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Superplasticity for Solid-Recycled AZ31 Magnesium Alloy

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The solid state recycling is proposed as new recycling in metallic materials. One of the features for the solid state recycling is production of a high performance metal showing high strength and superplasticity from scraps because grain refinement is obtained during the solid state recycling. In the present paper, superplasticity and cavitation of the solid-recycle AZ31 Mg alloy are investigated. The elongation to failure of the solid recycled specimen was lower than that of the virgin extruded specimen. The cavity volume fraction in the solid recycled specimen was larger than that in the virgin extruded specimen. Therefore, it is suggested that significant cavitation is responsible for the lower elongation in the solid recycled specimen.
Key words: Mg alloy, recycle, grain refinement, superplasticity, cavitation

1. INTRODUCTION

Magnesium alloys are currently the lightest alloys used as structural metals and they have advantages such as specific strength and specific elastic modulus. Magnesium alloy products have been applied to automobile parts, electric appliance cases, etc. [1,2]. It is metallurgically difficult to refine magnesium scraps by remelting processes. Hence, most of the current recycling processes are downgrade recycling [3]. In order to increase the applicability of magnesium alloys, it is necessary not only to attain good characteristics (high strength, high ductility, high corrosion resistance, creep resistance, etc.), but also to develop useful recycling processes [4].

Recently, "solid state recycling" as a new method of recycling metals has been proposed [5-8]. In the solid state recycling, metal scraps are recycled by consolidation using plastic deformation processes such as hot extrusion [5-7] and BMA (Bulk mechanical alloying) [8]. The solid recycled magnesium alloy shows high strength due to grain refinement and homogeneous dispersion of the oxide film on the surface of scraps [5]. Futhermore, grain refinement of metal leads to superplasticity. Superplastic forming is expected to be applied to the actual processing for magnesium products due to poor ductility and formability in a solid state due to the HCP. Mabuchi *et al.* [5] investigated the tensile properties of AZ91 magnesium alloy recycled by the solid recycling process, and they showed that the solid recycled alloy shows a superplastic behavior, but that the elongation to failure of the solid recycled specimens is lower than that of the extruded specimen processed from a as-cast ingot. In the present study, superplasticity and cavitaion of a solid recycled AZ31 magnesium alloy are investigated.

2. EXPERIMENTAL PROCEDURE

Chips were prepared as magnesium alloy scraps by machining an as-received AZ31 (Mg - 2.9mass%Al - 0.85mass%Zn - 0.46mass%Mn) magnesium alloy in a lathe without lubricants. The machined chips are shown in Fig. 1. The machined chips were filled into a container with a diameter of 40 mm and extruded at 503 K with an extrusion ratio of 44:1 in air. For comparison, extrusions were processed from an as-received AZ31 magnesium alloy block under the same conditions as the extrusions from machined chips. In the present paper, extrusions from machined chips are called solid recycled specimens and those from as-received blocks are called virgin extruded specimens.

Superplastic behavior was investigated by tensile tests at 623K and at 3.3 x 10^{-4} s^{-1} to 3.3 x 10^{-2} s^{-1}. The tested specimens had a gauge length of 10 mm and a gauge diameter of 2.5 mm. The tensile axis was parallel to the direction of extrusion.

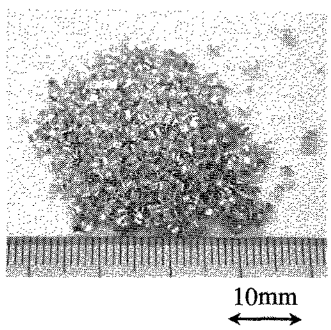

Figure 1 Photograph of machined chips of AZ31 magnesium alloy.

The volume fraction of cavities in the gauge length of the deformed specimens was measured by hydrostatic weighing in water, using a corresponding gauge head as a density standard. Also, the grain boundary sliding was investigated by scanning electron microscopy.

