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Letter

Rapid precipitation of T-phase in the 2024 aluminum alloy via cyclic electropulsing treatment

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ABSTRACT

The effect of cyclic electropulsing treatment on the microstructure, conductivity and mechanical properties of 2024 Al alloy was investigated in this study. The result shows that electropulsing with an optimized parameter makes the Al alloy exhibit better conductivity and mechanical property as compared to a non-electropulsed sample. The microstructure examinations indicate that the improved conductivity and mechanical behavior can be attributed to the rapid precipitation of T-phase particles surrounded by dislocation loops under electropulsing.

1. Introduction

The 2024 Al–Cu–Mg alloy, as a heat-treatable material, exhibits certain excellent properties, such as high tensile strength, good damage tolerance and creep resistance. With the excellent thermal stability, these alloys are considered to be candidate materials for future applications in the aerospace industry [1–3]. For example, the primary use of T3 and T4 2024 aluminum alloy sheet is making aircraft wing and fuselage structures [4,5]. T-phase ($Al_{20}Cu_2Mn_3$) is the most common precipitate phase in Al–Cu–Mg alloys. It can precipitate as early as during homogenization treatment, and once there, does not dissolve and re-precipitate during subsequent heat treatments [6]. As a stable particle phase, the T-phase dispersoids prevent abnormal grain growth at high temperature. In addition, the T precipitates play a key role in dislocation pinning and accumulating [7,8], hence the uniform and fine T precipitates are always desirable.

Electropulsing treatment (EPT) is a new potential approach for material processing and preparation. In the past decades, electroplasticity has been investigated in previous work [9–11]. Zhu et al. [12] exhibited that the elongation to failure increased with the severely deformed Cu strip recrystallizing in a short time as a result of accelerating atom diffusion. Xu et al. [13] reported that electropulsing increased the elongation to failure of AZ31 alloy dramatically at high strain rate owing to dynamic recrystallization. However, few investigations have been done on using electropulsing to accelerate the precipitation of the solid solution treated Al alloys.

The present work will study the effect of EPT on the mechanical property and microstructure of 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 thickness in this investigation. The sheets were homogenized at 490 °C for 24 h, and hot rolled 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. Solid solution treatment (SST) was performed at 495 °C for 40 min and water-quenched. The EPT were performed immediately by self-made electropulsing generator (Fig. 1), which could generate AC pulse current with 50 Hz frequency. 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. The current density was the result of RMS value divided by the cross-sectional area of the sample. In this study, we used the cycle index of a cyclic (cyc) current starting from 5, and the current parameters were shown in Table 1.

Resistance measurement was performed on a QJ57 direct current resistance bridge, and the results were converted to electrical conductivity. The electrical conductivity values reported here represents an average of at least three measurements. Room temperature mechanical properties were measured by electrical universal testing machine CRIMS DDL-100. Tensile tests were carried out at a strain rate of 10^{-3} s^{-1} at room temperature. The optical micrograph and field emission scanning electron microscopy (FESEM, JEM-2100F) specimens were prepared

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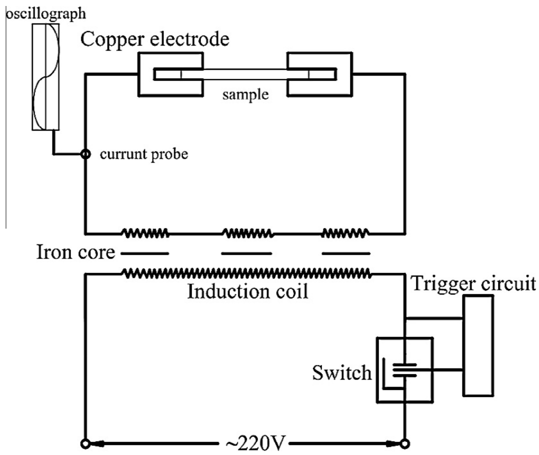

Fig. 1. Schematic illustration for the eletropulsing system.

Table 1
Pulse current parameters for the EPT.

Electropulsing parameters	Values
Frequency (Hz)	50
Discharging duration of one cyclic current (ms)	100
Current density (MA/m^2) and discharge voltage (V)	0.085 and 3
	0.190 and 4
	0.255 and 5
Cyclic index	5
	10
	15

through mechanical polishing and followed by etching with Keller reagent (2 mL HF, 3 mL HCl, 5 mL HNO_3 and 190 mL water). The specimens for transmission electron microscope (TEM) observation were prepared by the standard twin-jet electropolishing method with a voltage of 10–15 V in 80% ethanol and 20% perchloric acid at −30 °C. The TEM observations were carried out on a JEM-2100F and operated at 200 kV.

