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USE OF THE SUPERPLASTICITY PHENOMENON FOR DEVELOPING A PROCESS FOR FABRICATING PARTS FROM MAGNESIUM ALLOYS

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Superplasticity of magnesium alloy ZK60A with an ultrafine-grain structure is investigated. It is shown that parts can be produced from this alloy by the method of superplastic gas forming.

INTRODUCTION

In recent years, the market of parts fabricated from magnesium alloys has increased by 20% every year due to a continuous decrease in the cost of production of magnesium alloys. The most promising directions are (*1*) the production of casings for such electron devices as video cameras, mobile phones, notebooks, etc. and (*2*) the production of car parts. In these two fields the application of magnesium alloys can grow considerably.

Today over 90% of magnesium parts are produced by the method of pressure casting (PC). At the same time, we have a market for parts from deformable magnesium alloys. These materials have improved physical and mechanical properties such as elevated strength and creep resistance. Fabrication of parts from sheets of magnesium alloys increases their rigidity and lowers the mass.

Production of articles from deformable magnesium alloys is a difficult process because magnesium alloys have a low ductility. Sheets are formed into parts by the method of deep extrusion at 150 – 200°C. It has been shown recently that superplastic gas forming is another effective means for making parts from sheets of magnesium alloys. Sheets of magnesium alloys having a fine-grained structure exhibit superplasticity at low temperatures and deformation rates close to 10^{-2} sec^{-1} [1]. This fact is very important from the standpoint of prevention of intense oxidation of alloys and of the possibility of fabrication of parts with complex geometry from a superplastic magnesium alloys at an acceptable cost.

Special Features of the Process of Forming Parts from Sheets of Magnesium Alloys in Superplastic State

We are interested in developing a process for making parts with complex geometry from sheets of magnesium alloys in the state of superplasticity. However, practical implementation of such a technology is limited by the relatively low rates of deformation of magnesium alloys. For example, the rate of deformation at which a standard AZ31 alloy exhibits superplasticity does not exceed 10^{-3} sec^{-1}. Accordingly, the duration of gas forming is about 40 min or even more. The necessity for using a low rate of superplastic forming limits commercial use of superplastic magnesium alloys in the aerospace industry. At the same time, the market for superplastic magnesium sheets grows in the electron and automotive industries. Consequently, in order to organize an economically efficient large-scale production of parts in these industries sheets of magnesium alloys should possess superplasticity at elevated deformation rates, i.e., about 10^{-2} sec^{-1}. This should reduce the time of fabrication of one part to about 60 sec and ensure the production of about 60,000 parts a year.

It is obvious that this task can be solved only by the creation of an inexpensive process for fabricating sheets from magnesium alloys. Magnesium has a low ductility at a temperature below 225°C. For this reason sheets are fabricated from magnesium alloys with the use of intricate processes of thermomechanical treatment including multistage cold or warm rolling with low degrees of reduction and recrystallization annealing. The number of passes can reach 40. In addition, we should bear in mind that sheets can be produced only from a low-alloy magnesium alloy with a moderate

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Fig. 1. Sheets of alloy ZK60A after rolling at 300°C.

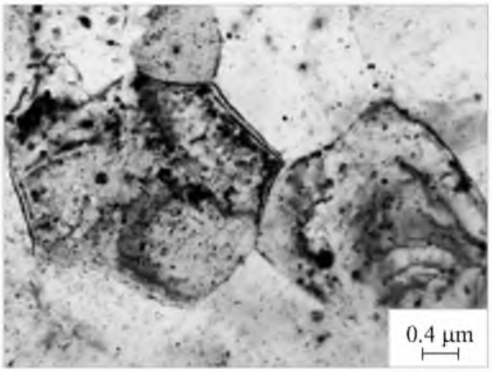

Fig. 2. Microstructure of alloy ZK60A after rolling.

strength. On the other hand, the automotive and electronic industries primarily use alloy AZ91 (Mg – 9 wt.% Al – 0.8 wt.% Zn) and the aircraft industry uses alloy ZK60 (Mg – 6 wt.% Zn – 0.65 wt.% Zr). Both alloys possess a high strength. Most of the other known alloys are primarily used when processibility and castability of the metal of enhanced ductility at room temperature are of primary importance. Consequently, it is exceptionally important to develop a rolling process that would yield sheets of high-strength magnesium alloys. Solution of this task will widen considerably the market of magnesium alloys, especially in the light of the steady tendency for decrease in their cost.

