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# Electropulsing induced evolution of grain-boundary precipitates without loss of strength in the 7075 Al alloy

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ABSTRACT

The influence of electropulsing on the peak-aged (T6) microstructures in the 7075 Al alloy was investigated in this study. The results show that parts of the intragranular precipitates dissolve in the matrix during electropulsing, and the electropulsing treated sample exhibits discontinuous dissolution of the grain-boundary precipitates (GBP). After re-aging, the mechanical properties of the re-aged (RA) sample are nearly the same as that of T6 temper, meanwhile, the grown discontinuous GBP were obtained. Hence it is a promising method to change the distribution of GBP without loss the strength in the 7075 Al alloy.

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## 1. Introduction

The 7000-series Al alloys (Al–Zn–Mg–Cu) have been extensively used for structural components in aerospace industries due to their high strength and low density [1]. The high strength of this series of Al alloys is due to the fine and uniformly distributed precipitates which are formed during the artificial aging [2]. The precipitation sequence of 7000-series Al alloys can be described as [3]: solid solution → GP-zones → $\eta'$ → $\eta$-$MgZn_2$. For the T6-temper 7000-series Al alloys, the GP-zones and $\eta'$ phases are the main precipitates, while the equilibrium phase $\eta$ is the main hardening precipitate for the over-aged (T7×) alloys [4,5]. As is known, the 7000-series Al alloy is susceptible to the stress corrosion cracking (SCC), although T6 heat treatment makes Al alloy obtain the optimized hardening, due to the continuous precipitates at the grain boundary, the SCC resistance decreases significantly [6,7]. It has been proposed that the SCC resistance can be improved by increasing both the size and the inter-particle distance of the GBP [2]. On one hand, the coarse and dispersed GBP could capture hydrogen atom and release hydrogen molecules, which would reduce the content of hydrogen in grain boundaries and restrain the hydrogen-induced crack [8]; on the other hand, when there was crack initiation, the discontinuous GBP will prevent crack propagation [9]. The T7× and retrogression and re-aging (RRA) heat treatment can improve the SCC resistance, however, at the expense of strength as compared with the T6 treatment [10]. Besides, although RRA was recognized as an effective way to reduce the SCC velocities and maintain the strength close to the peak aged condition, it is hard to select the appropriate retrogression parameters, for example, the temperature and the holding time.

The electropulsing treatment (EPT) is an instantaneous and precise high-energy input method, and has been applied for grain refinement, plasticity improvement, phase transformation, and many other fields [11–14]. In recent years, it is indicated that the EPT can accelerate the second-phase dissolving in the matrix [15,16], therefore, the distribution of precipitates (which place at grain boundary and grain-interior) will be significantly affected by the EPT in Mg alloys. These studies are fruitful, however, few investigations have been done on the effect of EPT in Al alloy. The present work will study the effect of EPT on the mechanical properties and the precipitate evolution of 7075-T6 Al alloy.

## 2. Experimental

The commercial 7075 alloy (5.63 wt.% Zn, 2.35 wt.% Mg, 1.64 wt.% Cu, balance Al) was provided in the form of 6.3 mm thickness in this investigation. The sheets were homogenized at 733 K for 24 h, and hot rolled with a reduction thickness of <30% per pass to 2 mm thick strip at 623 K. To obtain the continuous GBP, the sheets were heat treated at T6 temper (solid solution treatment (SST) at 748 K for 1 h and water-quenched, then artificial aging at 393 K for 24 h). The EPT were performed immediately by self-made electropulsing generator [17], which could generate AC pulse current with 50 Hz frequency. In this study, the current density $j_e$ was optimized to 200 $MA/m^2$ with a duration of 220 ms. After EPT, the samples were re-aged at 393 K for 24 h.

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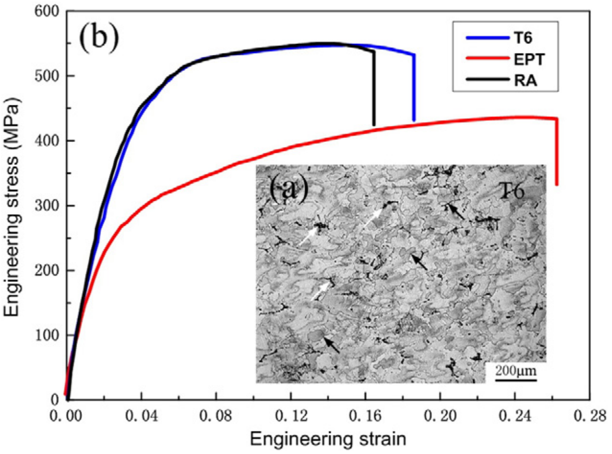

**Fig. 1.** (a) Optical microstructures of T6 treatment, (b) typical tensile engineering stress–strain curves of 7075 alloy under different processing conditions.

