

Effect of electropulsing on anisotropy behaviour of cold-rolled commercially pure titanium sheet

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Abstract: The specimens cut from the cold-rolled pure titanium sheet at 0°, 45° and 90° to the rolling direction were treated by high density electropulsing (maximum current density $J=(7.22-7.96)\times 10^3$ A/mm², pulse period $t_p=110$ μs). The mechanical properties and microstructures of the cold-rolled, electropulsed and conventional annealed commercially pure titanium sheet were examined by using uniaxial tension test machine and optical microscope (OM), respectively. The results show that the deformation behavior of the electropulsed pure titanium sheet is significantly different from that of conventional annealed pure titanium sheet. The difference of the mechanical properties between the 0°, 45° and 90° direction specimens is almost diminished. It is mainly due to the increase in dislocation mobility and formation of lamellar microstructure after the electropulsing.

Key words: commercially pure titanium; anisotropy; lamellar microstructure; electropulsing treatment

1 Introduction

The aerospace, aeronautic and automobile industry are continuously driven to minimize the operational costs especially in these challenging economic times[1]. One of the most effective methods to reduce costs is through mass reduction of the aircraft and automobile structural materials[2]. For this reason, lightweight titanium and its alloys are still the primary material of choice for aerospace, aeronautic and automobile applications[3–4]. The titanium and titanium alloys are also used widely in the chemical, nuclear, biomedical, energy, electronics and civilian industry etc due to their low density, good corrosion-resistance and high biocompatibility[5–7]. It is reported that the most titanium application in Japan is pure titanium sheets[8].

Hexagonal close packed (hcp) metals like α -Ti and its alloys are inherently anisotropic in physical and mechanical properties which are induced by the crystallographic texture. The very pronounced textures in rolled titanium sheets give rise to strong mechanical properties anisotropy, and have a detrimental influence on the other properties, such as fatigue, creep, working and shaping behaviours[9]. Although several investigations have been done on the rolling and

annealing textures in titanium sheets[10], very little has been reported on the influence of electropulsing treatment on the anisotropy of pure titanium sheet.

In the previous studies[11], we have reported that the electropulsing treatment can effectively relieve anisotropy of the cold-rolled TA15 sheet. With the increase of current density, a degree of recrystallization is increased. The microstructure of TA15 sheet transforms from primary α laths grain to α equiaxed grain. When the maximum current density is 5.4×10^3 A/mm², the difference of the mechanical properties among the 0°, 45° and 90° direction specimens is almost diminished. In this work, the influence of electropulsing on anisotropy of cold rolling pure titanium sheet was studied.

2 Experimental

The cold-rolled TA1-A CP Ti sheet (0.5 mm in thickness) was used as the experimental material in this work. Sheet tensile specimens with a gage length of 25.0 mm, a width of 7.0 mm and a thickness of 0.5 mm were cut from the cold-rolled CP Ti sheet along the 0°, 45° and 90° to the rolling direction. These specimens were divided into five groups (A–E): the original as-rolled specimens A were not subjected to treatment; specimens

B were annealed at 650 °C for 30 min, and specimens C, D and E were subjected to single high current density electropulsing treatment (EPT). The specimens C, D and E were treated with maximum current density of 7.22×10^3 , 7.64×10^3 and 7.96×10^3 A/mm², respectively. Specimens A and B were employed as compared specimens. The tensile tests at room temperature were conducted to examine the mechanical properties using an MTS 810 test machine, and the tensile speeds were 5.0 mm/min. The microstructures were investigated by optical microscopy (OM).

Electropulsing was performed under ambient conditions by capacitor banks discharge. The experimental arrangement for the electropulsing treatment is shown in Fig.1. The waveform of electropulsing was detected in situ wave by a Rogowski coil and a TDS3012 digital storage oscilloscope and it is a damped oscillation wave (see Fig.2). The pulse duration of an electropulsing was about 800 μ s, and the

pulse period $t_p = 110$ μ s.

