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A Study on the Boss Forming Process of AZ31 Mg Alloy Sheet

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A series of boss forming tests has been carried out using an AZ31 Mg alloy sheet at 250 °C, 300 °C, and 350 °C with various lubrication conditions to obtain optimum process conditions. The Mg alloy sheet had a homogeneous distribution of very fine sized grains. Surface defects generated during boss forming process could be reduced by changing the friction conditions, as prescribed by FEM analysis using the DEFORM 2D program. The modified boss forming process, lubricating only on the front side, was found to be successful in manufacturing the boss without defects.

Keywords: boss forming, AZ31 Mg alloy, FEM analysis, lubrication, surface defect

1. INTRODUCTION

Most Mg alloy products are fabricated by die casting [1] or the semi-solid thixo-molding process [2]. These processes are generally known to generate inner void and inhomogeneous microstructures. The commercial use of hot rolled Mg alloy sheets has therefore been increased steadily in recent years. Mg alloy sheets have, however, their own disadvantages in terms of formability, especially in forming complex shapes like a boss. Superplastic forming processes [3,4] might be, in this regard, used to form the complex shapes of Mg alloy sheets. Structural superplasticity is now well accepted to be caused by grain or phase boundary sliding (GBS/PBS) [5] together with appropriate accommodation mechanisms for the geometric incompatibilities generated by the GBS/PBS [6,7]. This superplastic deformation is now well understood to develop for fine grain sizes generally less than 10 μm under high forming temperatures [3,8].

Surface defects generated during boss forming become fatal flaws in the appearance of notebook computers and cameras. This study will therefore discuss the cause and improvement of surface defects generated during the boss forming process in view of friction between material and mould.

2. EXPERIMENTAL PROCEDURES

An AZ31 Mg alloy sheet of 2 mm thickness was produced by hot rolling at the RIST pilot plant. The microstructures were then observed using an optical microscope. Boss forming equipment used in this study is illustrated schematically in Fig. 1.

Disc shape specimens of 10 mm diameter were used to form bosses with 2 mm diameter at 250 °C, 300 °C, and 350 °C. The bosses were formed by holding for 0 s, 30 s, 60 s, and 300 s after compressing to the position of 1.2 mm. Friction conditions were also varied with the lubricant MoS_2 to obtain optimum conditions for reducing the surface defects. Boss heights were then measured and the surface defects were observed with an optical microscope and also a compact digital camera. A series of FEM analyses has also carried out by using a DEFORM 2D under similar experimental conditions to elucidate the formation of surface defects. Effective strains and damages were then provided at 300 °C and 350 °C under various friction conditions.

3. RESULTS AND DISCUSSIONS

3.1. Microstructures

The AZ31 Mg alloy sheet had a homogeneous grain distribution with a grain size of less than 10 μm, as shown in Fig. 2. The microstructure formed at 150 °C in Fig. 3(b) showed fine grains by recrystallization in the boss while showing an

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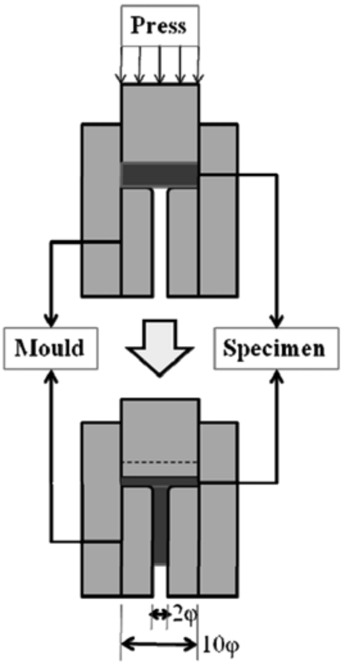


Fig. 1. Schematic illustration of the laboratory scale boss forming equipment.