In the present work we describe results concerning fabrication of sheets from alloy ZK60A with a fine-grained structure, which is capable of superplastic deformation, and the properties of the sheets.

METHODS OF STUDY

We studied commercial magnesium alloy AK60A (Mg – 5.8 wt.% Zn – 0.65 wt.% Zr) obtained by chill casting. The alloy was homogenized at 450°C for 24 h. Then it was deformed by direct extrusion with a total degree of deformation of about 0.8 at 390 – 330°C. The pressed preforms were cut into cylinders 90 mm in diameter and 180 mm long. These cylinders were upset at 350°C with a deformation degree of 1.4. The upset material was used for cutting preforms with a size of 8.4 × 45 × 180 mm. These preforms were heated to 300°C, held for 30 min, and rolled into sheets with a length of 200 mm, a width of 70 mm, and a thickness of 2.5 mm with 20 – 50% reduction per pass. The total reduction was about 70%. The rolling direction was parallel to the reduction axis in the preceding pass. The rolling was performed on a quarto mill with isothermal internal rolls 65 mm in diameter and 250 mm long, which had been heated to 300°C.

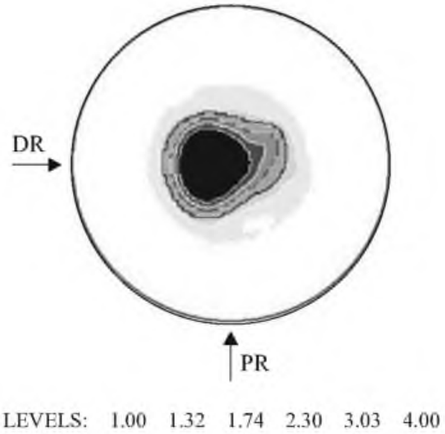

Fig. 3. (0002) pole figure of a 2.5-mm-thick sheet of alloy ZK60A with ultrafine grains: DR) direction of rolling; PR) perpendicular to the direction of rolling.

The specimens for the tensile tests, 6 × 3 × 2 mm in size, were cut from the thus obtained sheets in the direction of the rolling. The tests were conducted at a temperature of 20, 200, 250, and 300°C at a deformation rate ranging from 1.4×10^{-4} to $1.4 \times 10^{-2}\ \mathrm{sec}^{-1}$. The rate sensitivity of the yield stress was determined by the method of step changing of the rates. The microstructure was studied using a JEM-2000EX transmission electron microscope. The crystallographic texture was determined with the help of (0002) pole figures.

RESULTS AND DISCUSSION

Rolled sheets of alloy ZK60A are presented in Fig. 1. The alloy is rolled easily. The sheets have a high quality due to the initial two-stage deformation including extrusion and compression. The side surfaces have no cracks. The preliminary deformation (extrusion and compression) ensured formation of a recrystallized structure (its fraction was 75%) with a mean grain size of 4.9 μm, which improved the adaptability of the alloy to isothermal rolling. As a result, we were able to fabricate sheets at a temperature of 300°C in 3 – 4 passes with total reduction of the thickness from 10 to 0.35 mm.

Figure 2 presents a typical microstructure of a sheet from alloy ZK60. Due to the isothermal conditions of the rolling the microstructure formed in the sheets was homogenous and had a mean grain size of 3.7 μm. The grains had a nearly equiaxial shape and the dislocation density in the grains was low. Such refinement of the grains was provided by successive three-stage deformation and subsequent isothermal rolling. Analysis of the (0002) pole figure (Fig. 3) shows the

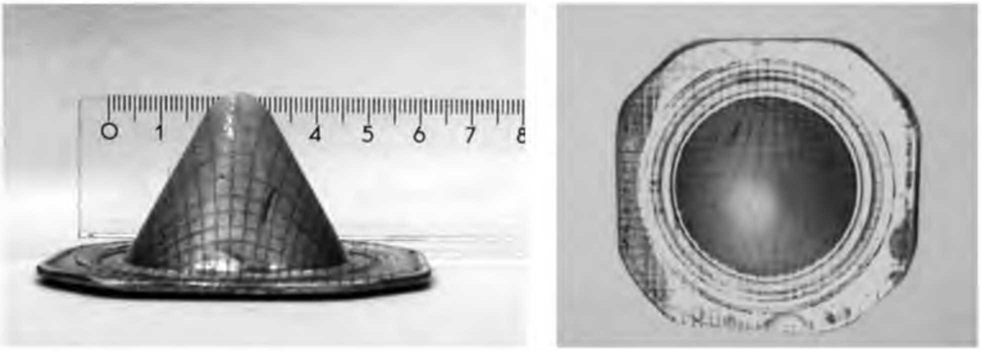

Fig. 4. Cone-shaped cup obtained by the method of superplastic gas forming from a sheet of alloy ZK60A with ultrafine-grained structure.

presence of a well manifested texture. The basic planes lie in the plane of the rolling.

