Superplastic Deformation Behavior of 7075 Aluminum Alloy

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A study has been made to investigate the effect of a prior amount of warm rolling on the superplastic forming behavior of a standard grade 7075 aluminum alloy. The thermomechanical treatment process presented for grain refinement includes furnace cooling from the solution treatment temperature to the overaging temperature, warm rolling from 65-85% deformation, recrystallization, and artificial aging treatment. Increasing the amount of warm rolling beyond 80% deformation does not produce material with higher elongation to failure when the thermomechanical treatment process presented is used. The largest value of elongation to failure was 700%, which was obtained for a specimen having a grain size of 8 μm at a strain rate of $6 \times 10^{-3}S^{-1}$. The fracture surface exhibits a granular appearance indicative of an intergranular fracture mode. Dislocation activities within grains were observed, indicating the occurrence of dislocation slip during grain boundary sliding.

Keywords 7075 aluminum alloy, superplastic deformation, thermomechanical treatment, warm rolling

1. Introduction

Superplasticity has been the subject of numerous investigations, and a significantly wide variety of alloy systems are known to exhibit this property.[1-4] The structural prerequisites for developing superplastic materials have been well established for metal base materials. They mainly consist of:

1) fine grain size;
2) presence of second phase;
3) size and distribution of second phase; and
4) grain boundaries and their resistance to tensile separation.

The mechanism of superplastic deformation in fine-grained aluminum alloys is explained mainly in terms of grain boundary sliding accommodated by slip and grain boundary sliding accommodated by diffusional flow.[4] The aerospace industry needs structural, superplastic aluminum alloys that are formable at strain rates $>10^{-3}S^{-1}$ for the economic benefits of superplastic forming to be realized. The standard, structural, superplastic aluminum alloy in the aerospace industry is 7475 aluminum alloy, which has an optimum forming strain rate near $10^{-4}S^{-1}$. Technologically, it would be desirable to increase the maximum strain rate for superplastic flow. The most accessible feature that can be modified to achieve such an enhancement in superplasticity is to decrease the grain size.

In the current study an investigation of the effect of a prior amount of warm rolling on the superplastic forming behavior of a standard grade 7075 aluminum alloy at a strain rate of $6 \times 10^{-3}S^{-1}$ is presented.

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2. Experimental Procedures

The chemical composition of the 7075 aluminum alloy studied in this research is, in wt.%, Zn 5.9, Mg 2, Cu 1.32, Mn 0.2, Cr 0.12, Fe 0.42, and Si 0.19. A thermomechanical treatment process was carried out to produce a fine-grained microstructure by using a modified Wert method[5] (Table 1). Deformations (from 65-85%) were carried out by rolling at temperatures between 180-200 °C. Between passes through the rolling mill, specimens were inserted into the furnace for 5 min. Tensile testing was done in a three-zone furnace; chromel-alumel thermocouples for temperature control and measurement. The 7075 aluminum alloy was tested at 500 °C at the initial strain rate of $6 \times 10^{-3}S^{-1}$. Grain sizes before testing (recrystallized microstructure having equiaxed grains) were measured using

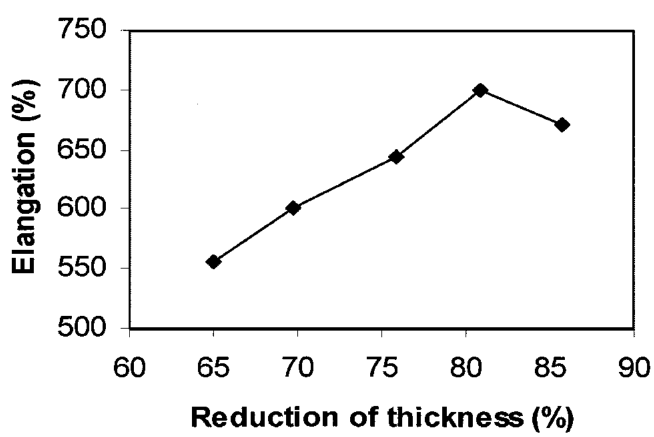

Fig. 1 Influence of warm rolling on elongation- to failure of the 7075 aluminum alloy

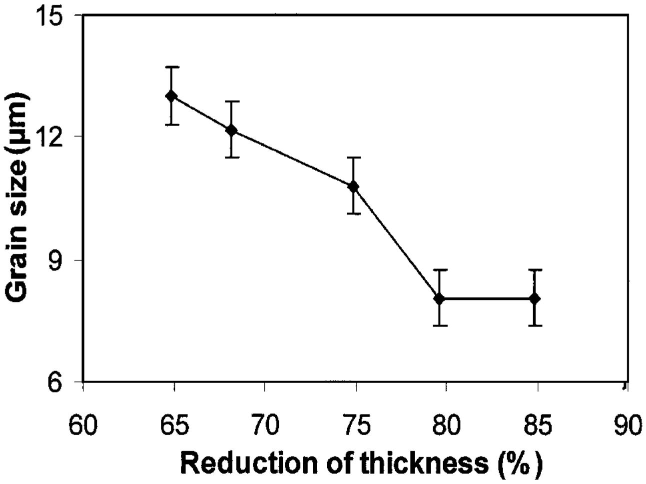

Fig. 2 Influence of warm rolling on grain size of the recrystallized 7075 aluminum alloy