3. Results and discussion

The tensile properties of the samples are showed in Table 2. From the table, it is clear that under EPT conditioning, strength is higher as compared to that of SST, but ductility shows the same behavior. The alloy displayed a rapid treating response, and the longer the duration, the higher the density of current providing a stronger effect when controlled within a certain range. However, it also causes the properties to decrease reversely if the parameters are out-of-range. This phenomenon may occur due to the changed distribution of the precipitation induced by the high current, which will be discussed in the section below. When the current passed the sample, the transient thermal stress was obtained. The thermal stress can be described by [14] $\sigma = E\alpha\Delta T$, where E is Young's modulus, α is the thermal expansion coefficient and ΔT is the temperature rise. As is known, the EPT makes a rapid temperature rise, moreover, the water-cooled electrodes constraint the expansion of the samples. Hence, the strong stress induced by high enough current density makes the sample bend severely.Fig. 2a represents the optical microstructure of the solid solution treated 2024 Al alloy. It can be seen that the recrystallization occurs in the alloys, and there still are some residual phases around the equiaxed grains, while the samples with EPT have no marked change in optical micrographs (not shown). Fig. 2b shows the typical tensile stress–strain curves of 2024 Al alloy at different

Table 2
Mechanical properties of the samples at room temperature.

Current density (kA/mm^2)	Cycle index (one cycle discharge duration is 100 ms)	UTS (MPa)	YS (MPa)	Elongation (%)
0 (SST)	–	443	265	26.1
0.085	5cyc	441	279	27.3
	10cyc	453	279	27.3
	15cyc	453	316	19.9
0.190	5cyc	456	293	30.1
	10cyc	465	301	31.0
	15cyc	423	255	20.5
0.255	5cyc	430	253	25.7
	10cyc	420	262	20.2
	15cyc	Bending severely		

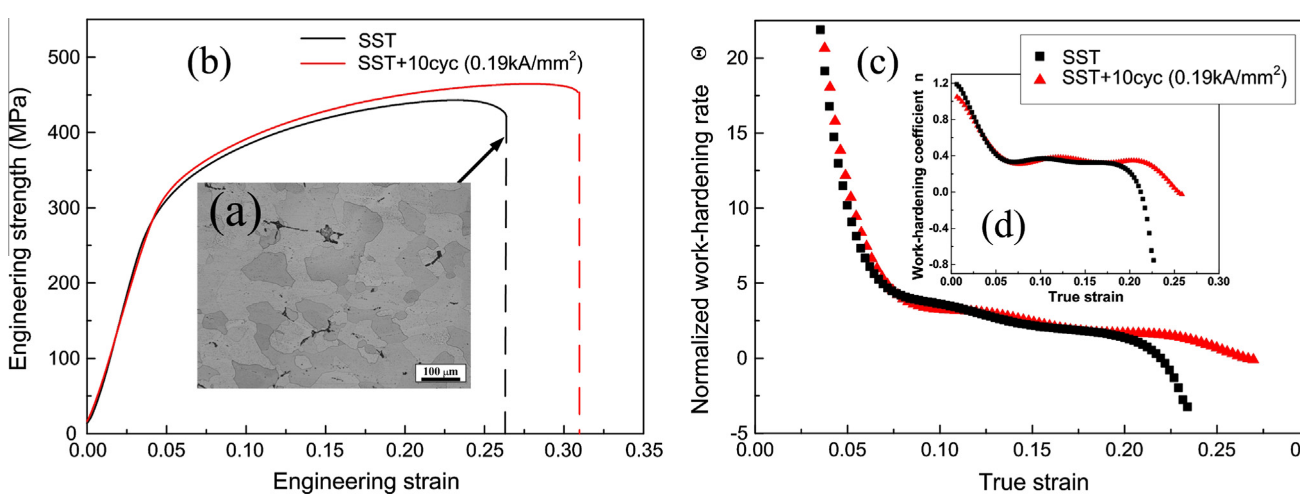

Fig. 2. (a) Microstructure of the solid solution treated sample, (b) typical tensile engineering stress–strain curves of 2024 alloy under different processing conditions, (c) comparison of the normalized work-hardening rate and (d) work-hardening coefficient n curves of two types of samples.