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Rapid communication

Rapid grain refinement of 2024 Al alloy through recrystallization induced by electropulsing

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ABSTRACT

The hot rolled 2024 Al alloy subjected to electropulsing was investigated in this study. The results show that the electropulsing treated sample with optimized parameter exhibits notable improvement of mechanical properties and greatly refined microstructure. The main grain refinement mechanism is recognized as rapid recrystallization under EPT. It is a promising method of processing techniques to optimize the mechanical behavior.

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1. Introduction

The precipitation hardened 2024 aluminum alloy has important applications in the aerospace industry due to its high specific strength and good fracture toughness, as well as excellent fatigue properties [1,2]. As is known, grain size is regarded as a key microstructural factor which can affect all aspects of the mechanical behavior. Hence, controlling grain size is recognized as a way to obtain desired properties [3]. Severe plastic deformation (SPD) processing is effective for producing ultrafine grained alloys with superior strength. But the ductility of SPD-processed materials is usually inadequate for practical demand [4–6].

Electropulsing treatment (EPT) is an instantaneous high energy input method, and has been extensively applied in science and engineering fields [7], such as electroplasticity [8], phase transformations [9,10], and recrystallization [11,12]. In recent decades, many studies have indicated that the EPT can make marked grain refining via different mechanisms. For example, Zhou et al. [13] used EPT to synthesize the fine grain structured materials from coarse grained materials. They proposed that the fine microstructure resulted from the solid-state phase transformation under EPT. It is well known that there is no phase transformation in the Al alloys, so the recrystallization is considered to be an effective way to refine the grains. Jiang et al. [14] reported that the EPT increased elongation to failure of AZ91 alloy remarkably with a decrease in tensile strength owing to the accelerated recrystallization. However, as the resistivity and melting temperature of al alloys are low, it is hard to get the fine grains via the EPT. In the present work, we will study the effect of EPT on the mechanical properties and microstructure of the hot rolled 2024 Al alloy.

2. Experimental

The commercial 2024 alloy (4.42 wt% Cu, 1.49 wt% Mg, 0.51 wt% Mn, balance Al) was provided in the form of 6 mm thick sheets in this investigation. The sheets were homogenized at 490 °C for 24 h, and hot rolled (HR) with a reduction thickness of 30% per pass to 2 mm thick strip at 350 °C, then were cut into pieces of 45 mm length and 10 mm width. The EPT was performed immediately by a self-made electropulsing generator, which could generate AC pulse current with 50 Hz frequency (Fig. 1). The discharging duration and density of the pulse current were determined by a controllable program on a computer. The value of root-mean-square (RMS) current was monitored by a welding monitoring equipment. In this study, the current density j_e was optimized to 200 MA/m^2 with a duration of 240 ms.

The tensile tests were conducted on a servo-hydraulic materials testing system (MTS, MTS810, USA) at the strain rate of 10^{-3} s^{-1} under room temperature. Specimens ground and polished for tensile testing were dog-bone shaped sheets with gauge length 30 mm, and cross section of 4 × 2 mm^2. The optical micrograph

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specimens were prepared through a conventional mechanical polishing and followed by etching with Keller reagent (2 mL HF, 3 mL HCl, 5 mL HNO_3 and 190 mL water). Tensile fracture morphologies of the samples were obtained by scanning electron microscopy (SEM, Carl Zeiss JSM-5310, Germany). The linear intercept method was used to measure the grain size in this study. The number of analyzed grains on the HR and HR+EPT specimens was about 200 and 1000, respectively.

3. Results and discussion

The microstructure of the HR and the HR+EPT samples is shown in Fig. 2a–c. Due to the hot deformation, the coarse grains are elongated along the rolling orientation, as shown in Fig. 2a. When the specimens are treated by electropulsing, the rapid heating produces compressive stress and high temperature [15], the temperature rise induced by Joule heat of EPT can be described as $\Delta T=\rho j_e^2(C_\rho d)^{-1}t_c$ [16], where ρ is the resistivity, C_ρ is the specific heat, d is the density, and t_c is the duration of discharging. Typical conditions were as follows: $\rho=4\times10^{-8}\ \Omega$ m; $C_\rho=875$ J/kg K; $d=2.78\times10^3$ kg/m^2. Based on the optimized parameter, the calculated value of ΔT is 158 K. So $T=\Delta T+T_0=451$ K, where T_0 (293 K) is room temperature; nevertheless, it should be noted that owing to the non-uniform defects, the current can make local overheating of the sample [17]. On account of the relationship between atom diffusion and temperature, $D_1=D_0\exp(-(Q/RT))$, where D_0 is the diffusion preexponential factor, Q is the activation

