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# Influence of Pulsed Current on Superplasticity of Fine Grained 1420 Al-Li Alloy

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**Abstract.** The effects of an externally applied electropulse on the superplastic deformation behavior and microstructure of 1420 Al-Li alloy were studied. The flow stress of superplastic deformation was reduced by the high-density electropulse while the elongation was increased. The optimal electrical parameters for superplastic deformation were 192A/mm$^2$ of current density, 150Hz of frequency and 30s of duration at 480 ℃and 0.001s$^{-1}$. The elongation raised by 68% compared to that without electropulse. Furthermore, the grain was refined and the average grain size was reduced after superplastic deformation with the optimal electropulse. It is noted that the electropulse promoted the recrystallization and restrained the grain growth.

## 1. Introduction

1420 Aluminum-lithium alloys have been receiving a great deal of attention for application in aerospace industry because of their low density, high specific strength and stiffness, and good weldability. However, Al-Li alloys exhibit lower ductility and higher notch sensitivity at room temperature [1-3]. In recent years, several researches have been conducted about superplastic forming of Al-Li alloy, which can obtain favorable forming effect [4-5]. While the higher temperature and lower strain rate are necessary during superpalstic deformation, which have been result in inefficiency and high cost. In the 1963, Troitskii OA etc. [6] have discovered that a significant interaction between electrons and dislocations also occurs for the application of high density current pulses during the plastic deformation of metals. They termed the effect an “electroplastic effect”, and concluded that the mobility of dislocations might also beenhanced by the directed (drift) electrons associated with the passage of an electriccurrent. Since then, works by Conrad [7-9] and Stepanov et al. [10-11] had shown that pulsed current directly affects the macroscopic plastic strain behavior in metals. Conrad had studied the effect of external electric field on superplastity [12], and claimed that external electric field could decrease the flow stress and increase the strain rate hardening parameter m. To investigate these findings further, this work pursued an in-depth analysis of the effectof electropulse on the deformation behavior and microstructure of 1420 Al-Li alloy during superplastic tensile deformation. Through testing, the optimum electric parameters were obtained, and the methods for improving superplastic deformation condition and performance were found.

## 2. Material and Experimental Procedure

The chemical composition of hot rolled 1420 Al-Li alloy plate with a thickness of 8.5 mm is listed in

Table 1. Thermomechanical processing (TMP) on hot rolled plate is used to obtain a fine grained structure. The detail procedures of TMP were as following: solution-treated at 475 ℃ for 2h, quenched in water and then over-aging at 300 ℃/48h+400 ℃/4h, subsequently preheated at 300~400 ℃for 1h, and then rolled to the final thickness of about 2mm.The rolling reduction per pass is 10%~20% and a rolling speed is about 0.427m/s. Finally, rapid recrystallization process is conducted at 510 ℃ for 30 min. The microstructure of the plates is shown in Fig 1 and the average grain size is about 12μm.

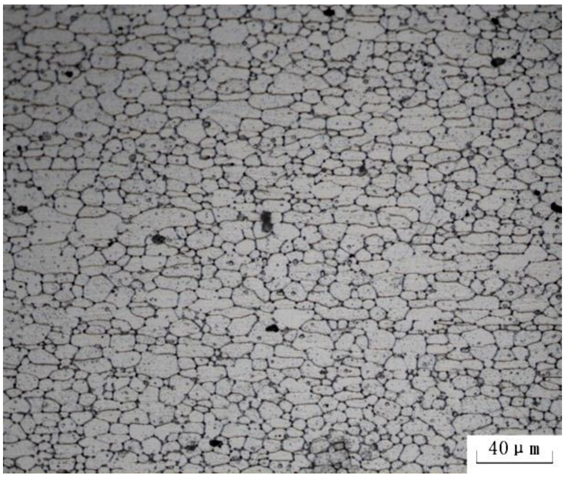



**Figure 1.** Microstructure of fine grained 1420 Al-Li alloy

**Table1.** Chemical composition of 1420 Al-Li alloy (wt %)

| *Element* | *Li* | *Mg* | *Zr* | *Fe* | *Si* | *Ti* | *Cu* | *Al* |
|---|---|---|---|---|---|---|---|---|
| Measured | 2.0 | 5.2 | 0.12 | 0.07 | 0.03 | ≤0.1 | 0.03 | Bal |

