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Microstructure and superplasticity of an Al-Zn-Mg-Cu alloy

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A new superplastic process was introduced in this paper. This new process is very simple and easy to use in practical production. Continuous recrystallization occurred during superplastic deformation and very fine grained microstructure formed, which provides excellent superplasticity for the Al-Zn-Mg-Cu alloy 7075.

1. Introduction

Superplasticity in aluminum alloys has been the subject of numerous research, development, and application efforts in the past thirty years. Grain refinement of aluminum alloys is usually needed to obtain superplasticity. For the grain refinement of 7475 and 7075 alloys, the TMT developed by Wert *et al*. [1, 2] is well known. The process includes solution treatment, overaging at high temperature followed by water quench, warm rolling at 493 K and finally rapid heating. However, there is some difficulty to apply the above TMT to industrial production. A new TMT was developed by Yoshida [3] which includes hot rolling, solution treated and slow cooling (less than 0.2 K/s) from the temperature range of 673–753 K, cold rolling and finally rapid heating. The grain size is less than 10 μm and the alloy sheet exhibit splendid superplastic properties at 773 K or over. Metallographic observations show that static recrystallization occurs in the alloys during rapid heating.

In Al-Li alloys [4, 5] and other alloys [6–8] with the addition of Zr, the alloys with warm or cold rolled microstructures were usually superplastic deformed. The continuous recrystallization occurred during superplastic deformation and fine grained microstructures were obtained. Compared with the TMT used in 7475 and 7075 alloys, the thermomechanical treatment is simple. However, Al-Zn-Mg-Cu alloys are thought to be discontinuous recrystallized alloys and it is very difficult to get the fine grained microstructures and excellent superplasticity by continuous recrystallization.

In this paper, a simple process has been developed for 7075 alloy that includes solution treatment, furnace cooling and rolling. The rolled alloy was superplastic deformed directly. The temperature of superplastic deformation was increased during superplastic deformation. The alloy exhibits excellent superplasticity. A similar superplastic processing was conducted to the received sheet to examine the effect of increasing temperature stretching.

2. Experimental

The material used was 7075 alloy with the chemical composition of Al-5.90Zn-2.60Mg-1.20Cu-0.24Cr-0.26Fe-0.16Si (all in wt %). The hot pressed rod was forged at 723 K. Then the alloy was solution treated at 758 K for 2 h and furnace cooled to 623 K, then rolled 85% in the reduction of thickness at the initial temperature of 623 K at 6 passes. Between passes the material was not reheated so the rolling was warm rolling + cold rolling. The final thickness of the plates was 1 mm. Tensile specimens with a 4 mm gage width and an 8 mm gage length were stretched at 593–773 K in the strain range from 2×10^{-4} to 2×10^{-3} s^{-1}. The microstructures were studied by optical and transmission electron microscopy.

3. Results and discussion

The testing condition and tensile elongation of the alloy are given in Table I. It can be seen that the alloy exhibits a tensile elongation of 350% when stretched at 773 K. While the alloy exhibits much higher elongation when stretched at low temperature and increasing temperature (593–723 K) during tensile tests. At optimum condition, the elongation of the alloy is higher than 920%.

From Table I it can be also seen that the elongation of the alloy decreases with the initial tensile temperature at increasing temperature stretching. The alloy exhibits lower elongation at constant temperature stretching. The optimum superplastic strain rate is also higher that of the 7475 alloy by conventional thermomechanical treatment (2×10^{-4} s^{-1}).

Fig. 1 shows the flow stress-tensile elongation curve of the alloy at optimum condition. The flow stress-tensile elongation curve of the 7475 alloy when stretched after stand TMT (solution treated and quenching-overaging-warm rolling-recrystallization treatment) is also given for comparison. From Fig. 1 it can be seen that the flow stress of the 7475 alloy increases slowly and reaches the stable condition at about 100% during superplastic deformation. While the flow stress of the 7075 alloy increases rapidly and reaches the maximum at about 25%. The flow stress decreases gradually afterwards and reaches the stable condition at about 220%. The stable stress of the 7075 alloy is much lower than that of the 7475 alloy.