3 Results and discussion

3.1 Uniaxial tension mechanical properties

Fig.3 shows the comparison of the anisotropy of CP Ti sheet under different conditions. It is found that the original cold-rolled and conventional annealed pure titanium sheet specimens have obvious anisotropy. For cold-rolled CP Ti sheet, the specimen in 45° direction has higher yield strength, tensile strength and larger elongation than the specimens in the other two directions (Fig.3(a)). In case of conventional annealed specimens (Fig.3(b)), the difference in yield strength, tensile strength and elongation is more significant compared with the cold-rolled specimens. It is observed that the specimen in 0° direction displays most significant work-hardening property among the specimens in the three directions. For the electropulsed specimens C and D, yield strength, tensile strength and work hardening behavior at the three different directions are almost the same (Fig.3(c) and (d)). The yield strength, tensile strength, elongation and work hardening behavior of specimens E have different levels (Figs.3(e)), but the difference is smaller compared with the original cold-rolled and conventional annealed CP Ti sheet specimens. Figs.4–6 show the ratios of the maximum value to the minimum value of the elongation, tensile strength and yield strength for the specimens A–E, respectively. It is further demonstrated that the electropulsing treatment can effectively relieve anisotropy of the cold-rolled CP Ti sheet.

It should be mentioned that, because electropulsing time is very short (about 800 μ s), the thick oxidation layer and the thick gas absorbing layer on the metals surface could not be formed after the electropulsing treatment. It demonstrates a remarkable advantage of the electropulsing treatment for the cold-rolled pure titanium sheet.

3.2 Analysis of optical microstructure

Fig.7 shows the optical microstructures taken from specimens A, B, C, D and E. It is found that tweed-like lamellar microstructure was observed (Figs.7(c), (d) and (e)) after the electropulsing. And with increasing the maximum current density, the fraction of lamellar microstructure is increased.