Constant cross-head speed tests were conducted using an Instron universal test machine equipped with a resistance furnace. The highest temperature of heating furnace could be reached 1000 ℃ and a uniform temperature was maintained at ±5 ℃. The tensile tests were carried out at 480 ℃ and an initial strain rate of $0.001s^{-1}$.The specimens were held at test temperature for 10min for uniform temperature distribution. The tensile specimen was held in the furnace by high-temperature alloy grips and insulated between grip and tensile machine by ceramic. Pulsed current was applied to the specimen by connecting the two electrodes as shown in Fig.2.Electropulses with various frequencies and peak current and pulse widthof60μs were applied to the specimen. Themechanical test was started, at the same time; the impulsing power was turned on. When the duration t reached the set value, the impulsing power was turned off, but the tensile test was still continued. The detailed parameters were listed in Table2.

**Table2.** Parameters of electric superplastic tensile test at 480 ℃, $0.001s^{-1}$

| Number | Current density, $A/mm^2$ | Frequency, Hz | Duration, s |
|---|---|---|---|
| 1 | 192 | 150 | 0,15,30,60,90,120 |
| 2 | 192 | 0,120,150,200,250,300 | 30 |
| 3 | 0,150,167,192,200,213 | 150 | 30 |

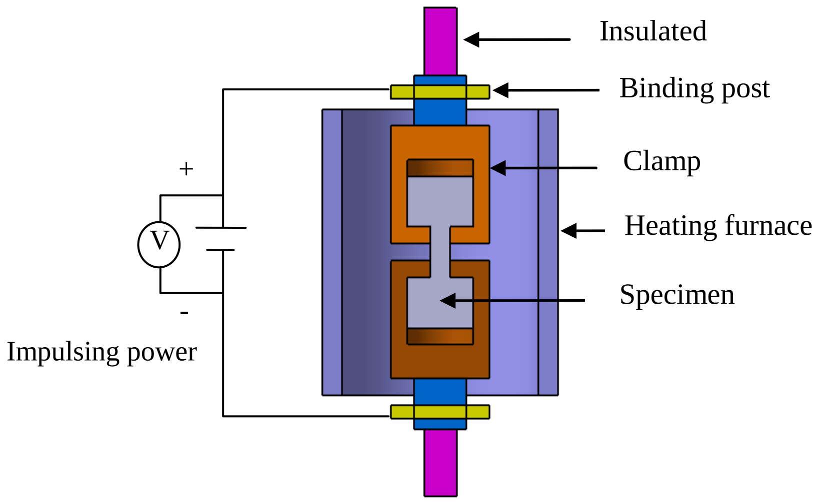
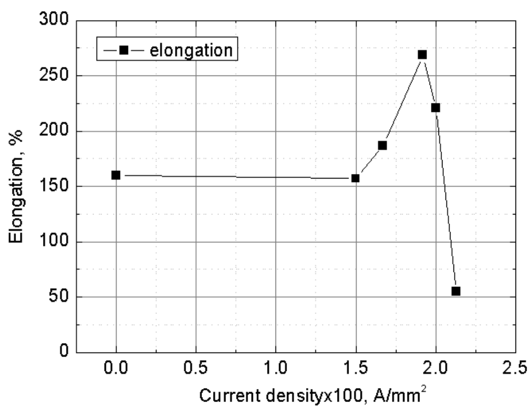