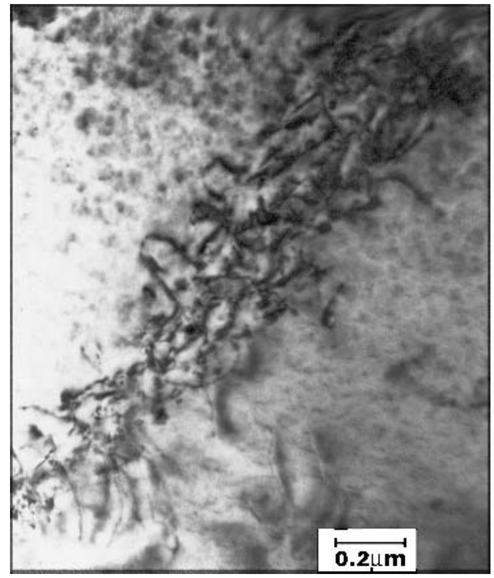

Fig. 3 TEM showing dislocation activities in the 7075 aluminum alloy tested at 500 °C

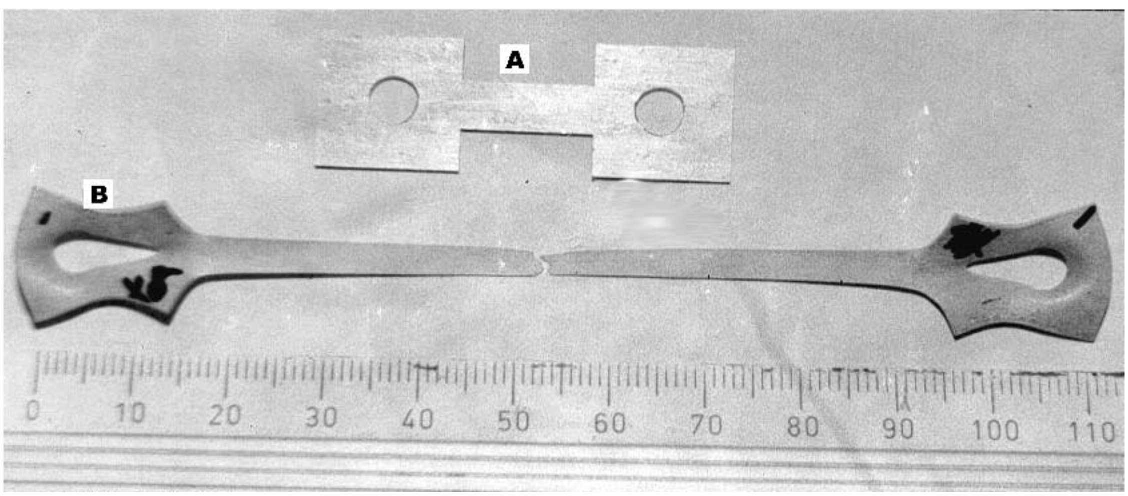

Fig. 4 Tensile specimens of 7075 aluminum alloy: **(a)** the original specimen; **(b)** the specimen tested at 500 °C at strain rate of $6 \times 10^{-3}S^{-1}$

Table 1 Thermomechanical Treatment Process Parameters Used in This Study

Step	Temperature	Time	Conditions
Solution treatment	500 °C	1 h	Furnace cooling to 380 °C
Overaging	380 °C	2.5 h	Furnace cooling to 190 °C
Warm rolling	180 °C	65-85%	Reduction of thickness
Recrystallization	500 °C	0.5 h	Water quench
Aging	180 °C	1 h	Water quench
Tensile testing	500 °C	···	Strain rate = $6 \times 10^{-3}S^{-1}$

the ASTM E112 standard intercept method with three concentric circles. Tensile and fracture surfaces were examined by scanning electron microscopy (SEM), and the microstructure was evaluated by transmission electron microscopy (TEM).