The *m* values of the alloy in optimum condition (specimen 1-5) are given in Table II. The *m* values were measured during superplastic deformation by changing load method. The *m* values increases during superplastic deformation and keeps stable after 250%.

Optical microscopic observation has found that the alloy exhibits coarse recrystallized microstructure (grain size is larger than 30 μm) after forging and solution treatment. The grains were highly elongated after rolling. These elongated grains were recrystallized and fine grains were formed during increasing temperature stretching.

Transmission electron microscopic observation has been found the fine second-phase particles with the size of 0.1 μm in the alloy after solution treatment. Energy Dispersive (EDS) analysis shows that the particles are mainly Cr-rich dispersoids. After furnace cooling the second-phase particles with two different sizes were precipitated (Fig. 2a). EDS analysis shows that the coarse particle ($\sim$1 μm) is M phase, the mixture of $MgZn_2$ and MgAlCu phases. While the fine particles ($\sim$0.1 μm) are M phases and Cr-rich dispersoids. High density of dislocations were introduced by rolling and the secular structure with the size of 1–2 μm was formed (Fig. 2b). During increasing temperature stretching recovery occurred firstly and subgrains with low misorientation angles were formed. Continuous recrystallization occurred then and fine grained microstructure was formed. Grain coarsening occurred afterwards. Fig. 3 shows the microstructure after superplastic deformed 200 and 350% at increasing temperature stretching. Continuous recrystallization occurred in most area after deformed 200% and homogeneous grains can be seen (Fig. 3a). There are also very small area with subgrains (Fig. 3b). Some small grains on the grain boundary can be also seen,

TABLE I Tensile elongation of the alloy in different condition

Specimen	Tensile condition	Elongation (%)
1-1	773 K, constant temperature, 1×10^{-3} s^{-1}	350
1-2	723–773 K, increasing temperature, 1×10^{-3} s^{-1}	420
1-3	673–773 K, increasing temperature, 1×10^{-3} s^{-1}	520
1-4	648–773 K, increasing temperature, 1×10^{-3} s^{-1}	850
1-5	598–773 K, increasing temperature, 1×10^{-3} s^{-1}	920[a]

[a]Specimen was not failure.

TABLE II The *m* values of the alloy during superplastic deformation

Elongation (%)	*m* value	Elongation (%)	*m* values
13	0.230	30	0.240
60	0.280	100	0.325
140	0.380	200	0.450
250	0.505	300	0.505

