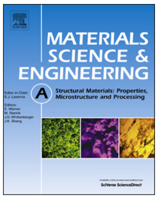

Effect of hot rolling and heat treatment on microstructure and tensile properties of high strength beta titanium alloy sheets

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ABSTRACT

Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe is a high-strength β titanium alloy that shows excellent tensile properties. This paper presents the effect of hot rolling and heat treatment on the microstructure and tensile properties of this alloy. Microstructure observation shows that the α+β rolled alloy leads to smaller β grain size than the β rolled alloy in all heat treatment conditions. Solution treatment of the alloy in the α+β field can also lead to smaller β grain than solution in the β field. Tensile results indicated that the strength of the alloy was improved greatly by aging heat treatment, which was attributed to the secondary α phase. The 790 °C rolled alloy can obtain an ultimate strength of 1744 MPa by solution at 800 °C plus aging at 440 °C. The strength decreases and ductility increases with the increase of aging temperature. Moreover, the ductility of the alloy is significantly determined by the rolling and solution procedure. Rolling and solution treated at the α+β field results in better ductility than rolling and solution at the β field. Therefore, to obtain the high ductility, the α+β rolling and α+β solution should be chosen as long as possible before aging heat treatment.

1. Introduction

β titanium alloys exhibit the highest strength-to-weight ratio of all titanium alloys [1]. The high strength can be obtained by precipitation of fine secondary α phase during aging at a lower temperature. Many high-strength β titanium alloys have been developed over the decades since the first β titanium alloy Ti–13V–11Cr–3A1 was developed and used extensively on the SR-71 “Blackbird” reconnaissance airplane [2]. Ti–10V–2Fe–3Al alloy used to be the most widely used high-strength β titanium alloy developed by Timet in 1971 [3]. In 1989, Timet developed an oxidation-resistant β titanium alloy, Ti–15Mo–2.7Nb–3Al–0.2Si, for plug and nozzle assembly for the trent 800 engine [2,3]. In the 1990s, a high-strength β titanium alloy Ti–5Al–5Mo–5V–3Cr was developed based on the Russian alloy VT22 to replace the Ti–10V–2Fe–3Al alloy on the main landing gear of a Boeing plane [4,5].

Recently, the U.S. Army has used titanium alloys on current combat vehicles [6], which have caused concern among some researchers regarding the use of the alloys in military field due to the good mechanical properties of high-strength β titanium alloys. Bartus [7] compared the ballistic performance between Ti-5553 with different heat treatment conditions and Ti–6Al–4V plates, founding that the Ti-5553 plate after solution at 827 °C and aging at 593 °C showed a higher limit velocity than the Ti–6Al–4V plate against ballistic impact and fragment simulation projectile tests. Sukumar et al. studied the ballistic impact behavior of β-CEZ in different microstructural conditions against 7.62 mm armor piercing projectiles and results show that the β-CEZ titanium alloy in as-rolled and at β solution treated and aged conditions has no significant improvement in ballistic penetration resistance compared to Ti–6Al–4V alloy [8]. In addition, β-21S mortar barrel was designed, manufactured, and tested by the U.S. Army to reduce the weight of the barrel on the 81 mm M253 mortar [9].

In general, β titanium alloys could achieve good mechanical properties by different solutions and aging heat treatments after forging or rolling, but the microstructure and mechanical pro perties are very sensitive to deformation and heat treatment [10–14]. Li et al. have studied the effect of solution temperature on microstructures and tensile properties of high-strength Ti–6Cr–5Mo–5V–4Al alloy, finding that the alloy in α/β solution and aging condition showed a better combination of strength and ductility than the alloy in β solution and aging condition [12]. Ivasishin et al. have performed a comprehensive comparison of the mechanical properties of some high strength β titanium alloys (TIMETAL-LCB, Ti-15-3, β21S, and VT22) with different conditions [13]. Santhosh et al. studied single and duplex aging of Ti–15V–3Cr–3Sn–3Al alloy, showing that the duplex aging resulted in higher hardness and strength compared to single aging treatments [14]. Although a few projects have researched

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the relationship between the processing-microstructure-property of high-strength β alloy, further research is needed.

Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5F alloy is a new high-strength β titanium alloy developed in China [15]. The moly equivalent (Mo Eq) of the alloy is 11.4, which belongs to near β titanium alloy. The alloy was reported to exhibit excellent tensile properties after forging followed by heat treatments. An excellent balance of strength (the ultimate strength is 1409 MPa) and ductility (the elongation is 16.2%) obtained by the solution at 775 °C and aged at 560 °C, and an ultrahigh strength of 1624 MPa with a moderate elongation (6.2%) can be achieved with the solution at 775 °C and aged at 440 °C. In this study, the Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe alloy sheets were first prepared. Our previous works [15] focused on the improvement of the tensile properties of the as-forged Ti–3.5Al–5Mo–6V–3Cr–2Sn––0.5Fe alloy via the heat treatment. Being different from Ref. [15], the purpose of this study is to investigate the influence of hot rolling and heat treatment on microstructure and tensile properties of Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe high-strength titanium alloy.

