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Tensile and Microstructure for One Ti Alloy Plate

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Abstract

A multi-step isothermal forging and subsequent multipass rolling was used to produce one kind of two phase titanium alloy plate with thickness of 2.2 mm. Tensile properties at ambient temperature and at two kinds of high temperatures were investigated for the plate with submicrocrystalline (SMC) structure in present work. Microstructures and fractographies of the alloy plate before and after tensile tests were also observed by scanning electron microscope. The results indicated that the alloy possesses favorite integrated tensile properties at ambient temperature, the average UTS and elongation for the longitudinal sample is 1070 MPa and 20%, while which for the transverse sample is 1103 MPa and 15%. The tensile elongation of the alloy plate is as high as 1078% at 780˚C with a primary strain rate of 1.7×10^{-3} s^{-1}. The microstructure is fine for the alloy plate solutioned at 700˚C for 1 h, AC, and the grain size after tensile test is 2 μm and 3 μm for the longitudinal and transverse plates. Fractography for the as-annealed plate is composed of a large number of dimples and voids after tensile test at ambient temperature.

Keywords

Two Phase Ti Alloy Plate, Elongation, Microstructure, Fractography

1. Introduction

The poor cold and thermoplastic deformation ability of titanium alloys hinders their processing, especially when making components with complex shape as aircraft parts, and the efficiency is not high enough [1]. In order to solve this problem, lots of special forming processes have been proposed, among which superplastic forming (SPF) is considered to be an effective one and much attention has been put on it [1] [2] [3] [4]. In recent years, SPF has been widely used on titanium alloys for higher material utilization and more complex product shape than that of conventional forming method. At present, the most widely used superplastic titanium alloy is Ti-6Al-4V alloy [4] [5], and its superplastic forming temperature is as high as 900˚C with relatively higher forming cost, higher requirements for process equipment, especially resistance of high temperature and oxidation for mould materials. The superplastic forming of Ti-6Al-4V alloy was usually carried out in inert gas for the active behavior of titanium at relatively higher forming temperature. Oxide coating on the formed parts surface should be removed, resulting in additional cost increase and the performance deterioration. Other titanium alloys have been investigated, either with higher superplastic temperature, or with lower strain rate from 10^{-4} s^{-1} to 10^{-5} s^{-1}, or with relatively smaller elongation [1]. β rich $\alpha + \beta$ typed SP-700 alloy (Ti-4.5Al-3V-2Mo-2Fe) has better cold and hot working formability than Ti-6Al-4V alloy, higher superplastic elongation and lower forming stress and superplastic forming temperature [6] [7]. Its superplastic temperature is 775˚C or so, about 140˚C lower than that of Ti-6Al-4V alloy [6] [7].

Many reports can be found in literature on microstructure, superplasticity and mechanical properties for titanium alloys with fine grains [1] [2] [5]. Alloys with submicrocrystalline (SMC) structure (the average grain size between 0.1 - 1 μm), show favorite comprehensive mechanical properties and superplasticity at relatively lower temperatures [3] [8] [9] [10]. Fine-grained SMC structures can be effectively got by severe plastic deformation using following processes including Equal-channel Angular Pressing (E-CAP), Multi-step Isothermal Forging, Torsion Straining under high pressure or cumulated pack rolling, etc., more and more attention have been paid on the above processes in recent years.

One kind of α plus β type titanium alloy (Ti-Al-V-Mo-Fe-Zr) bars with submicrocrystalline structure was developed at Northwest Institute for Nonferrous Metal Research by multi-step isothermal forging plus multipass rolling [3]. Superplastic tensile test, elongation measurement, microstructure observation and superplastic deformation mechanism were carried out and discussed for the alloy bars. Little research on superplastic deformation and superplasticity was studied on the alloy plate [3]. In the present work, multi-step isothermal forging plus multipass rolling were used to process the alloy plate with submicrocrystalline structure. Tensile behavior and microstructures of the alloy were investigated.

2. Experimental Materials and Procedures

A d100 mm × 340 mm (about 12 kg) ingot was produced by electrode consumption vacuum arc furnace for two times. The α/β transition temperature for the ($\alpha + \beta$) alloy is 862˚C ± 8˚C. A multi-step isothermal forging was used to produce thickness 31 mm billet. The billet was rolled to thickness 5 mm billet at temperature about 800˚C then rolled to thickness 3.4 mm billet at temperature of 630˚C or so. The billet was eventually rolled to thickness 2.2 mm plate at ambient temperature. Tensile samples were cut from the rolling plates and annealed at 700˚C for 1 h, air-cooling. The gauge width of the specimens was 15 mm. Tensile tests were made at ambient temperature, at 780˚C and 800˚C, respectively. And the primary strain rates were 3.33×10^{-3} s^{-1} and 1.7×10^{-3} s^{-1}. The tensile experiments were made on CSS-1100 electron tensile machine with continuously adjustable clamping chuck moving speed within the range of 0.05 - 500 mm·min^{-1}, the precision of heating furnace is ±1˚C. Microstructures of the specimens before and after tensile tests were observed using JSM 6460 scanning electron microscope (SEM).