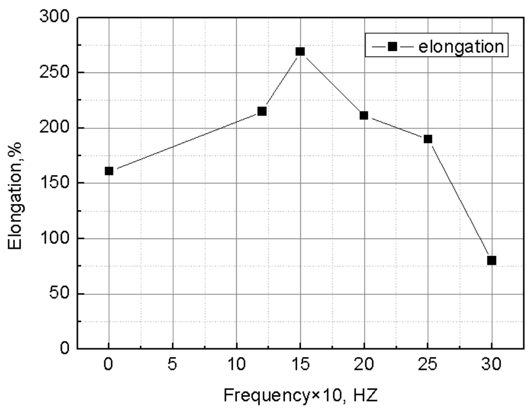

**Figure 2.** Schematic diagram of electro-superplastic tensile test

## 3. Results and Discussion

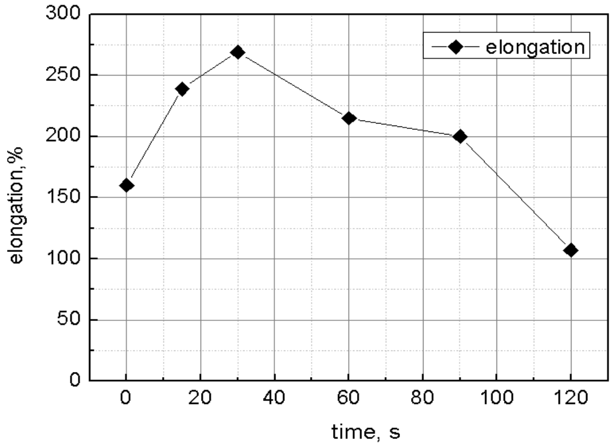
Elongation is the main parameter which is used to evaluate the superplastity. The effects of current density j, frequency f and duration t of electropulsing on elongation of 1420 Al-Li alloy superplastic tensiling are shown in Fig.3. After exceeding a critical current density $j_c$ of 150A /mm$^2$, elongation is firstly increased and then decreased with current density j raised. The elongation reached the maximum elongation of 270%atthe current density of 192A /mm$^2$, which occurs 68% increase compared to non-EST (Electro-superplastic tensile). The frequency and duration of electropluse also have a significant effect on the elongation. When the frequency and duration increase, the elongation is firstly increased and then decreased. When the frequency reaches 300Hz, the elongation is decreased rapidlyto 80%. This value is lower than that of non-EST. It is inappropriate that the duration of electropulse is t kept for a long time. The elongation is decreased when the duration is over 30s. Because the cavities are nucleated and grown during superplastic deformation, when they are grown to a certain size, the electropulse can accelerate the development of the cavities, and has a disadvantageous effect on the deformation. Under the experimental conditions, the optimal electrical parameters for superplastic deformation are 192A/mm$^2$ of pulsed current density, 150Hz of frequency and 30s of duration.




(a)Current density - Elongation




(b) frequency – Elongation




(c) Duration-Elongation

**Figure 3.** The effects of electric parameter on elongation of 1420 Al-Li alloy

Typical true stress-strain curves obtained in the constant cross-head speed tests with and without electropulse at the temperature of 440 ℃and 480 ℃with an initial strain rate of $0.001s^{-1}$ are shown in Fig.4. The tensile behaviors are in agreement with those reported by others [11]. The strain hardening firstly occurs up to some strain, which is followed by softening. At the same strain rate, the flow stress is decreased as the temperature increases. Electropulse can not only decrease the flow stress but also improve the deformation property during superplastic deformation of fine grained 1420 Al-Li alloy. For example, the peak stress is 29.2MPa and the strain is 0.66 when superplastic deformation is conducted at the temperature of 440 ℃and strain rate of $0.001s^{-1}$, but the peak stress is dropped to 19MPa and the strain is increased to 0.84 when electropulse is applied under the same temperature and strain rate. The reduction in peak stress is about 35% and the increase in strain is 27%. Upon increasing temperature to 480 ℃, the electropulse also had influence on the tensile curve, and the influence law is similar to 440 ℃. The trend of tensile curve is a steady state when electropulse is conducted at 480 ℃ and $0.001s^{-1}$.

