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ENHANCEMENT OF SUPERPLASTIC FORMING LIMIT OF MAGNESIUM SHEETS BY COUNTER-PRESSURIZING

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Abstract

As often reported for various metallic materials, fine-grained wrought magnesium can exhibit extensive superplasticity at elevated temperature, which makes superplastic forming (SPF) of magnesium a promising process for manifacturing complex-shaped, lightweight thin-walled structural components. The superplastic tensile deformation of magnesium is commonly accompanied by substantial cavitation in its failure stage, which is also typical to quasi-single phase aluminum alloys.

In this regard, a series of bulge test have been conducted with independent inflating/counter-pressure control. By evaluating the superplastic forming limit along Limit Dome Height (LDH), considerable improvement was reproduced by counter-pressurized conditions. Constitutive modeling and microstructural analysis imply that this is mainly achieved by the retardation of nucleation and growth of cavities under hydrostatic stress.

Introduction

Magnesium alloys are considered promising structural materials due to their lightweight, high specific strength, excellent machinability and superior damping capacity [1,2]. Wrought magnesium products are drawing more interest recently along the development of continuous casting and coil rolling integrated process, which gives a significant cost-competitive edge [3].

As for the high temperature deformation of wrought magnesium, a considerable degree of superplasticity has been reported [4,5]. Additionally, cavity formation followed by intergranular fracture have also been identified in previous studies [6,7]. Since those phenomena are also common in the superplastic forming (SPF) of aluminum alloys, the superimposition of hydrostatic pressure has been introduced in order to retard the nucleation and growth of cavities, and enhance the elongation accordingly [8-11].

In the present study, superplastic formability of strip cast and warm rolled commercial AZ31B sheets has been investigated. Simple spherical bulge tests with counter-pressure variation have been conducted to identify quantitative relationship to the forming limits.

Experimental

Equipments and Materials

In order to conduct superplastic formability tests, a hot bulge tester was fitted into a 600 tonf hydraulic servo press as illustrated in fig. 1. The die set was enclosed into split furnace and connected with gas inlet/outlet whose pressures are controlled independently. Strip cast and warm rolled commercial AZ31B sheets have been selected as test materials. Samples have thickness of 1.5 mm and as-received grain size was measured to be 8.3 μm (fig. 2).

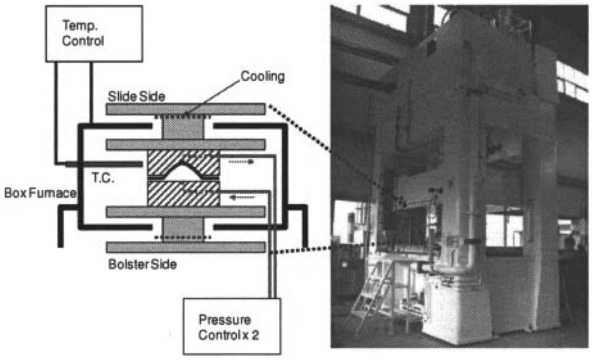

Figure 1. Schematic configuration of the hot bulge tester.

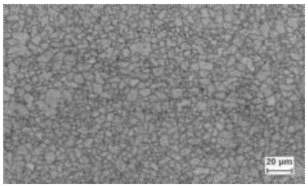

Figure 2. As-received microstructure of magnesium sheet.

Experiment Conditions

As aforementioned, simple spherical bulge tests have been conducted with various pressurizing configuration, as noted in table I.

Table I. Bulge test process window.

Parameters	Values
Bulge Geometry	Circular w/Dia = 100mm
Temperature	400°C
Inflating Pressure	0.1 ~ 0.5 MPa
Counter-Pressure	0 ~ 3 MPa

Results

Superplastic formability limits have been evaluated by recording limit dome height (LDH) up to fracture, which considered to be the most straightforward measure.

As shown in fig. 3, LDH increases with decreasing inflating pressure and increasing counter-pressure. It should be noted that counter-pressurizing does not exhibit considerable enhancement when inflating pressure is 0.4 MPa and higher.

The evolution of cavities has been investigated by measuring cavity volume fraction in the top region of the dome using image analysis of optical microscopy (fig. 4). As the amount of inflation (i.e., strain) was fixed at 50 mm, the cavitation was significantly decreased with increasing counter-pressure, which verifies the retardation of cavity nucleation and growth under high hydrostatic pressure.

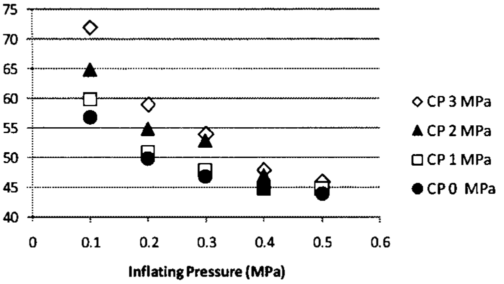

Figure 3. Superplastic formability limits with inflating and counter-pressure variation.

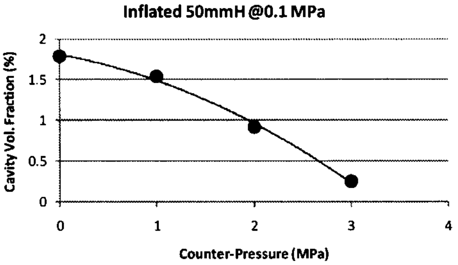

Figure 4. Cavity volume fraction as a function of counter-pressure.

From previous studies, it has been reported that the cavity growth during the superplastic deformation is predominantly controlled by plastic strain (ε) and the governing equation of the cavity growth rate (φ) can be formulated as [12-15]:

$$\varphi = \varphi_0 \exp(R \cdot \varepsilon) \ ,$$

where φ_0 is the initial volume fraction of the cavities.

The exponential constant R is a function of constitutive parameters and stress states with following formulation;

$$R = 3/2\left\{\frac{m+1}{m}\right\}\sinh\left[2\left(\frac{2-m}{2+m}\right)\{Q/3 - P/\sigma\}\right] \ ,$$

where m is the strain rate sensitivity of the material, P is the superimposed pressure, and Q is a geometric factor which equals 1, 2 and 1.73 for uniaxial stress, equibiaxial stress and plane strain, respectively.

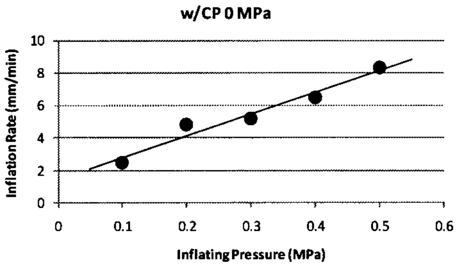

Figure 5. Inflation rate as a function of inflating pressure.

Since the inflation rate, which obviously consistent with the strain rate, is proportional to inflating pressure as shown in fig. 5, the test results under high inflating pressure corresponds to the high strain rate deformation regime with relatively lower strain rate sensitivity.

In this regard, the cavity growth rate exponent R is expected to have larger value at higher inflating pressure due to smaller m, which gives analogy for the insensitiveness to counter-pressurizing in that region.

Summary and Concluding Remarks

In order to control the cavitation, counter-pressurizing was implemented on the superplastic forming of commercial AZ31B sheets and promising results are obtained as follows.

1. Hydrostatic compressive stress imposed by counter-pressure effectively retarded cavitation during the bulge tests, which resulted in enhanced forming limits.

2. In the region of high inflating pressure and speed, the effect of counter-pressurizing was diminished, which considered to be attributable to low strain rate sensitivity.

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