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# Deformation Characteristics of Fine-grained Magnesium Alloy AZ31B Thin Sheet during Fast Gas Blow Forming

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***Abstract*—A series of experiments were performed by use of stepwise pressurization profiles for gas blow forming of an Mg alloy with a male die. Decreasing the forming time for gas blow forming of a commercially available fine-grained Mg alloy AZ31B thin sheet with a thickness of 0.6 mm has been studied in the present work. The results indicated that it was feasible to form a shallow rectangular pan with a height of 10 mm in less than 320 sec. The distribution of thickness along the transverse cross section of the formed pan was confirmed by the results as being sensitive to the pressurization profiles. Grain growth was not a serious problem for forming at a temperature of 370°C. Grain size increased from about 5.1 μm to a maximum size of about 7.1 μm. The maximum cavity volume fraction in the formed pan was about 1.1% for two different pressurization profiles.**

***Index Terms*—AZ31B Mg alloy, Gas blow forming, Pressurization profile**

## I. INTRODUCTION

Magnesium is the lightest metal that can be used in structural applications when alloyed with other elements. Research on Mg alloy focusing on mechanical properties has become very active in the past decade [1]–[3]. In recent years, die casting of Mg alloys has been developed for electronic appliances and automotive components [4], [5]. However, casting is not an ideal process in manufacturing thin-walled Mg components due to its low yield and low good rates. A potential solution would be to turn to the sheet forming processes.

In light of hexagonal close-packed (HCP) structure, Mg and its alloys have crucial drawback of poor formability, especially at room temperature, than aluminum and its alloys. Therefore, sheet metal forming operation for Mg alloy would be generally carried out at temperatures up to 300 °C [6]. In order to improve the formability of the Mg alloy thin sheet, the fine-grained (less than 10 μm) AZ31B Mg alloy has been developed and is commercially available. Components using the fine-grained AZ31B alloy sheet could be manufactured either by press forming or superpplastic gas blow forming process. Fine-grained AZ31B alloy requires careful process control to maintain the desired constant strain rate during superplastic forming. The strain rates are typically very low compared with most metal forming processes. A significant problem in commercial applications of superplastic forming with AZ31B alloy is the low forming rates ($10^{-3}$-$10^{-4}$ $s^{-1}$), which is undesirable in a manufacturing process for mass production. In order to meet the need for industrial applications, it is necessary to increase the forming rate during gas blow forming.

The present work has explored the deformation characteristics of a commercial grade fine-grained AZ31B alloy during gas blow forming by use of rapid pressurizing profiles with the intention of reducing forming time. Gas pressure forming was performed to deform the sheet into a male die cavity to form a rectangular shaped pan. Backpressure and lubricant were not used during forming. Effects of pressurization profiles on the formability were studied. Experimental results were quantitatively analyzed and the results were presented.

## II. MATERIALS AND EXPERIMENTAL PROCEDURE

POSCO Company, Korea, provided the Mg alloy AZ31B-O thin sheet with a thickness of 0.6 mm used in this work. The analyzed chemical composition was (wt-%) Mg-3.01Al-0.98Zn-0.32Mn. The average grain size was about 5.1 μm before forming. The optical image of the microstructure of sheet is presented in Fig. 1. The sheet was formed into a rectangular shaped male die cavity by compressed gas. The dimensions of the formed rectangular pan were 70 mm (length) × 40 mm (width) × 10 mm (height); as shown in Fig.2. Gas blow forming was carried out at a lower die temperature of 370°C and an upper die temperature of 240°C according to the pressure-time profiles shown in Fig. 3. The terms PT320 and PT240 used in the present paper refer to the pressurization profiles for the forming periods of 320 and 240 sec, respectively. The pressurization profiles used in this work did not result in constant strain rates as the deformation proceeded; the strain rate changed with time