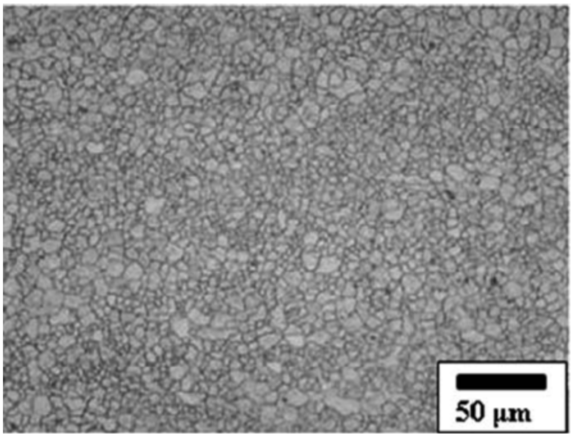


Fig. 2. Microstructure of AZ31 Mg alloy.

intact grain in the sheet. The microstructure, however, formed at 450 °C in Fig. 3(c), showed coarse grains by grain growth in both the boss and the sheet. The microstructure change could not contribute to the formation of surface defects but friction change by temperature variation could generate the surface defects. Low friction in boss forming with low temperature might cause the surface defects as shown in Fig. 3(b).

3.2. Boss forming

Strain rate was calculated from Eq. 1, derived from an extrusion equation [9],

$$\dot{\varepsilon} = \frac{6V_0D_0^2\tan\alpha}{D_0^3-D_f^3}\ln\left(\frac{D_0^2}{D_f^2}\right) \qquad (1)$$

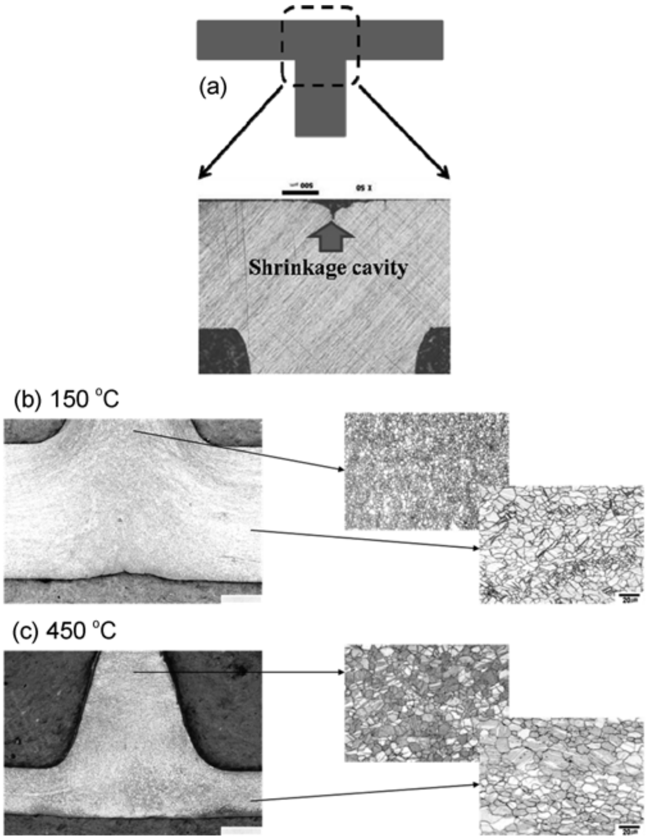


Fig. 3. (a) Formation of a shrinkage cavity and microstructure change at (b) 150 °C and (c) 450 °C.

The parameter V_0 denotes the pressing speed, D_0 the container diameter, D_f the boss diameter, and α the semi-angle of dead zone. Strain rate 0.01/s, corresponding to press speed of 0.02 mm/s, represents a fast superplastic forming region [3,8].

3.2.1. Shrinkage cavity

A surface defect was observed after boss forming with lubrication as shown in Figs. 3(a) and 4. This surface defect was similar to a shrinkage cavity formed during the solidification of metals.

These shrinkage cavities were generated during boss forming with lubrication on both the mould and the press punch. In the cases of notebook computers and cameras, these defects become fatal flaws in overall appearance. The forming process therefore has to be improved by first clarifying the cause of these shrinkage cavities.

3.2.2. FEM analysis

A series of FEM analyses was performed by using the DEFORM 2D to elucidate the causes of shrinkage cavity formation. The friction coefficient is known to be 0.3 for high temperature metal forming with lubrication [10]. The distributions of effective strains after boss forming are shown in Fig. 5. The enlarged part in Figure shows a shrinkage cavity, corresponding to the experimental results.

