103 Superplasticity in a 7475 Aluminum Alloy subjected to severe plastic deformation

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A high-strength 7475 aluminum alloy subjected to severe plastic deformation through hot equal channel angular extrusion (ECAE) with and without isothermal rolling (IR) was studied in tension at strain rates ranging from 2.7×10^{-5} to $5.6 \times 10^{-2} \text{ s}^{-1}$ and temperature of $\sim 450^\circ\text{C}$. It was established that IR slightly affect the superplastic ductilities. The alloy subjected to ECAE exhibited the maximum elongation of $\sim 720\%$ at a temperature of 450°C and an initial strain rate of $5.6 \times 10^{-3} \text{ s}^{-1}$. Superplastic elongation of $\sim 660\%$ was recorded at strain rates higher than 10^{-2} s^{-1} , in isothermally rolled 7475 aluminum alloy.

Keywords: Aluminum alloy; Fine-grained structure; Equal channel angular extrusion; Rolling; Superplasticity; Microstructure

1. Introduction

The 7475 aluminum alloy (AA7475) is widely used as structural materials because of its high strength combined with sufficiently fracture toughness, fatigue and ductility. Fabrication of the complex airframe parts requires enhanced workability, that can be achieved by making this material superplastic through grain refinement [1,2]. Recently, it has been shown that in aluminum alloys the grain size may be significantly reduced by imposing a severe plastic deformation (SPD) through ECAE [3-7]. Aluminum alloys having such an ultra-fine structure are capable to exhibit superplastic ductilities at higher strain rates ($>10^{-2} \text{ s}^{-1}$) or lower temperatures [3-7]. ECAE is highly suitable for achieving superplasticity in bulk billets of aluminum alloys which may be used in superplastic forging operations. Also, it was recently shown [7-9] that aluminum alloys with ultra-fine grain structure could be produced in sheets through combination of ECAE and rolling. Therefore, the ECAE followed by rolling is considered as an advanced technique for the fabrication of thin superplastic aluminum sheets.

The present study was initiated in order to evaluate the potential for using ECAE and ECAE+IR to attain a fine grain size in the bulk billets and sheets of the 0.16% Zr modified AA7475. The aim of present experiments is to show that ECAE and ECAE+IR may be used to achieve high strain rate superplasticity (HSR SP) at relatively low temperatures in the AA7475.

2. Material and experimental procedure

The material used was a modified version of the AA7475 with a chemical composition Al-6%Zn-2.5%Mg-1.8%Cu-0.16%Zr-0.23%Cr (in weight %). This alloy was manufactured by direct chill casting followed by solution treatment at 490°C for 24 h and annealing at 410°C for 8 h. Then ingot was cut into rods with 20 mm in diameter and 100 mm in length. The rods were repetitively pressed through the dies at 300°C to a total strain of ~ 12 , and the samples were rotated by 90° in the same direction between each pressing (i.e. route Bc).

The as-pressed rods were heated at 300°C and then rolled to a final thickness of 1.7 mm, giving a total reduction of 85%. A 6-high mill with isothermal internal rollers was used. The internal rollers were heated and kept at 300°C during rolling.

Tensile specimens of 6 mm gauge length and $1.5 \times 3 \text{ mm}^2$ cross-section were machined parallel to the extrusion and rolling direction for extruded and rolled samples, respectively. These samples were tensioned to failure in the temperature interval of $425\text{--}450^\circ\text{C}$ at strain rates ranging from 2.7×10^{-5} to $5.6 \times 10^{-2} \text{ s}^{-1}$. The values of the strain rate sensitivity m were determined by strain rate jump tests [1,2]. The other details of mechanical tests were described in previous reports [9, 10], where the methods of optical metallography, transmission electron microscopy and electron backscattering diffraction (EBSD) analysis were also described.

3. Experimental results

Typical EBSD maps after ECAE and ECAE followed by IR are presented in Fig. 1. It is clearly seen in Fig. 1a, that a non-uniform microstructure consisting of two components is developed after 12 passes of ECAE. The first one is new developed grains with high-angle grain boundaries (HAGBs).

Fig. 1. Microstructure of the AA7475 after ECAE (a) and ECAE followed by IR (b).