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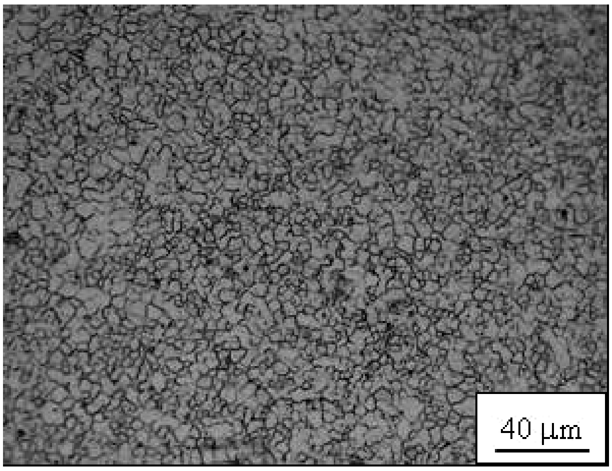


Fig. 1. Optical image of the microstructure of the fine-grained AZ31B Mg alloy.

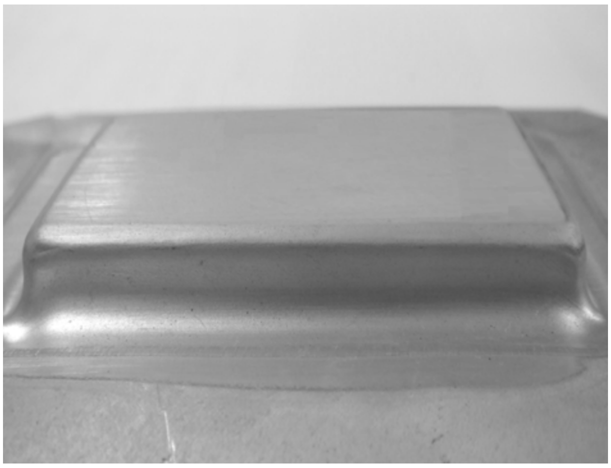

Fig. 2. Male die formed rectangular pan using fast gas blow forming.

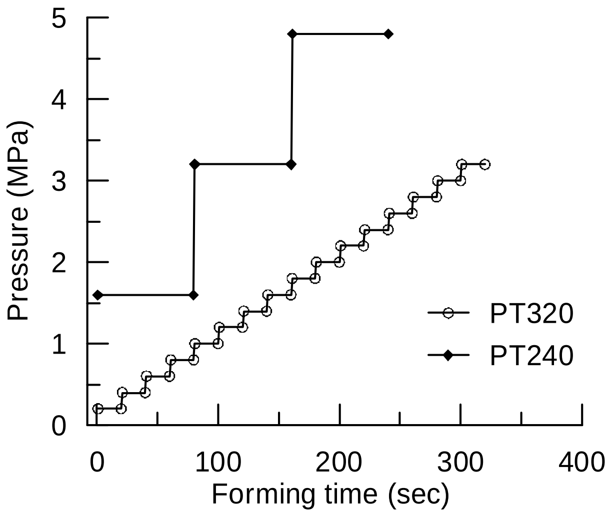


Fig. 3. Pressure-time profiles developed for fast gas blow forming.

during forming. Several interrupted tests were performed to deform the sheets to various degrees for each pressurization profile, the test piece could then be utilized to evaluate the evolution of deformation during forming. In order to obtain the fundamental information on the characteristics of a male die forming of Mg alloy AZ31B, lubricant and backpressure were not used in this study.

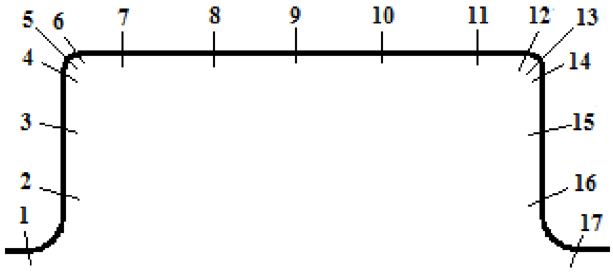


Fig. 4. The corresponding positions at which thickness, grain size and cavity volume fraction were measured.