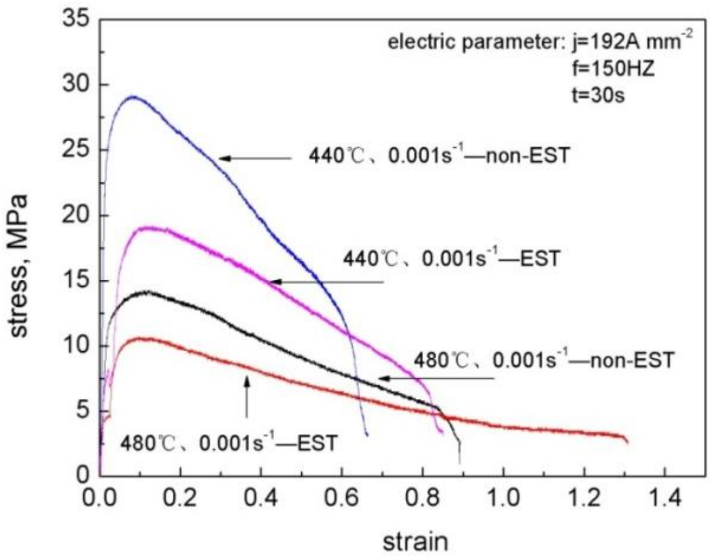



**Figure 4.** True stress-strain curves at different parameters

The original microstructure of 1420 Al-Li alloy is not completely recrystallization, and partial strip grains exists. Because dynamic recrystallization is occurred during superplastic deformation, local microstructure is refined. Fig.5 shows micrographs of the grain in specimensdeformed with and

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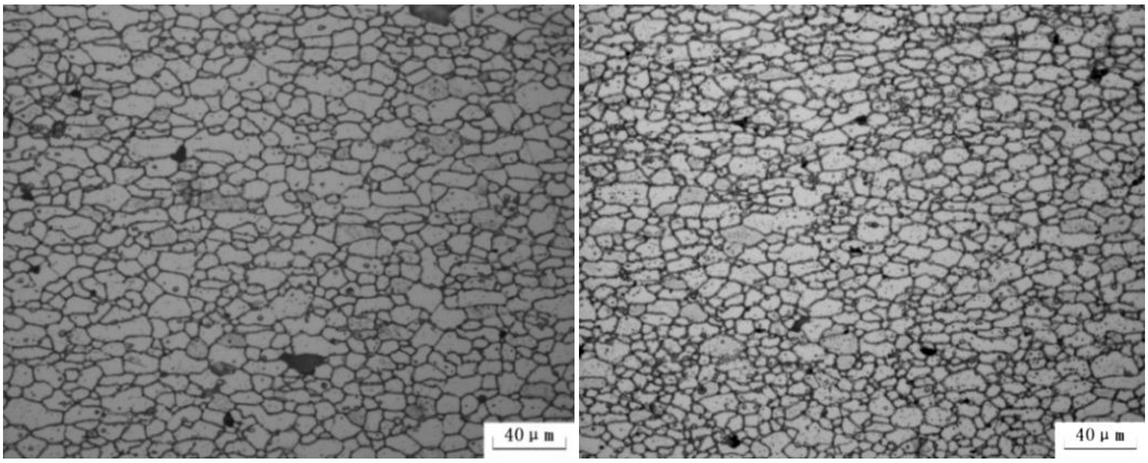
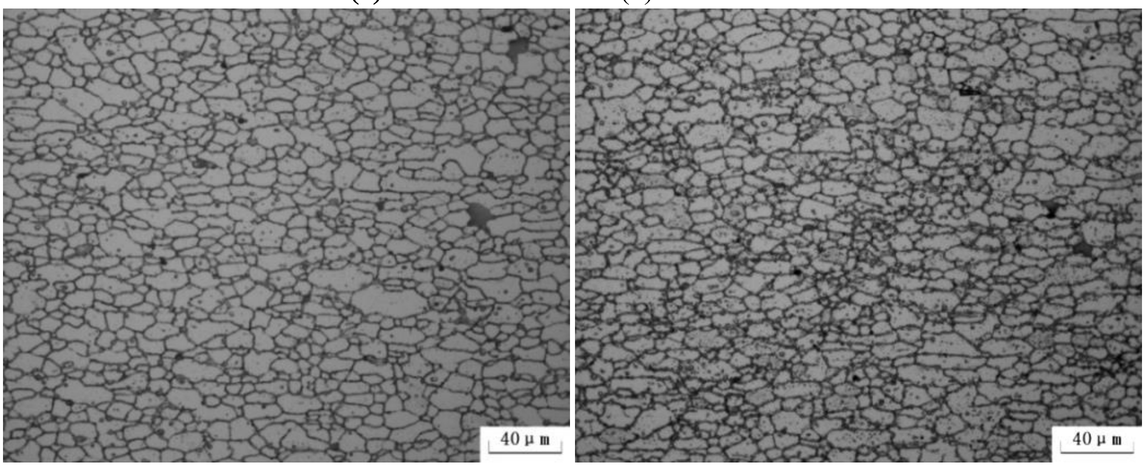
without electropulse at the temperature of 480 ℃ and strain rate of $0.001s^{-1}$. It is evident that the electropulse brings significant effect to microstructure, and the grains become more refined and uniformity after superplastic deformation under the electro pulse acting at the same strain.