The mechanical properties of the sheets from alloys ZK60A (with grain size of 3.7 mm) at room temperature are as follows: $\sigma_r = 304$ MPa, $\sigma_{0.2} = 233$ MPa, $\delta = 34\%$. The sheets with exceptionally fine grains have a high yield point and ultimate rupture strength and a considerable elongation. This improvement of mechanical properties can be associated with the strong refinement of grains as a result of the three-stage deformation.

Alloy ZK60A exhibits superplasticity in a temperature range of 200 – 300°C (see Table 1), which is much lower than the temperature of 450°C at which it was discovered in the same alloy with grain size of 10 μm [2]. We obtained $\delta = 1174\%$ and $m = 0.56$. For the specimens with very fine grains, which were deformed at 250°C at a rate of 5.6×10^{-4} sec^{-1}, the yield stress (18 – 20 MPa) corresponded to the same characteristic in alloys with a fine crystal structure deformed at 450°C [2]. The yield stress increased considerably with decrease in the temperature and growth in the deformation rate. The total elongation increased when the deformation rate was decreased at a temperature ≤ 250°C, but at 300°C the maximum elongation was observed at a deformation rate of 2.8×10^{-3} sec^{-1}. Considerable elongation ($\delta = 566\%$) was detected after deformation at 300°C at a rate of 1.4×10^{-2} sec^{-1}, which corresponds to superplasticity attained as a result of deformation at a high rate.

We fabricated a cone-shape cup presented in Fig. 4 from a sheet of alloy ZK60A by the method of gas superplastic forming at 300°C. The deformation rate used was about 10^{-2} sec^{-1}. The tests showed that a high capacity for forming can be ensured at a high rate of deformation of the superplastic material.

CONCLUSIONS

1. Three-stage deformation at elevated temperatures ensures formation of a structure consisting of very fine grains in sheets of a magnesium alloy. Formation of structure with ultrafine grains in alloy ZK60A permits hot rolling at a lower temperature. The sheets have high mechanical properties at room temperature and exhibit superplasticity at 200 – 300°C.

TABLE 1. High-Temperature Mechanical Properties of Alloy ZK60A (a sheet) with Ultrafine-Grained Structure

t, °C	$\dot{\varepsilon}$, sec^{-1}	$\sigma_{\varepsilon=50\%}$, MPa	$\sigma_{\varepsilon=100\%}$, MPa	δ, %	m
200	1.4×10^{-4}	42	42	389	0.36
	5.6×10^{-4}	57	57	302	0.34
	2.8×10^{-3}	92	76	180	0.18
250	5.6×10^{-4}	18	20	1174	0.56
	2.8×10^{-3}	36	39	1150	0.52
	1.4×10^{-2}	61	59	342	0.25
300	5.6×10^{-4}	12	14	574	0.44
	2.8×10^{-3}	20	21	686	0.50
	1.4×10^{-2}	22	37	566	0.50

Notations: $\dot{\varepsilon}$) rate of deformation; $\sigma_{\varepsilon=50\%}$ and $\sigma_{\varepsilon=100\%}$) flow stress at deformation of degree $\varepsilon = 50\%$ and $\varepsilon = 100\%$, respectively; δ) elongation; m) coefficient of strain rate sensitivity of the flow stress.

2. Superplastic gas forming of sheets from magnesium alloys is commonly performed at a temperature of 400 – 450°C and deformation rate of about 10^{-3} sec^{-1}, which is connected with the requirement of high elongation and high coefficient of rate sensitivity at a low yield stress. Under such conditions the total elongation does not exceed 600%.

3. Sheets from alloy ZK60A with ultrafine-grained structure have considerably higher superplasticity at a temperature below 300°C and higher deformation rate, i.e., about 10^{-2} sec^{-1}. The good formability of such sheets makes it possible to fabricate parts with complex geometry by the method of superplastic gas forming at relatively low temperatures in a shorter time. The very fine grain size is preserved and this ensures elevated mechanical properties.

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