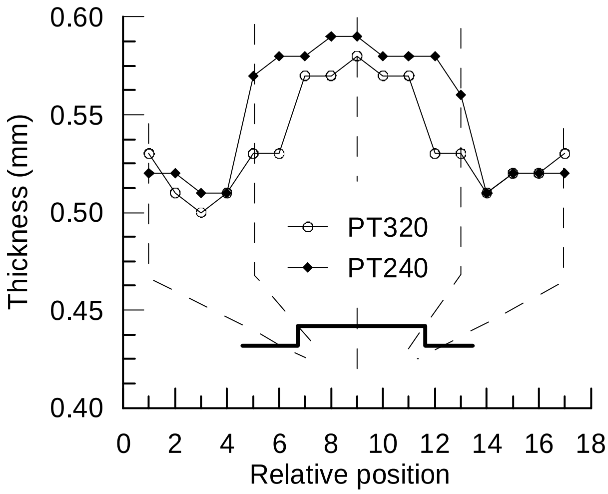


Fig. 5. Thickness distribution of the completely formed rectangular pan along the transverse cross section forming at two different pressurization profiles.

Optical microscopy was used to inspect cavitation of the test piece. The specimens for metallographic examination were mechanically polished and then slightly etched to remove smeared metal covering the cavities. Cavity volume fractions were measured by computer imaging equipment and calculated by using IMAGE-J software. The optical image was first converted into a binary video image. The number of pixels in the cavity (black area) were counted and divided by the total number of pixels in the image to obtained cavity volume fraction. Fig. 4 shows the corresponding positions at which thickness, grain size and cavity volume fraction of the formed pans were measured.

## III. RESULTS AND DISCUSSION

### A. Thickness Distribution

Fig. 5 depicts the thickness distribution of the completely formed rectangular pan along the transverse cross section at two different pressurization profiles. The thinnest region does not locate at the upper corner for a male die forming. The thinnest region falls at the location near the lower corner on the side wall. The thinnest thickness values are 0.51 and 0.50 mm for forming at pressurization profiles of PT240 and PT320, respectively. For forming without lubrication, the interfacial friction is large, when the sheet makes contact with the die surface, the deformation in that contact area is

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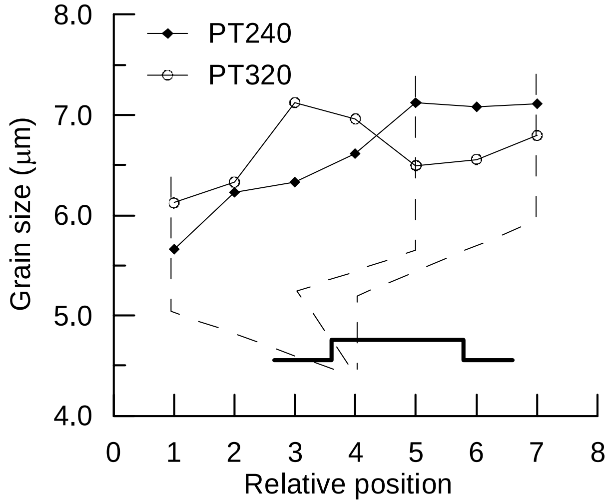


Fig. 6. Grain size distribution along the transverse cross section of the completely formed rectangular pan for forming at two different pressurization profiles.