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 the room temperature, and at least 3 specimens were tested. The specimens ground and polished for tensile testing were dog-bone shaped sheets with gauge length 30 mm, and cross section 4 × 2 mm. The optical micrograph 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). The TEM observations were carried out on a JEM-2100F and operated at 200 kV. The linear intercept method was used to measure the size of the precipitates in this study. Hundreds of particles were analyzed, respectively.

## 3. Results and discussion

Fig. 1a represents the optical microstructure of the T6 temper 7075 Al alloy. It can be seen that the recrystallization occurs in the alloys, and there still are some residual phases (white arrows) around the equiaxed grains (black arrows). It should be noted that the T6 heat treatment consumes large amounts of deformation energy. Recovery and recrystallization are dramatically accelerated at elevated temperature, therefore the optical microstructure (grain size) loses the driving force to change after T6 temper [18]. As a result, the samples with EPT have no marked change (not shown). As is known, the artificial aging also has no obvious effect on the grain size of the alloy, hence the dissolution and precipitation will be the primary changed factors in the strengthening mechanisms. Fig. 1b shows the typical tensile stress–strain curves of 7075 Al alloy at different processing states. As shown in the engineering stress–strain curves, the T6 sample has an ultimate tensile strength (UTS) of 550 MPa and an elongation to failure close to 18.5%. The EPT increased the elongation of the sample with the strength decreasing, which implies that the secondary phases dissolve in the matrix. While the sample is re-aged at elevated temperature, the strength gets back to that of T6 temper with slightly lower elongation.

In this study, the Joule heating effect induced by electropulsing can be described as $\Delta T = \rho j_e^2 (C_\rho d)^{-1} t_c$ [19], where ρ is the resistivity, $C_\rho$ is the specific heat of 7075 Al alloy, d is the density of the alloy [20], and $t_c$ is the duration of discharging. Typical conditions were as follows: $\rho = 5.7 \times 10^{-8}$ Ωm; $C_\rho = 960$ J/kg · K; $d = 2.8 \times 10^3$ kg/m$^2$. The

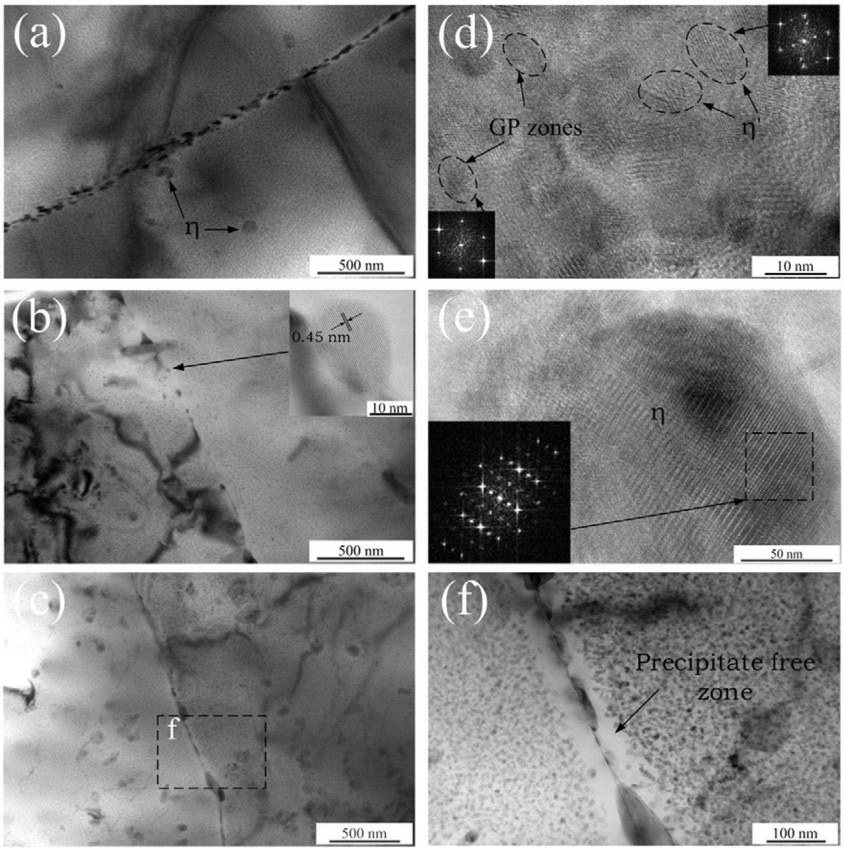

**Fig. 2.** TEM micrographs showing the GBP in different conditions: (a) T6, (b) EPT, (c) RA and (f) the magnification of the microstructure in the RA sample, (d) the high resolution TEM (HRTEM) and fast Fourier transform (FFT) image showing the η′-phase and GP zones for the T6 sample, (e) the HRTEM and FFT images of a typical precipitate showing the η-phase in the T6 sample.

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