3.3 Discussion

The lamellar microstructures are formed, which

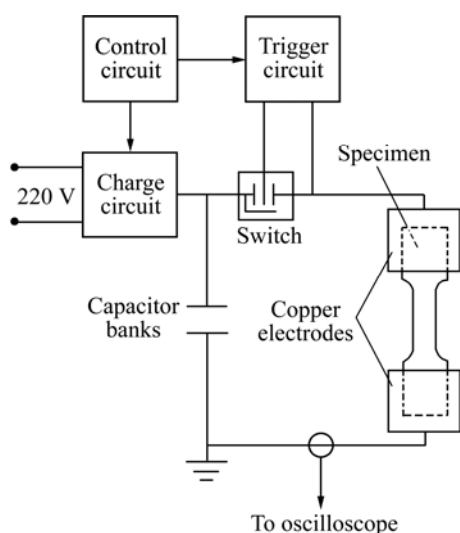


Fig.1 Schematic of experimental arrangement

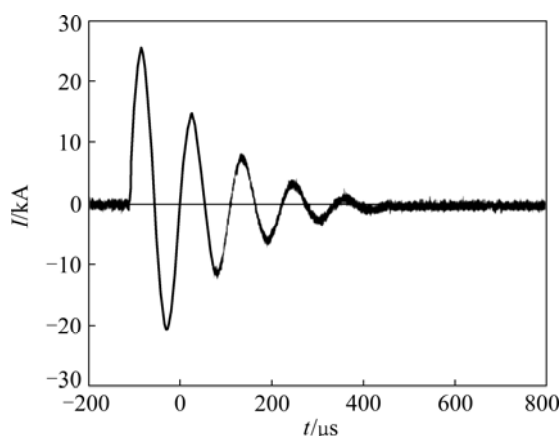


Fig.2 Typical electropulsing waveform

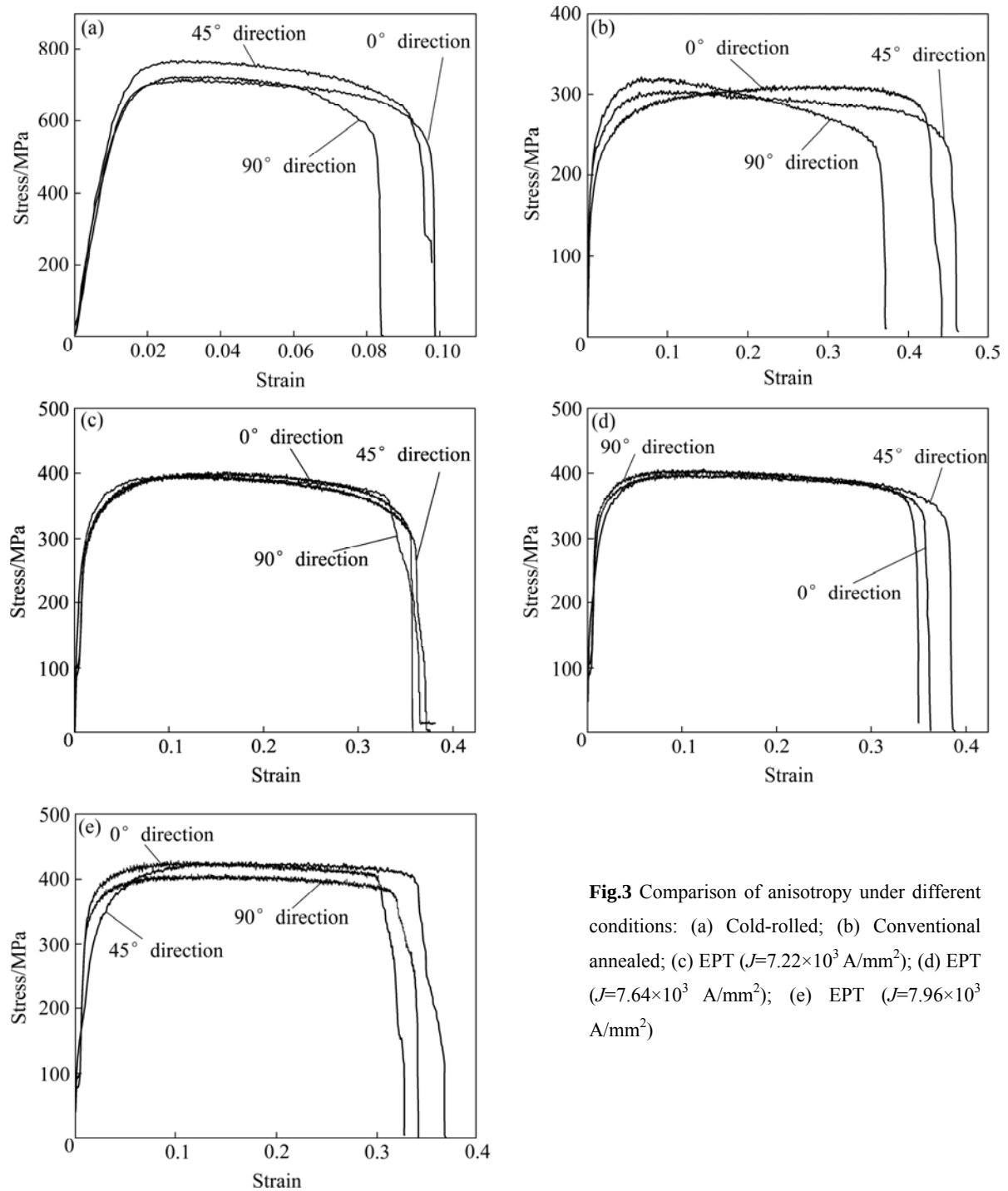


Fig.3 Comparison of anisotropy under different conditions: (a) Cold-rolled; (b) Conventional annealed; (c) EPT ($J=7.22 \times 10^3 \text{ A/mm}^2$); (d) EPT ($J=7.64 \times 10^3 \text{ A/mm}^2$); (e) EPT ($J=7.96 \times 10^3 \text{ A/mm}^2$)

originate from rapidly phase transformation during electropulsing treatment. The course of temperature rise can be regarded as an adiabatic course due to a very short time during the electropulsing treatment. The average temperature rise of the specimen by Joule heating is written as follows [12]:

$$\Delta T = (c\rho S^2)^{-1} \int_0^\infty I^2 dt \quad (1)$$

where I is the amplitude of pulse, t is the corresponding

duration, S is the cross-sectional area of the specimen, γ , ρ and c are the electrical resistivity, the density and the specific heat of the experimental material, respectively. For TA1-A CP Ti sheet, $E=108 \text{ GPa}$, $\alpha = 8.2 \times 10^{-6} / ^\circ\text{C}$, $\gamma=0.47 \text{ } \mu\Omega\cdot\text{m}$, $\rho=4.51 \times 10^3 \text{ kg/m}^3$, $c=544 \text{ J/(kg}\cdot^\circ\text{C)}$. According to this expression the average maximum temperature changes ΔT_{max} are 630, 703 and 764 $^\circ\text{C}$, respectively.