In order to evaluate the grain size quantification ally, the average grain size is calculated under different deformation condition. Fig.6 shows the average grain size under different strain with and without electropulse at the temperature of 480 ℃ and strain rate of $0.001s^{-1}$. It should be noted that the electropulse significantly reduced the average size of grain, especially at the condition of lower strain. The average grain size is only 13.6μm of EST, and which is lower than 14.8μm of non-EST when the strain is 0.47. However, the grain size after superplastic deformation is all larger than origin grain size. It is noted that not only dynamic recrystallization occurs during superplastic deformation, but also grain growth exists. Grain growth is suppressed and nucleation of recrystallization can be accelerated by electropulse, so the average grain size is smaller than that of non-EST.




(a) ε=0.47 non-EST (b)ε=0.47 EST




(c)ε=0.69 non-EST (d)ε=0.69 EST

**Figure 5.** Microstructure of 1420 Al-Li alloy after superplastic deformation at 480 ℃, $0.001s^{-1}$(Electropulse parameters: $192A/mm^2$, 150Hz, 30s)

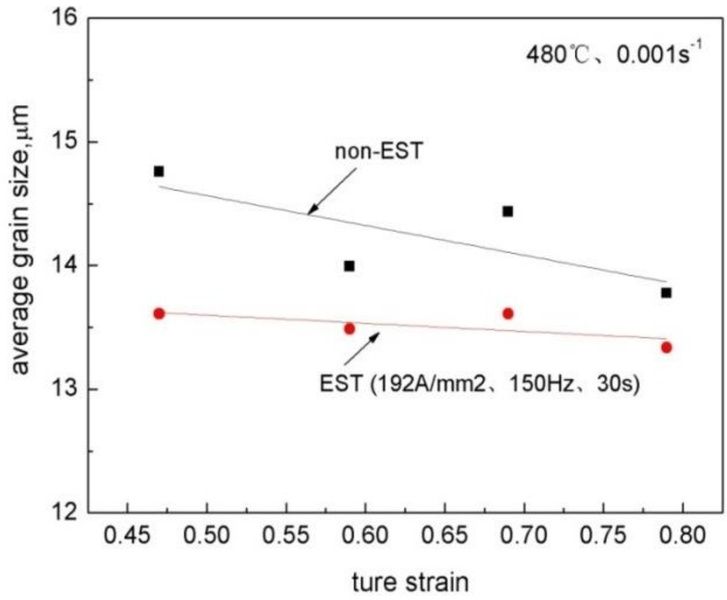



**Figure 6.**The relationship of the average grain size and strain under non-EST and EST

## 4. Conclusion

(1) An external electropulse applied during the superplastic deformation of 1420 Al-Li alloy bring significant effect to elongation. There is a critical current density of 150A/mm$^2$, and exceeding it the influence becomes obviously. The elongation is first evaluated and then reduced as the frequency and duration increasing. Under the experimental conditions, the optimal electrical parameters are192A/mm$^2$ of pulsed current density, 150Hz of frequency and 30s of duration.

(2) Electropulse can not only improve the deformation property but also bring significant effect to σ-ε curves. Under the same temperature and strain rate, the peak stress is reduced by electropulse during superplastic deformation. The trend of σ-ε curve is to steady state when electropulse is conducted at 480 ℃ and 0.001s$^{-1}$, compared to that without electropulse.

(3) It is noted that compared to without electropulse at the same deformation condition, grain is refined and average grain size is reduced after superplastic deformation under the parameter of 192A/mm$^2$, 150Hz, 30s. It is concluded that the effect of electropulse is primarily on promoting the grain nucleation and restraining the grain growth.

## 5. Acknowledgments

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