2. Materials and methods

The nominal composition of the alloy used in the present work is Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe, which has a β transus temperature of approximately 815 °C. The alloy was double melted by vacuum arc re-melting in a 40 kg ingot. The bottom of the ingot was cut and the surface was also machined to remove the defect parts. The ingot with a diameter of 150 mm was firstly forged down to a round bar, 80 mm in diameter. 20-mm thick rectangular materials were cut from the bar and hot rolled at 790 °C (α+β field) and 870 °C(β field) to sheets with 2-mm in thick sheets.

Samples from the as-rolled sheet alloy were solution treated at 800 °C for 1 h and 830 °C for 0.5 h respectively. The aging heat treatments were performed at a lower temperature ranging from 440 °C to 560 °C for 8 h followed by solution treatment. All of the samples were air cooled after solution and aging heat treatment. The program of solution and aging heat treatments is shown in Fig. 1.

Tensile properties of the alloy sheets along the rolling direction were tested on an Instron 5500R testing machine at room temperature. The flat tensile specimens were cut from the plate along the rolling direction with gauge length 18-mm and 2-mm thickness. The surfaces of the tensile specimens were polished with 400–2000 grid SiC paper in water. The microstructure observation of the alloy was characterized by scanning electron microscopy (SEM) on field emission gun scanning electron microscope Quanta 200FEG. The specimens for SEM analysis were polished with 400–2000 grid SiC paper in water and, then, electrolytic polished in reagent of 60% methanol, 30% butyl alcohol and 10% perchlorate.

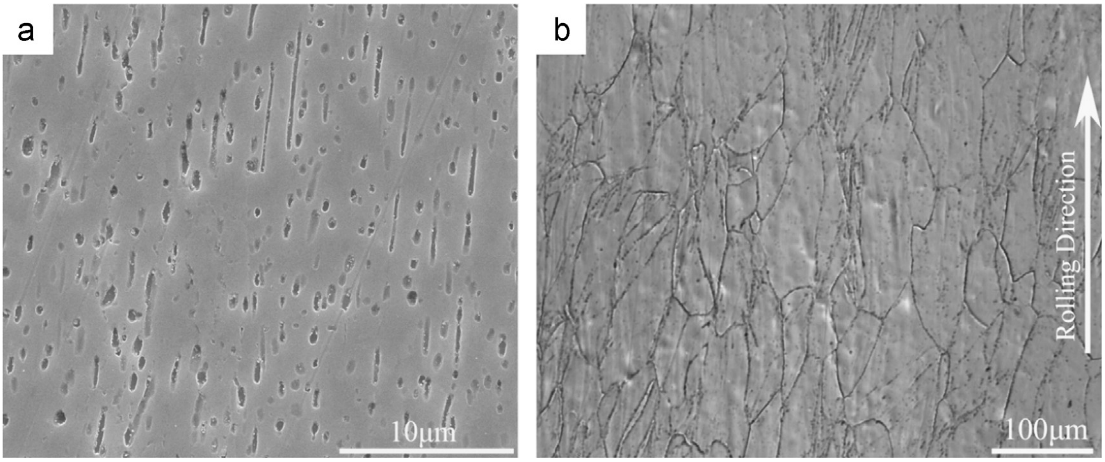

Fig. 1. Microstructure of the alloy rolling at: (a) 790 °C and (b) 870 °C.

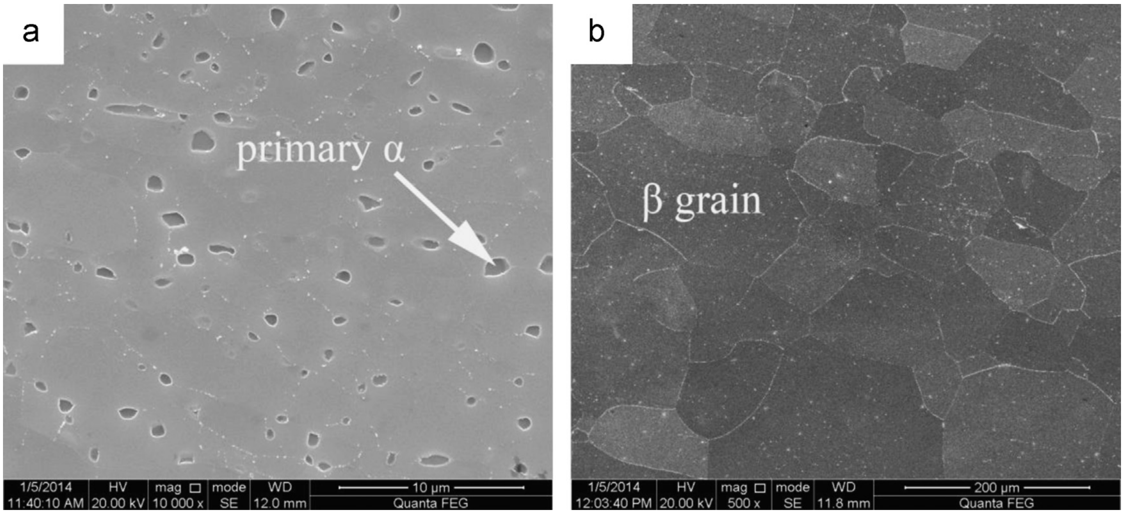

Fig. 2. Microstructure of the 790 °C rolled alloy solution treated at different temperatures: (a) 800 °C and (b) 830 °C.