The treatment by electropulsing is a high-speed

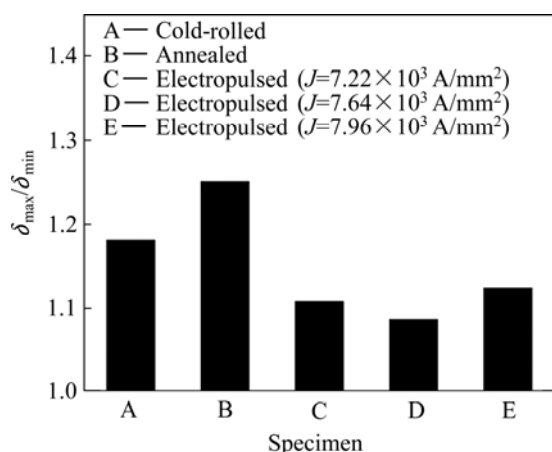


Fig.4 Ratios of maximum elongation to minimum elongation

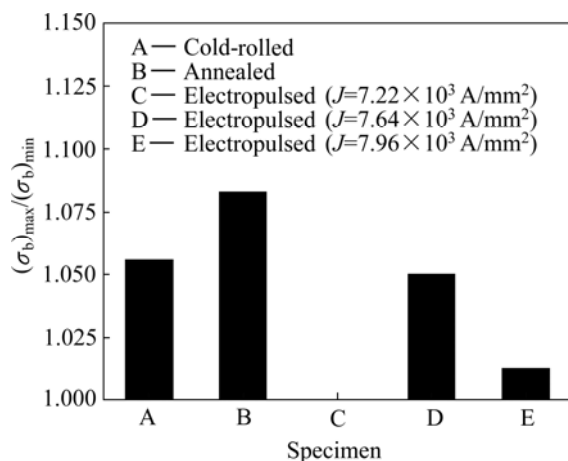


Fig.5 Ratios of maximum tensile strength to minimum tensile strength

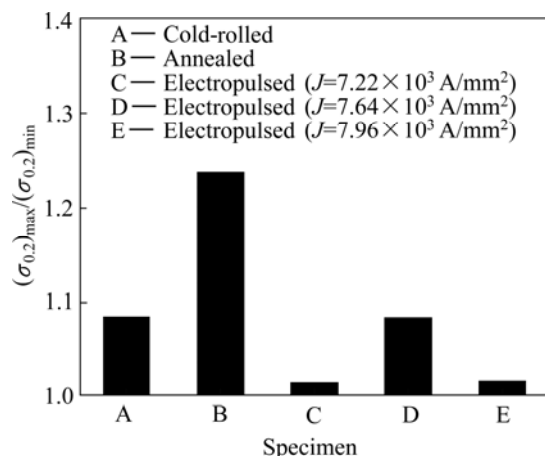


Fig.6 Ratios of maximum yield strength to minimum yield strength

heating process. The research on the dynamic process of thermal expansion shows that there are nonsynchronous changes between the temperature and the dynamic thermal expansion under the high speed heating [13]. Therefore, a transient thermal compressive stress occurs

under the high-speed heating condition [14]. It should be mentioned that the electropulsing has the selective effect. The above mentioned Joule heating and the transient thermal compressive stress by electropulsing are inhomogeneous. This means that the temperature increase and thermal compressive stress in the area with a defect are higher than that in the area without a defect. Therefore, it is completely possible that phase transformation occurs in the specimens (phase transformation temperature of TA1-A sheet is 882 °C). Therefore, under the electropulsing many lamellar microstructure in the CP Ti can be produced due to the local phase transformation. On the other hand, since electropulsing can introduce the Joule heating and instantaneous thermal compressive stress, dislocations move at very high velocity and extend dislocations overlap continuously can form microtwins under the instantaneous and tremendous compressive stress.

Obviously, the effect of the electropulsing treatment on the anisotropy of pure titanium sheet is related to formation of lamellar microstructure. On the one hand, a new texture component is associated with the twinned areas after twin appears. On the other hand, the formation of lamellar microstructure within the existing grains introduces additional boundaries, and this in turn governs the strain-hardening behavior and texture development [15–16]. The carefully investigation is needed to confirm the effect of lamellar microstructure on texture evolution.