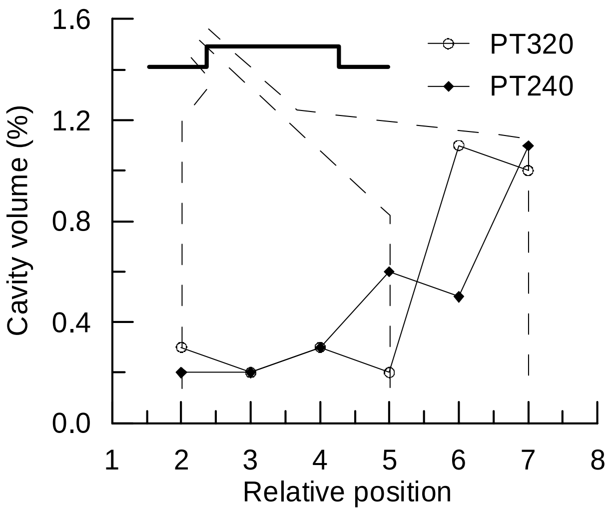


Fig. 7. Cavity volume fraction distribution along the transverse direction of the completely formed pan for forming at two different pressurization profiles.

restricted, and thinning is localized in the non-contact areas resulting in a greater degree of thinning. Major thinning effect takes place at the non-contact region of the sheet in the later stage of forming, therefore, more significant thinning was observed on the side wall region.

Thickness values on the top plane of the formed pans are about 0.58-0.59 mm and 0.57-0.58 mm for forming at pressurization profiles of PT240 and PT320, respectively. For fast gas blow forming, the imposed external pressure has a significant effect on the interfacial friction between deformed sheet and the die surface. The imposed pressures for forming at a pressurization of PT240 are much greater than those of PT320, a higher imposed pressurization profile results in a higher interfacial friction to reduce the thinning effect on the top plane of the formed pan in a male die forming.

### *B. Grain Size Distribution*

A plot of the distribution of grain size is given in Fig. 6. It indicates that grain growth did occur during forming. Different distributions of grain size were observed for forming at different pressurization profiles. Grain growth should be related to the amount of deformation and temperature in the deformed sheet. In this study, the upper die temperature is lower than that of lower die. As the sheet is loaded, the sheet sits on the top surface of the lower male die and is heated up by the lower die. At the time when the dies are closed, the periphery of the sheet will be cooled down due to a lower upper die temperature. Therefore, a temperature gradient will exist during forming. Grain growth in the side wall region should be resulted from strain-induced grain growth due to a higher deformation in the side wall with a lower temperature. The grain growth observed in the top plane of the formed pan should be the result caused by the static grain growth due to a higher temperature in this region. The thinning effect in the top plane of the formed pan is small than that in the side wall, however, the grain size in the top plane region is greater than that in the side wall region. This result reveals that static grain growth is the major factor to cause grain growth during fast gas blow forming.

Fig. 6 also shows that the locations with maximum grain size are different for forming at different pressurization profiles. The maximum grain size locates at position 3 which is the thinnest position of the pan formed at a pressurization profile of PT320. The forming time for forming at a pressurization profile of PT320 is longer than that of PT240 reducing the temperature gradient across the sheet during forming. The temperature at position 3 for forming at a pressurization profile of PT320 should be higher than that for forming at a pressurization of PT240, both static and strain-induced grain growth should have taken place at position 3 for forming at a pressurization of PT320 resulting in a larger grain size.

### *C. Cavity Distribution*

Fig. 7 displays the distribution of cavity volume fraction of the formed pan. It shows that the distributions of cavity volume fraction are not much different for forming at two different pressurization profiles. The maximum cavity volume fraction is about 1.1% for both pressurization profiles, indicating that cavitation is not a serious problem in this study. Cavitation in the fine-grained alloys during gas blow forming should be related to the strain rate, stress state, strain and grain size [7]–[9]. In this study, no obvious relationship between cavity level and the parameters mentioned above was observed. In general, the cavity level increases with grain size. A more detailed study should be performed to clarify the cavitation behavior of the fine-grained AZ31B Mg alloy during fast gas blow forming using a male die.