3. RESULTS AND DISCUSSION

Microstructure of the solid recycled specimen is shown in Fig. 2. A very small grain size of 3.5 μm was obtained for the solid recycled specimen. The grain size of the solid recycled specimen was the same as that of the virgin exturded specimen. The grain size of the as-received specimen prior to extrusion was 52 μm. Clearly, grain refinement was attainerd by hot extrusion. Mohri *et al.* [9] investigated microstructural evolution during hot deformation in a AZ91 magnesium alloy, and they revealed that a fine-grained microstructure was obtained due to continuous dynamic recrystallization. Therefore, it is suggested that the grain refinement of the extruded specimens is attributed to dynamic recrystallization during extrusion.

The variations in elongation to failure and flow stress at 623K as functions of strain rate for the solid recycled specimen and the virgin extruded specimen are shown in Fig. 3. The elongations of the virgin extruded specimen were 300% at 3.3 x $10^{-4}s^{-1}$ and 110% at 3.3 x $10^{-2}s^{-1}$, respectively. However, the lower elongations of 130% at 3.3 x $10^{-4}s^{-1}$ and 80% at 3.3 x $10^{-2}s^{-1}$ were obtained for the solid recycled specimen.

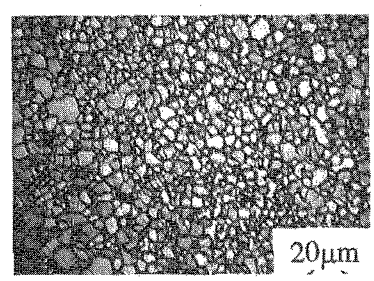

Figure 2 Microstructure of the solid recycled AZ31 magnesium alloy.

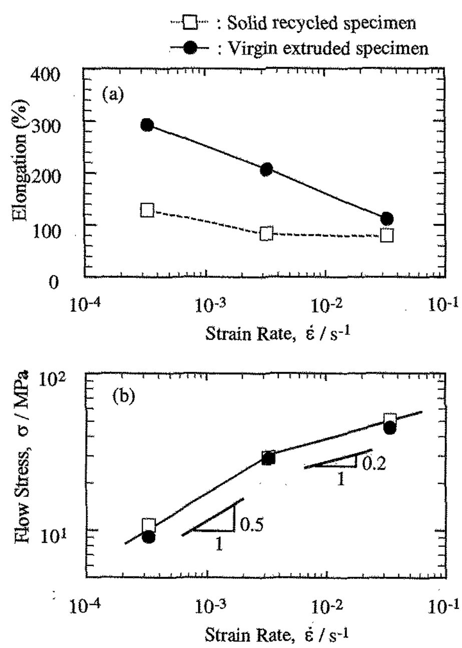

Figure 3 The variation in (a) elongation to failure and (b) flow stress at 623K as a function of strain rate.

In general, large elongation is obtained in the strain rate range where a high m value is observed, where m is the strain rate sensitivity of a stress. A high m value of about 0.5 was found in the strain rate range of 10^{-4} - 10^{-3} s^{-1} for both the solid recycled specimen and the virgin extruded specimen. This suggests that grain boundary sliding [10,11] is the dominant deformation process at 10^{-4} - 10^{-3} s^{-1} for both the solid recycled specimen and the virgin extruded specimen.

Figure 4 shows the side surfaces of the tensile specimens deformed at 3.3 x 10^{-4} and 3.3 x 10^{-2} s^{-1}. At the low strain rate of 3.3 x 10^{-4} s^{-1}, a bumpy surface, which indicates the occurrence of grain boundary sliding, was observed for both the specimens. It is clear that grain boundary sliding occurred in the strain rate range of 10^{-4} - 10^{-3} s^{-1} for both the specimens. Thus, there is no difference in deformation mechanism at 10^{-4} - 10^{-3} s^{-1} between the solid recycled specimen and the virgin extruded specimen. It is unlikely that the origin of the difference in elongation at 10^{-4} s^{-1} between the solid recycled specimen and the virgin extruded specimen is related to deformation mechanism.