3. Results and Discussion

3.1. Tensile Properties

Table 1 shows the tensile properties for the alloy plate tested at ambient temperature after being annealed at 700˚C for 1 h, air cooling. From the table, it can be seen that the alloy plate possesses favorite tensile properties at ambient temperature. The average UTS and elongation for the longitudinal sample is 1070 MPa and 20%, while which for the transverse sample is 1103 MPa and 15%. UTS of transverse sample increases 3.1% than that of longitudinal one, and elongation decreases 25%.

While for the longitudinal samples tested at 780˚C and 800˚C with the primary strain rate of 1.7×10^{-3} s^{-1}, the elongation is as high as 1000% or so, which is almost the same for the two tempratures, as shown in Table 2. And the maximum elongation of the alloy can reach to 1078%. It is generally believed that high strain rate above 1.0×10^{-3} s^{-1} can save superplastic forming time, save energy and avoid oxidation of titanium alloy at relatively higher temperatures [11]. It is obvious that the alloy plate has a high tensile elongation at two temperatures with the primary strain rate of 1.7×10^{-3} s^{-1} in present work. So it can

Table 1. Tensile properties for the as-anneled alloy plate tested at ambient temperature.

Direction	UTS/MPa	YS/MPa	EL/%	RA/%
Longitudinal	1079	1043	19	36
Longitudinal	1061	1035	21	39
Transverse	1099	1052	15	33
Transverse	1107	1050	15	36

Table 2. Tensile elongation for the as-annealed longitudinal samples tested at two temperatures with the primary strain rate of 1.7×10^{-3} s^{-1}.

Tesing temperature/˚C	EL/%
780	1078
780	1000
800	1000
800	990

be considered that the alloy plate might meet the requirement of high strain rate superplasticity at 780˚C and 800˚C.

Comparing Ti-6Al-4V alloy bar with the alloy plate, it is found that the elongation of fine-grained Ti-6Al-4V alloy with grain size smaller than 0.4 μm is 1100% at 750˚C with the similar order primary strain rate of 10^{-3} s^{-1} [3], while that of the alloy plate is 1000% or so. That is to say, the superplasticity of the alloy plate is almost equal to that of fine-grained Ti-6Al-4V alloy bar at approaching temperature or at the same order of primary strain rate.

3.2. Microstructure of the Alloy Plate before and after Tensile Tests

The microstructure of the cold-rolled and annealed plate with a thickness of 2.2 mm is shown in Figure 1. It can be seen from the figure that the grain shapes of the cold-rolled plates in transverse and longitudinal direction are almost the same, most of them are elongated stripe-like deformation microstructures. Fine-grain deformed microstructure can be found in the cold-rolled plates, and little difference exists between two directions. The average grain size for the cold-rolled alloy plate in rolling direction is slightly smaller than that in the transverse one, the width and the roughness between stripes in rolling direction is also slightly smaller than that in the transverse one. After the tensile test at room temperature, even more fine and fully broken grains without becoming elongated along the tensile axis can be found in both transverse and rolling direction for the as-annealed alloy plate, as shown in Figure 1(c) and Figure 1(d).

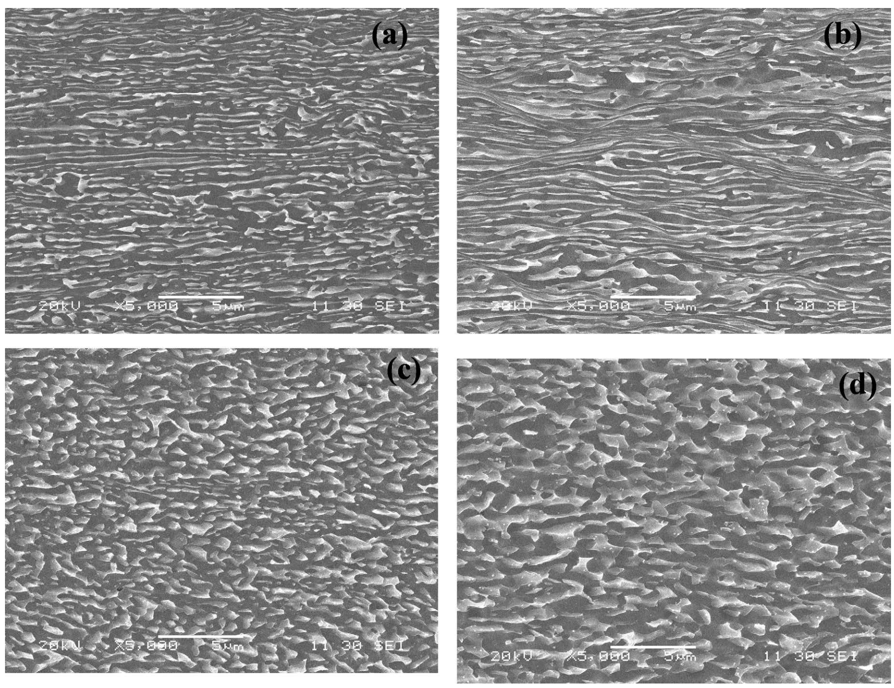

Figure 1. Microstructure of the as-cold-rolled ((a), (b)) and as-annealed alloy plate ((c), (d)) after tensile test at ambient temperature, (a), (c) longitudinal direction, (b), (d) transverse direction.