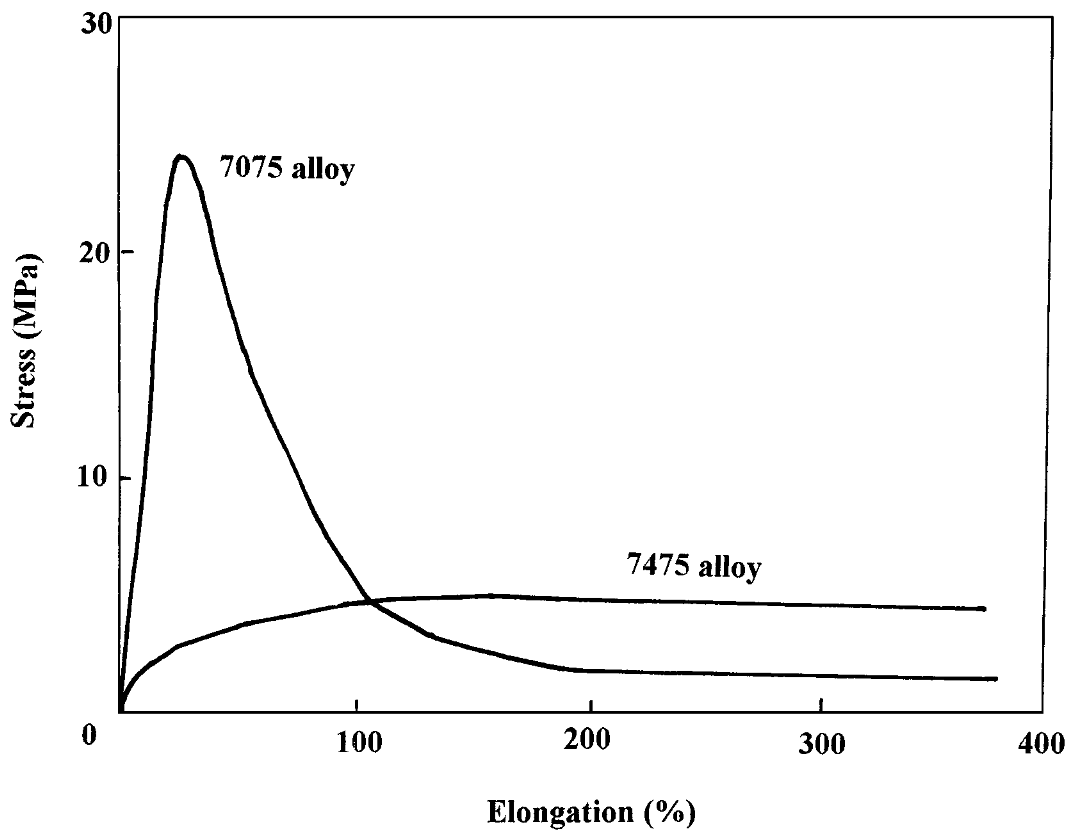

Figure 1 Tensile stress-elongation curves of the 7075 and 7475 alloys.

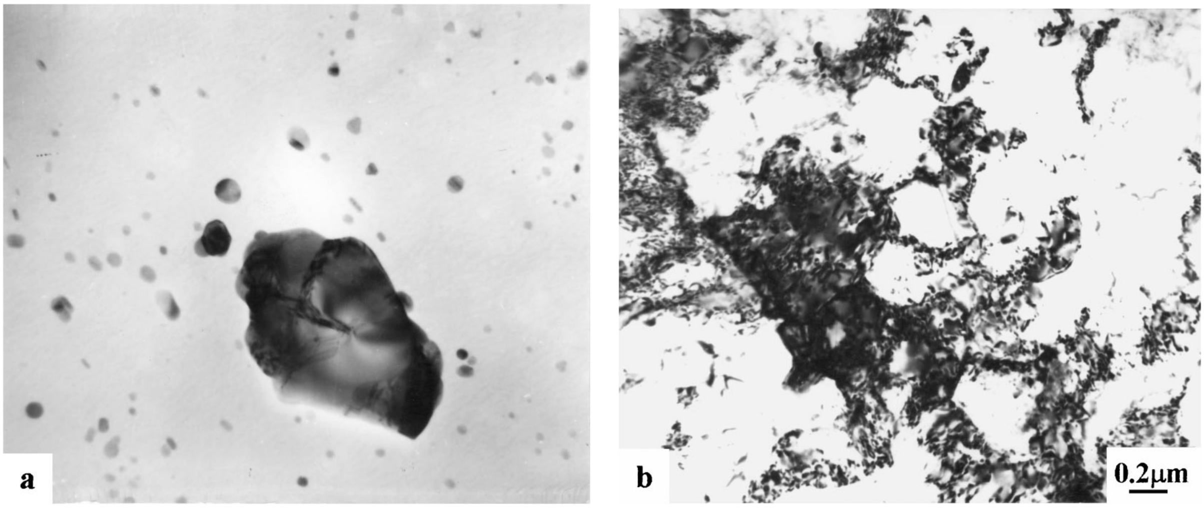

Figure 2 Microstructures of the 7075 alloy during pre-treatment: (a) solution treatment and furnace cooling and (b) solution treatment and furnace cooling → rolling.

