High-Strain-Rate Superplasticity in an AZ91 Magnesium Alloy Processed by Ingot Metallurgy Route

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The material used in the present study was a commercial magnesium alloy, AZ91. The alloy was initially produced by ingot casting. The material was solution treated at 686 K for 48 h, followed by hot extrusion at 523 K with a reduction ratio of 44. Microstructures were observed by a color laser 3D profiler microscope using a light screen mode and a transmission electron microscope.

Tensile specimens, machined directly from the extruded bars, had tensile axes parallel to the extruded direction. The specimens had a gauge length of 5 mm and a gauge diameter of 2.5 mm. To investigate the high-strain-rate superplastic...
behavior of the extruded material, constant strain rate tensile tests were carried out at $1 \times 10^{-2}$ s$^{-1}$ at temperatures ranging from 523 to 623 K in air. In addition, a strain rate change test was carried out at 548 K to obtain the strain rate sensitivity exponent, $m$, over the wide range of strain rates.

3. Results and Discussion

3.1 Microstructures of extruded material

The microstructure of as-extruded AZ91 was composed of equiaxed matrix grains and uniformly dispersed fine particles. The particles were observed to reside in the grain boundaries. The particle seems to be Mg$_{17}$Al$_{12}$. The particle diameter was estimated to be about 0.3 µm from the transmission electron micrographs. The matrix grain size, $d = 1.74 L$ ($L$ is the linear intercept size), of the as-extruded material was measured to be 1.7 µm. It is noted that fine-grained AZ91 was attained only by hot extrusion. The grain refinement is probably attributed to the dynamic recrystallization during hot extrusion. The grain size of the present material is also included in Fig. 1. It is evident that the small grain size of the present material is also owing to the low extrusion temperature.

The typical microstructure of extruded material is shown in Fig. 2 after the specimen was annealed at 548 K for 1.8 ks. The grains were still fine at this temperature. The grain sizes at given temperatures are shown in Fig. 3. The grain size was remained almost unchanged at temperatures below 573 K, but rapidly increased at higher temperatures. It is suggested that the Mg$_{17}$Al$_{12}$ precipitates can not contribute to pin the grain boundaries no longer at high temperatures. In Fig. 3, the grain sizes of AZ91 alloy processed by various routes are also included. It is obvious that PM alloy processed from RSP shows the high grain size stability even at 673 K. This is probably associated with the existence of stable oxide particles, which are introduced during atomization process.

3.2 Superplastic properties

The variation in (a) flow stress and (b) elongation-to-failure as a function of temperature is shown in Fig. 4. The flow stress was determined at a fixed strain of 0.1. The flow stress decreased monotonically with temperature below 573 K, but increased rapidly above this temperature and again decreased with temperature. The increase in flow stress above 575 K is probably associated with the rapid grain growth as has been shown in Fig. 3, since the flow stress of fine-grained material often depends on the grain size. The maximum elongation of 354% was obtained at a temperature of 548 K. The elongation value decreased at temperatures above 598 K in connect with the increase in flow stress and grain growth. Iwasaki et al. have already examined the superplastic behavior of IM AZ91 alloy at a temperature of 573 K. The data of IM AZ91 by Iwasaki et al. is included in Fig. 4. Their extruded material has similar grain size to the present result, although there is no description on the precipitates. It is evident that the present material exhibited lower flow stress and larger elongation at a
temperature of 573 K in spite of the similar initial grain size. The lower extrusion temperature of the present material may resulted in different distribution and size of precipitates, and thus difference in grain size stability at elevated temperature.

To characterize the effect of strain rate on plastic flow behavior, strain rate change test was carried out at 548 K. The variation in flow stress as a function of strain rate is plotted in Fig. 5. The flow stress for the present alloy increased with strain rate. The $m$-value, which was estimated from the slope of the line, exhibited 0.5 in the strain rate range investigated. This high $m$-value of 0.5 suggests the occurrence of superplasticity.\(^{19}\) It was found that the high-strain-rate superplasticity was attained in the IM AZ91 alloy processed by hot extrusion of ingot.

4. Summary

Hot extrusion was conducted at a relatively low temperature of 523 K to refine the microstructure of an ingot metalurgy magnesium alloy, AZ91. The resulting matrix grain size was 1.7 µm. Tensile tests revealed that high-strain-rate superplasticity was attained at $\sim 548$ K. The $m$-value was 0.5, and the large elongations of over 300% was obtained at a high strain rate of $1 \times 10^{-2}$ s\(^{-1}\). However, deformation above 598 K vanished superplasticity because of the rapid grain growth.

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