The average grain size for the alloy plate in rolling direction is also smaller than that in the transverse one, which is only 2 μm in rolling direction, while which is about 3 μm in transverse direction, which indicates that the superplaticity for the alloy plate has a feature of fine grains. And the reason why the alloy plate has good comprehensive properties at room temperature is also due to the fine (the grain sizes are all less than 10 μm) and even distributed grains.

At the initial stage of anneal process, the microstructure of the sample is refined by dynamic recrystallization, deformed grains are substituted by substructures through dislocation slip, climb and cross-slip, and are finally replaced by recrystallized grains [11]. In the subsequent annealing process, the grain size has a tendency to grow with longer holding time. Recrystallized grains grow up through continuously absorbing the surrounding dislocations. Till encountering boundaries, the driving force of dynamic recrystallization tends to weaken and the further growth of grains is constrained. When these dynamic recrystallization grains extend to contact each other, further coarsening is constrained, and the grain coarsening delays, fine grains can be got [11]. And the fine grains are benefit for the following superplatic deformation. The re-fined dynamic recrystallization grains meet a general requirement for fine-grain superplasticity [1].

3.3. Fractography for the Alloy Plate after Tensile Test

Fractography for the as-annealed alloy plate with the thickness of 2.2 mm after tensile test at ambient temperature is shown in **Figure 2**. The plate displays typical ductile tensile fracture features of large amounts of dimples. The fracture is the reflection of preferable tensile ductility and toughness for the alloy plate during tensile test at ambient temperature. The fracture morphology has little difference between transverse and longitudinal direction, which shows no directionality. So, the dimple fracture indicates that the alloy plate possesses excellent ductility and toughness in both longitudinal and transverse direction.

And voids of different sizes can also be observed. When the tensile deformation is small, a very small number of small-size holes appear in the fracture of the alloy plate. With the increase of deformation, more and more holes can be obviously observed in the fractography, and the holes tend to grow and connect

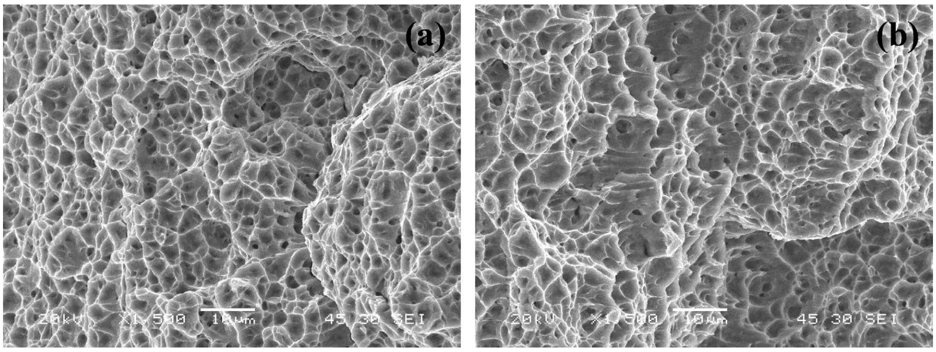

Figure 2. Fractography for the as-annealed alloy plate with the thickness of 2.2 mm after tensile test at ambient temperature, (a) longitudial direction, (b) transverse direction.

along the tensile direction. During the tensile test for the alloy plate, with the increase of tensile deformation, new small amount of small-size holes continuously nucleate and old holes gradually grow in the sample, so the final fracture of tensile sample is the result of hole growth and its connection.

4. Conclusions

1) The as-annealed alloy plate possesses favorite UTS and elongation at ambient temperature. The difference of average UTS between the longitudinal sample and the transverse one is not very big, while elongation of transverse sample decreases 25% than that of longitudinal one.

2) The elongation is 1000% or so for the alloy plate tested at 780˚C and 800˚C with a primary strain rate of $1.7 \times 10^{-3}\ s^{-1}$. This result confirms the superplasticity ability of the studied alloy plate at suitable temperature with relatively high strain rate.

3) The grain size is 2.5 ± 0.5 μm for the as-annealed alloy plate tensiled in longitudinal and transverse direction, which is benefit to the superplasticity of the alloy plate.

4) The fracture observation of the dimple features is the indication of excellent ductility for the alloy plate in longitudinal and transverse direction.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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