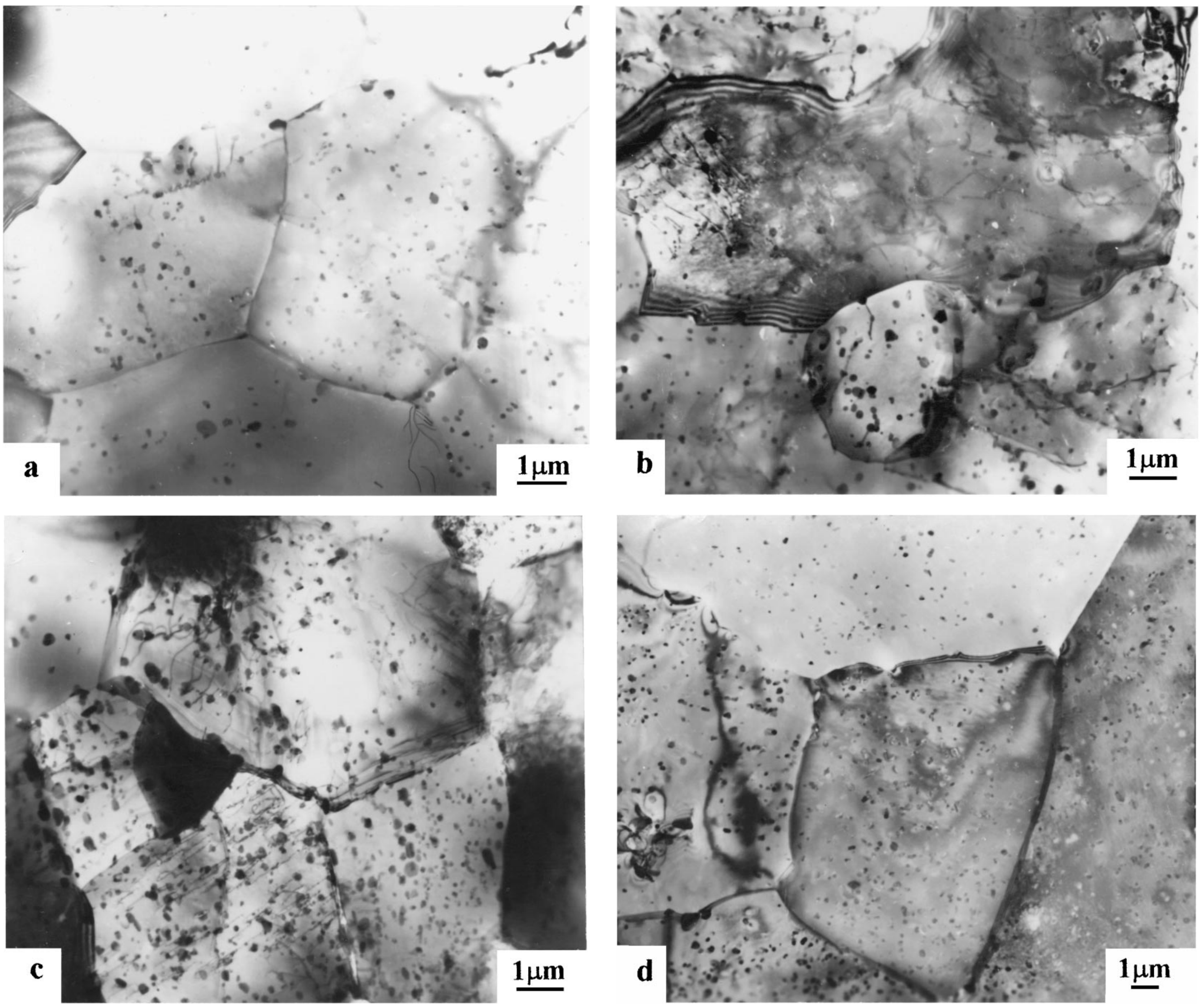

Figure 3 Microstructure variation during superplastic deformation: (a) $\varepsilon = 200\%$, grain morphology, (b) $\varepsilon = 200\%$, sub-grain morphology, (c) $\varepsilon = 200\%$, a small grain formed on grain boundary and (d) $\epsilon = 350\%$, grain morphology.