4 Conclusions

1) The electropulsing treatment can effectively relieve anisotropy of the cold-rolled pure titanium sheet. When the maximum current density is 7.22×10^3 A/mm², the difference of the mechanical properties among the 0°, 45° and 90° direction specimens is almost diminished.

2) The electropulsing time is very short (about 800 μs), the thick oxidation layer and the thick gas absorbing layer on the metals surface cannot be formed after the electropulsing treatment, which is significant meaning for the pure titanium, because titanium and its alloys have high chemical activity and their grain grows up easily during heating.

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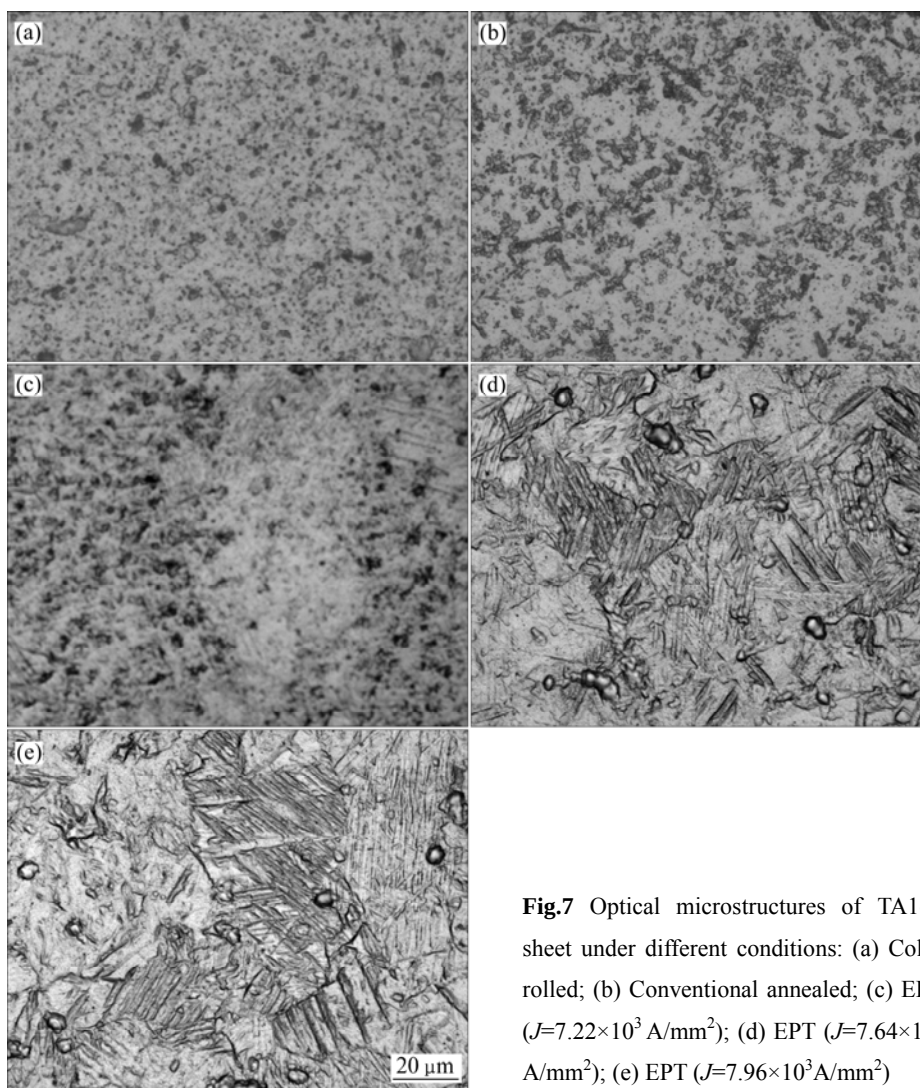


Fig.7 Optical microstructures of TA1-A sheet under different conditions: (a) Cold-rolled; (b) Conventional annealed; (c) EPT ($J=7.22 \times 10^3 \text{ A/mm}^2$); (d) EPT ($J=7.64 \times 10^3 \text{ A/mm}^2$); (e) EPT ($J=7.96 \times 10^3 \text{ A/mm}^2$)

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