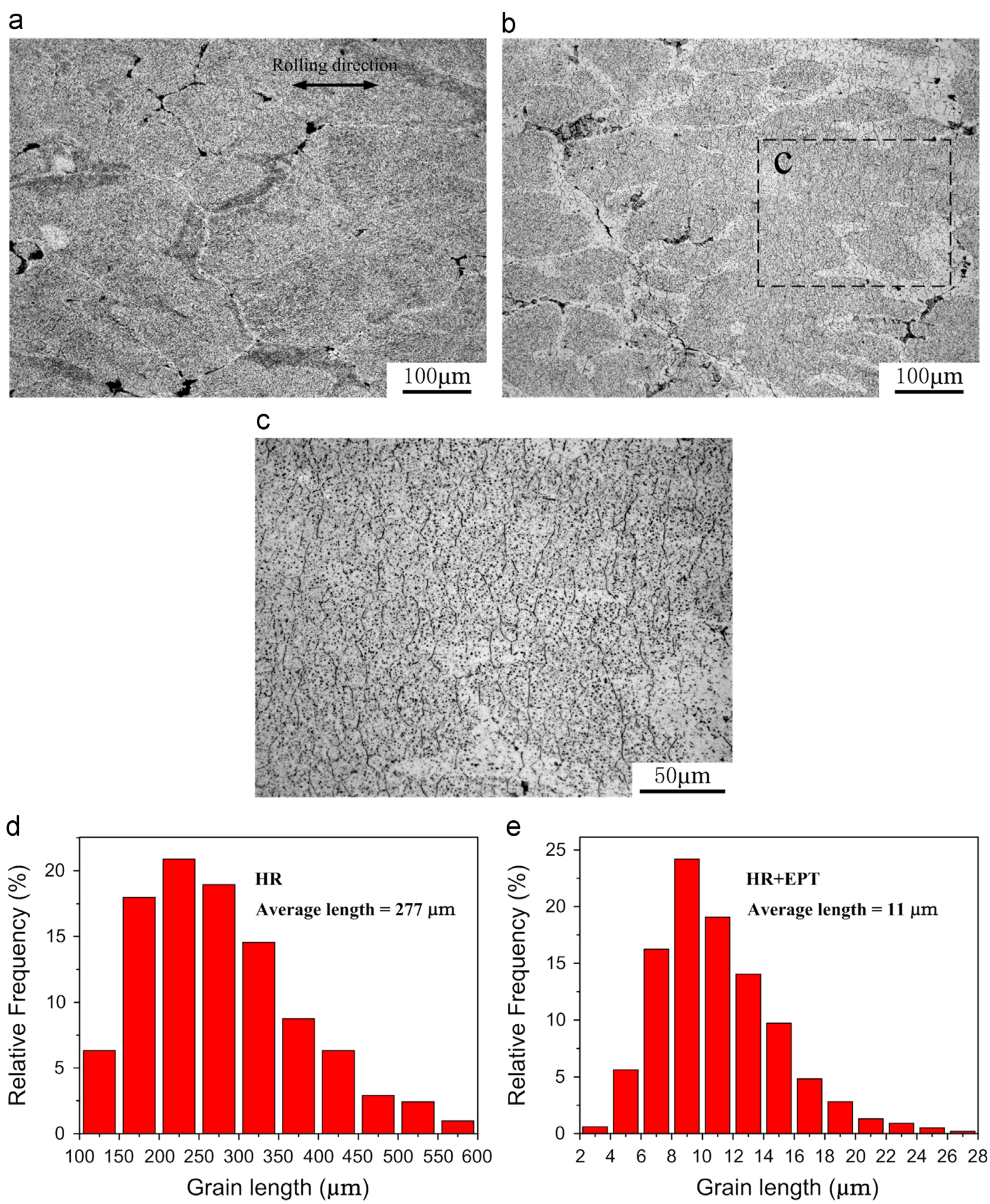

Fig. 2. (a) Microstructure of the HR sample, (b) and (c) the HR+EPT sample, and (d) and (e) effective grain length distribution with different conditions.

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