which is thought to be formed by dynamic recrystallization. Fig. 3c shows one of them. After deformed 300%, the recrystallization is completely finished and grains with misorientation degrees of 15 can be seen (Fig. 3d).

Fine grain sizes have previously been produced in aluminum alloys by two methods. The first approach used by Matsuki and co-workers [6–8] utilizes the role of Zr in maintaining very fine grain sizes through fine scale precipitation of Al_3Zr. Superplasticity was observed after appropriate thermomechanical treatments leading to continuous recrystallization. The second approach to make superplasticity is that of Wert *et al.* [1, 2]. On developing superplasticity in Al-Zn-Mg-Cu series Al alloys. The thermomechanical process includes 4 steps and refines the grains by discontinuous recrystallization. For the Al-Zn-Mg-Cu alloys have been thought to be typical discontinuous recrystallized materials. This process is still thought to be the only effective method in Al-Zn-Mg-Cu alloys to get fine grained microstructures. However, this process is very complicated, which needs long time of overaging and high heating rate for recrystallization, and not easy to apply in industrial production.

The new process combines rolling of the plates and thermomechanical treatment, omits water quenching, long time of overaging and rapid heating, changes warm rolling into continuous rolling. This process is very simple and similar to rolling process used in practical production, which is very easy to use in aluminum industry.

The flow stress-tensile elongation curves in Fig. 1 are consistent very well with the microstructural variation during superplastic deformation. Fine grained microstructure were formed by TMT for the 7475 alloy and the microstructure kept stable in superplastic deformation. While the rolled microstructure was recovered and recrystallized for the 7075 alloy during superplastic deformation, the flow stress kept stable after the recrystallization finished.

In aluminum alloys superplasticity is easy to obtain by continuous recrystallization. However, the superplasticity is not very good in wrought alloys except Zr containing alloys. The results indicate that the optimum temperatures for the recrystallization and superplastic deformation of the aluminum alloys are usually different. By increasing temperature stretching, the recrystallization occurs at low temperature and large proportion of superplastic deformation occurs at high temperature in the 7075 alloy. The alloy obtains excellent superplasticity firstly by continuous recrystallization and then by fine grained microstructures. Furnace cooling produced high density of secondary phase particles and continuous rolling introduced homogeneous deformation into the alloy. During the early stage of deformation continuous recrystallization occurred and fine grained microstructures were gradually formed, the material exhibited low *m* value. The *m* value increased then and the material showed fine grained superplasticity.

The alloy was processed by solution treatment → furnace cooling → continuous rolled 85%. The alloy exhibits excellent superplasticity during increasing temperature stretching. The pre-treatment is similar to the processing in the practical production. In order to examine the effect of increasing temperature stretching, the 7075 alloy purchased in the plant was deformed by increasing temperature stretching without any pretreatment. The alloy sheet with 2.0 mm was hot and cold rolled in the plant. The alloy exhibits more than 400% elongation at the strain rate of 8×10^{-4} and the temperature range 320–500 °C. This result is very important for practical production.

4. Conclusion

The 7075 alloy exhibits excellent superplasticity by solution treatment and furance cooling → continuous rolling combined with increasing temperature stretching. New process is very simple and easy to use in practical production. Continuous recrystallization occurs during superplastic deformation and very fine grained microstructure was formed, which simplifies the thermomechanical treatment and provides high strain rate and low stress for the alloy. This incresing temperature stretching is also suitable to the sheets produced in practical production.

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