During boss forming process, strain concentration can be

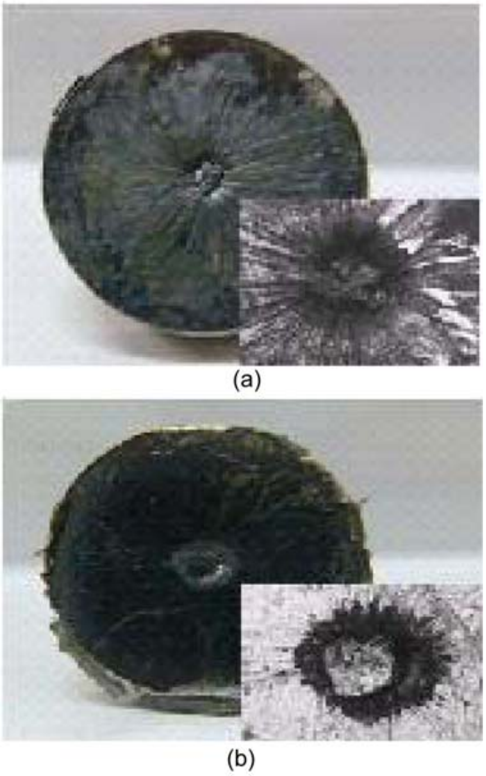


Fig. 4. Shrinkage cavities generated during a boss forming with lubrication at (a) 300 °C and (b) 350 °C by holding for 300 s after compressing to 1.2 mm position.

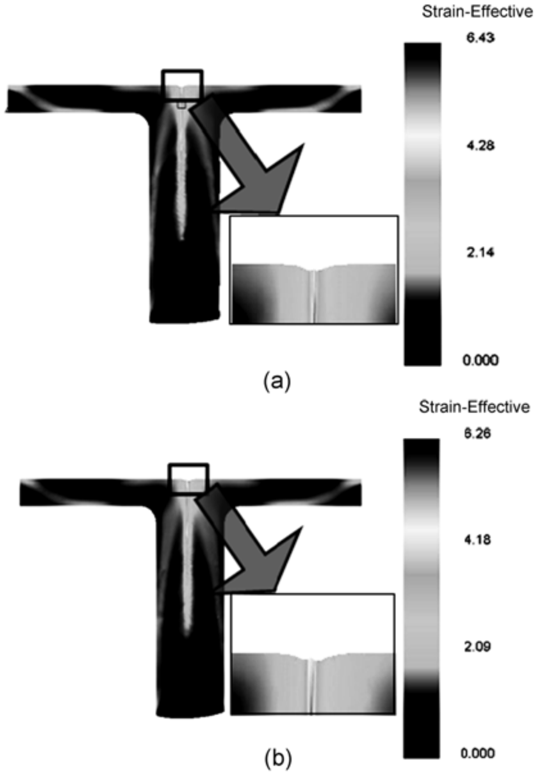


Fig. 5. Effective strain distribution obtained from FEM analyses with the friction coefficient 0.3 at (a) 300 °C and (b) 350 °C.

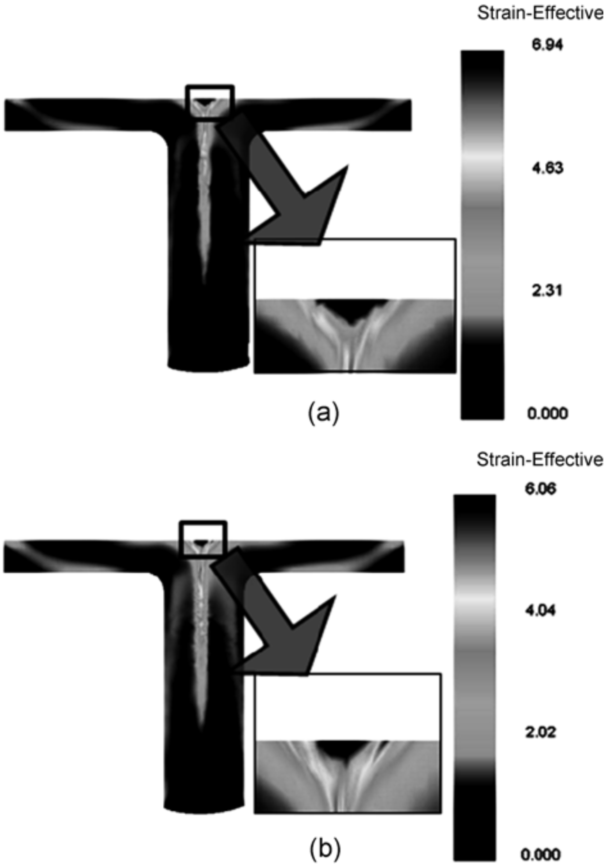


Fig. 6. Effective strain distribution obtained from FEM analyses with the friction coefficient 0.7 at (a) 300 °C and (b) 350 °C.