### *D. Thickness Evolution during Forming*

Fig. 8 depicts the evolution of thickness at different locations of the deformed sheet with forming time at two different pressurization profiles. For forming at a pressurization profile of PT320, the thickness at position 7 in the top plane decreases with increasing forming time, reaches a thickness of about 0.57 mm at a forming time of around 150 sec and then remains constant, as shown in Fig 8(a). Similar result was also observed at position 2 near the

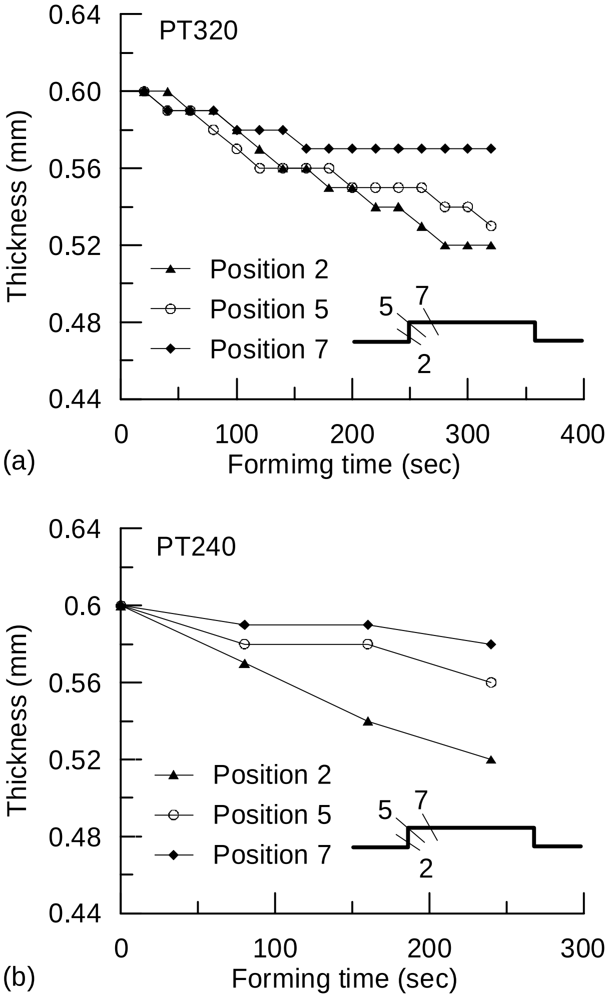


Fig. 8. Thickness evolution during forming for forming at two different pressurization profiles. (a) PT320, (b) PT240.

bottom corner on the side wall in the later stage of forming. Although constant thickness at position 5 (upper corner) took place in the middle stages of forming, no constant thickness was observed at the end of forming.

For forming at a pressurization profile of PT240, evolution of thickness with forming time presents a different trend, as shown in Fig. 8(b). The deformed sheet does not reach constant thickness towards the end of forming. For a male die forming, the sheet is placed on the top surface of the lower die. The interfacial friction would restrict the metal flow in the top plane region of the pan, and major deformation takes place in the side wall region. A pressurization profile of PT240 imposes a larger pressure which has the ability to pull the metal to flow from the top plane towards the side wall in the later stage of forming. Therefore, no constant thickness is reached in the later stage of forming.

## IV. CONCLUSIONS

A male die forming of a fine-grained Mg alloy AZ31B through usage of stepwise pressurization profiles was undertaken in this present study. Using non-optimum pressurization profiles allowed the fast gas blow forming to be achieved and significantly reduced the forming time. A rectangular shaped pan with a length of 70 mm, a width of 40 mm and a height of 10 mm could be successfully formed in less than 320 sec. Interfacial friction between the lower die surface and the deformed sheet restricted the metal flow in the top plane of the formed pan, major thinning effect took place in the side wall region. The distributions of cavity volume fraction were not much different for forming at two different pressurization profiles used in this study. The maximum cavity volume fraction was only about 1.1% for both pressurization profiles. Fast gas blow forming of Mg alloy AZ31B showed its potential for future applications.

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