Their fraction is $\sim 48\%$. The other type is highly elongated initial grains having a well-defined subgrain structure. The average size of fine grains and subgrains is $\sim 0.85 \mu\text{m}$. The fraction of HAGBs is $\sim 77\%$. Thus, the deformed structure is a partially recrystallized with high fraction of HAGBs. Subsequent IR not resulted in the formation of more uniform microstructure (Fig.1b). The fraction of HAGBs is $\sim 79\%$. In addition, IR following ECAE

increased slightly the average grain and subgrain size to $\sim 1.05 \mu\text{m}$.

Fig. 2 shows the flow stresses, σ , the coefficient of strain rate sensitivity, m , and the elongation-to-failure, δ , vs. strain rate relationships. The σ - $\dot{\epsilon}$ curve shows weak evidence of a sigmoidal shape, however, three regions of superplastic deformation can be identified [1,2]. The maximum values of elongation-to-failure and the coefficient of strain rate sensitivity were occurred in the second region and tend to decrease on either side of the strain rate associated with these maximum values (Figs. 2b and c). The AA7475 processed to ECAE demonstrate well-defined maximum elongation of 720% at 450°C

Fig. 2. Strain rate dependence of flow stress, σ , taken at $\epsilon \sim 0.34$ (a), coefficient of strain rate sensitivity, m , (b) and elongation-to-failure (c).

and $\dot{\epsilon} \sim 5.6 \times 10^{-3} \text{ s}^{-1}$. At other strain rates elongations do not exceed 450%. The alloy processed to ECAE followed by IR show maximum elongation of 660% at $\dot{\epsilon} \sim 1.4 \times 10^{-2} \text{ s}^{-1}$. This may suggest the occurrence of HSR SP in the AA7475 subjected to ECAE followed by isothermal rolling. The 0.16% Zr modified AA7475 exhibit maximum values of δ and the m coefficient at lower temperatures than conventionally TMPed AA7475 [12, 13]. For example, fully recrystallized AA7475 with grain size of about 7–14 μm are shown high superplastic properties ($\delta \sim 800$ –1200% and $m \sim 0.5$ –0.6) at temperature of $\sim 516^\circ\text{C}$ [12, 13]. The present alloy are capable to exhibit elongation higher 320% and $m > 0.3$ in the strain rate interval 10^{-3} – 10^{-2} s^{-1} while conventionally TMPed AA7475 showed

marginal superplastic properties at such strain rates [12,13].

4. Discussion

The present study demonstrates the feasibility of achieving grain refinement and superplastic ductilities in the 0.16% Zr modified AA7475. This work established ECAE and ECAE+IR as a very effective processing technique to introduce ultra-fine grain size of $\sim 1 \mu\text{m}$ in bulk billets and sheets of the AA7475 alloy. It is known [1,2,13], that the strain rate associated with highest superplastic ductility varies inversely with the grain size raised to a power of ~ 2 or ~ 3 ; the superplastic regime is displaced to higher strain rates when the grain size is reduced. Conventional TMP of the AA7475 results in grain size ranging from 7 to 14 μm [11, 12]. In contrast, ECAE and ECAE+IR provide the formation of partly recrystallized ultra-fine grained structure with the average size of 0.85 and $1.05 \mu\text{m}$, respectively. As a result, the present AA7475 showed optimum superplastic properties at strain rates close to 10^{-2} s^{-1} and temperatures appreciably less than those for the AA7475 subjected to conventional TMP [11, 12]. It is expected that optimization of parameters of the initial heat treatment as well as the ECAE and ECAE+IR processing routes, such as temperature, path or strain rate, can lead to uniform microstructure providing increased superplastic properties in the AA7475.

5. Conclusions

1. It was found that ECAE and ECAP+IR are useful for the formation of partly recrystallized ultra-fine grained structure in the 0.16%Zr modified AA7475.
2. The ultra-fine grained AA7475 exhibits some high strain rate superplasticity, with tensile elongations higher 320%, and a strain rate sensitivity coefficient higher 0.3 at strain rates of 10^{-2} s^{-1} and a temperature of 450°C .

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