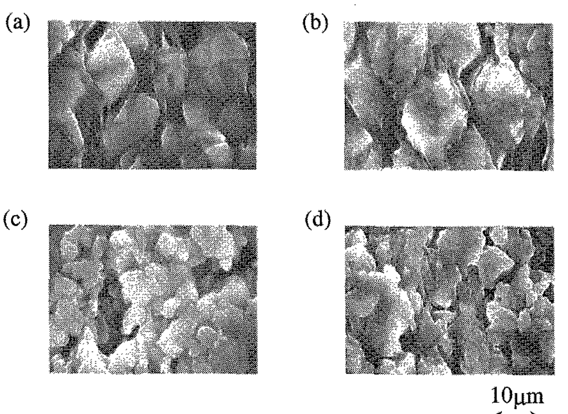

Figure 4 The side surface of the fractured tensile specimens, where (a) the solid recycled specimens deformed at 3.3×10^{-4} s^{-1}, (b) the virgin extruded specimens deformed at 3.3×10^{-4} s^{-1}, (c) the solid recycled specimens deformed at 3.3×10^{-2} s^{-1}, (d) the virgin extruded specimens deformed at 3.3×10^{-2} s^{-1}.

In a high strain rate range of 10^{-3} - 10^{-2} s^{-1}, the low m value of about 0.2 was obtained. Besides, grain boundary sliding was not active in both the specimens, compared with grain boundary sliding at 3.3 x 10^{-4} s^{-1}, as shown Fig. 4, indicating that there is no difference in deformation mechanism between the solid recycled specimen and the virgin extruded specimen in a strain rate range of 10^{-3} - 10^{-2} s^{-1} as well as 10^{-4} - 10^{-3} s^{-1}. The difference in elongation at a high strain rate of 10^{-2} s^{-1} between the solid recycled specimen and the virgin extruded specimen is somewhat smaller than that at a low strain rate of 10^{-4} s^{-1}.

The cavity volume fraction was investigated at a strain rate of 3.3×10^{-4} s^{-1} where there was the large difference in elongation between the solid recycled specimen and the virgin extruded specimen. The variation in cavity volume fraction as a function of strain is shown in Fig. 5. The volume fraction of cavities for the solid recycled specimen was larger than that for the virgin extruded specimen. Therefore, it is suggested that significant development of cavities is responsible for the lower elongation for the solid recycled specimen.

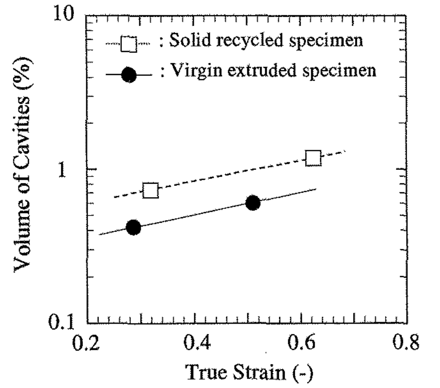

Figure 5 The variation in cavity volume fraction as a function of true strain for the AZ31 magnesium alloy specimens deformed at 3.3×10^{-4} s^{-1} and 623K.

In general, cavities are formed at grain boundaries in superplastic materials because cavity formation is attributed to the stress concentration caused by grain boundary sliding [12,13]. As a result of observation of cavity sites by optical microscopy, cavities were observed in the interior of grains as well as at grain boundaries in the recycled specimen. Watanabe *et al.* [14] noted that dislocation movement in the interior of grains plays an important role in accommodating grain boundary sliding in superplastic magnesium alloys. Oxides are considered to be dispersed in the recycled specimen. Therefore, it is suggested that dislocations are piled at the oxides dispersed in grains, resulting in cavity formation in the interior of grains in the solid recycled specimen.

4. SUMMARY

Superplasticity and cavitation in solid recycled AZ31 magnesium alloy have been investigated. The elongation to failure of the solid recycled specimen was lower than that of the virgin extruded specimen, though the strain rate sensitivity was the same for both the specimens.

The cavity volume fraction of thr solid recycled specimen was larger than that of the virgin extruded specimen. Therefore, it is suggested that significant cavitation is responsible for the lower elongation for the solid recycled specimen.

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