2. Results and Discussion

Elongation to failure measured at a constant true strain rate of $6 \times 10^{-3}S^{-1}$ of the 7075 aluminum alloy as a function of the

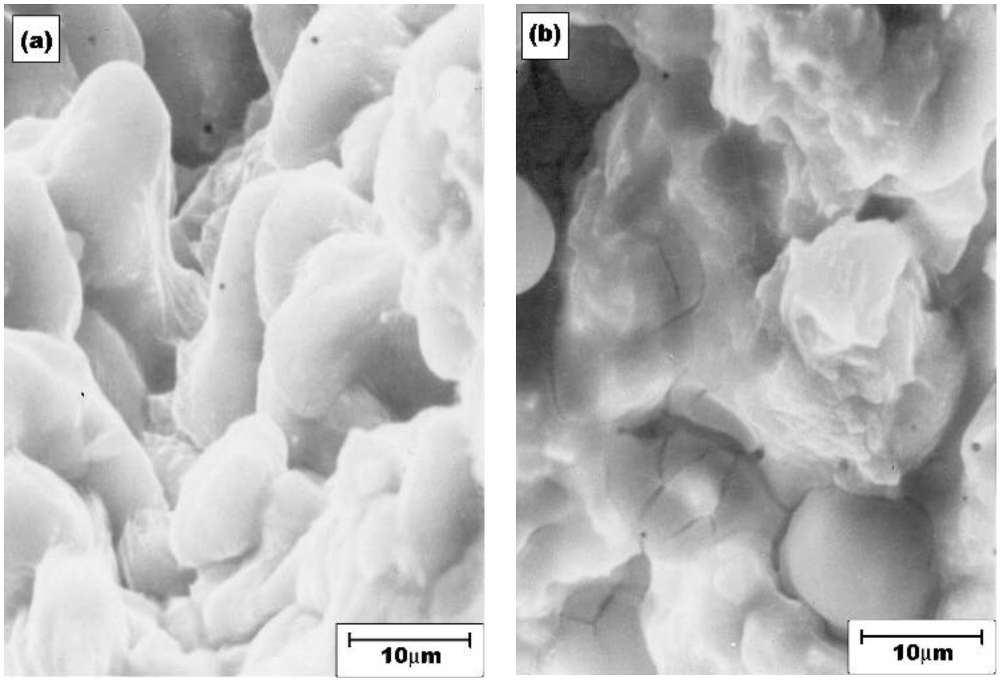

Fig. 5 SEM pictures of the fractures surface of the 7075 aluminum alloy tested at 500 °C; **(a)** warm rolled at 65% deformation, **(b)** warm rolled at 80% deformation

amount of warm rolling tested at 500 °C is shown in Fig. 1. The specimen warm rolled up to 80% deformation achieved the highest elongation to failure. The result shown in Fig. 1 implies that deformation beyond a strain of about 80% deformation does not create intense deformation zones around small particles. Grain size changes (of the recrystallized microstructure) as a function of warm rolling before testing is shown in Fig. 2. Increasing the amount of deformation beyond 80% does not produce finer grain sizes when the thermomechanical treatment process is used. Thus, the amount of warm rolling to produce an homogeneous, equiaxed, fine grained microstructure to obtain a superplastic deformation at a strain rate of $6 \times 10^{-3}S^{-1}$ should be around 80% deformation. Figure 3 shows the microstructure of the 7075 aluminum alloy as observed in the TEM in the gauge after superplastic forming deformation at 500 °C. A preliminary study of the microstructure indicates the presence of dislocation activities within grains, indicating the occurrence of dislocation slip during grain boundary sliding, probably to fulfill the accommodation role.

Figure 4 shows the macroscopic appearance of tensile specimen before and after superplastic deformation. No important macroscopic necking was observed in the gage sections of the failed specimens. It appeared that in all cases the failure was initiated by nucleation of micro-voids at grain-boundary-sliding. Subsequent vacancy diffusion and slip can enlarge voids into fissures, which propagate along the grain boundary resulting in intragranular cracking. A typical fracture surface for a superplastically deformed 7075 aluminum alloy specimen with a strain rate of $6 \times 10^{-3}S^{-1}$ is shown in Fig. 5. Close examination of the fracture surface revealed smooth, rounded grains on cavity interiors and evidence of localized microplasticity on the surfaces of some grains. Clearly, the two limiting factors in the total elongation to failure achievable in the 7075 aluminum alloy are the grain growth at high temperatures and the formation of micro-voids.

3. Conclusions

- Elongation-to-failure in excess of 700% was obtained with 7075 aluminum alloy at a strain rate of $6 \times 10^{-3}S^{-1}$. This superplastic forming behavior at high strain rate appears to be associated with the fine-grained microstructure in the alloy.
- Increasing the amount of warm rolling to 80%. Deformation causes intense deformation zones around all larger particles, thus providing a higher density of nucleation sites for new grains.
- TEM micrograph and SEM investigation of the fracture surface of the 7075 aluminum alloy indicated that during superplastic deformation grain boundary sliding accommodated by intragranular slip is the main mechanism of the deformation process.

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