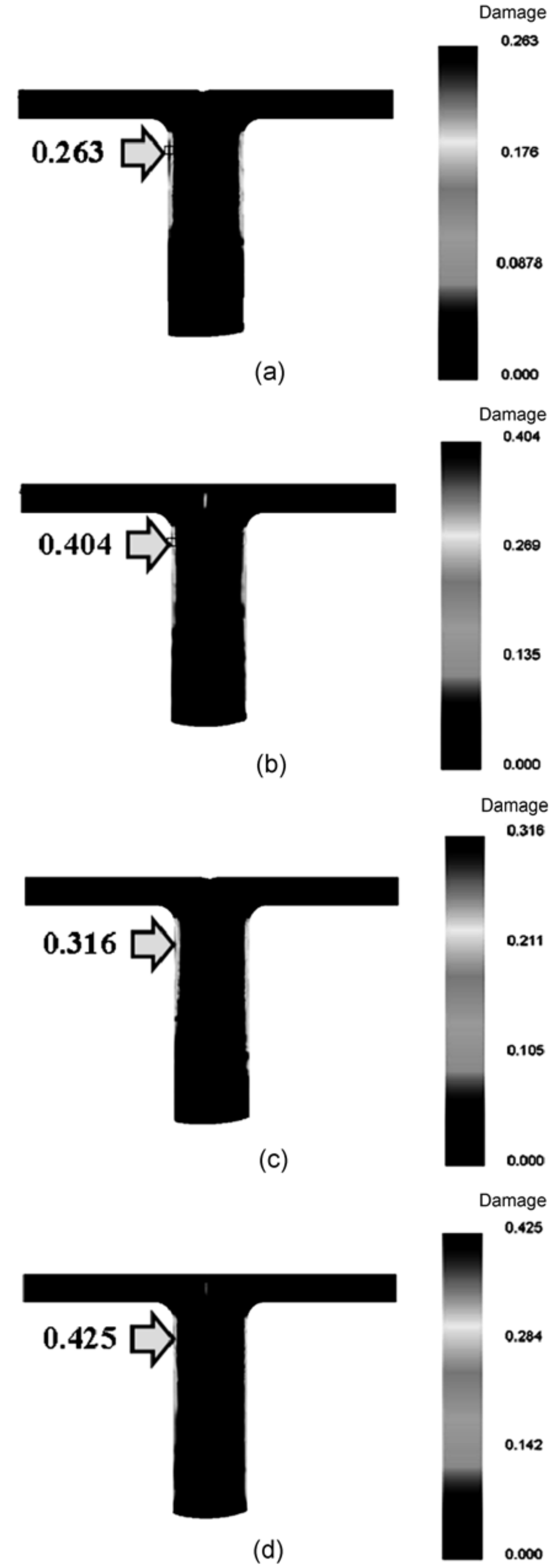
observed in the mid-part of a boss due to material flow into the center. This strain concentration is thus supposed to be the main cause of the shrinkage cavity formation.

This result then suggests minimising the material flow into the mid-part to reduce the formation of shrinkage cavities, which in turn requires a higher friction coefficient.

Shrinkage cavities are not observed in Fig. 6, obtained with the friction coefficient of 0.7, typically representing the hot forming condition without lubrication [10]. A higher friction coefficient appears, therefore, to reduce the strain concentration, resulting in the removal of shrinkage cavities. This result then implies that an actual boss forming without lubrication can reduce the possibility of shrinkage cavity formation.

The higher friction coefficient causes, on the other hand, a drastic increase in damage formation around the boss surface as shown in Fig. 7. This also provides a significant problem in the manufacturing processes. Lubrication on the front side is therefore required to reduce the damage formation around the boss surface, while a higher friction coefficient on the back side reduces the formation of shrinkage cavities.

The results of FEM analyses with the friction coefficients of 0.3 on the front side and 0.7 on the back side at 350 °C



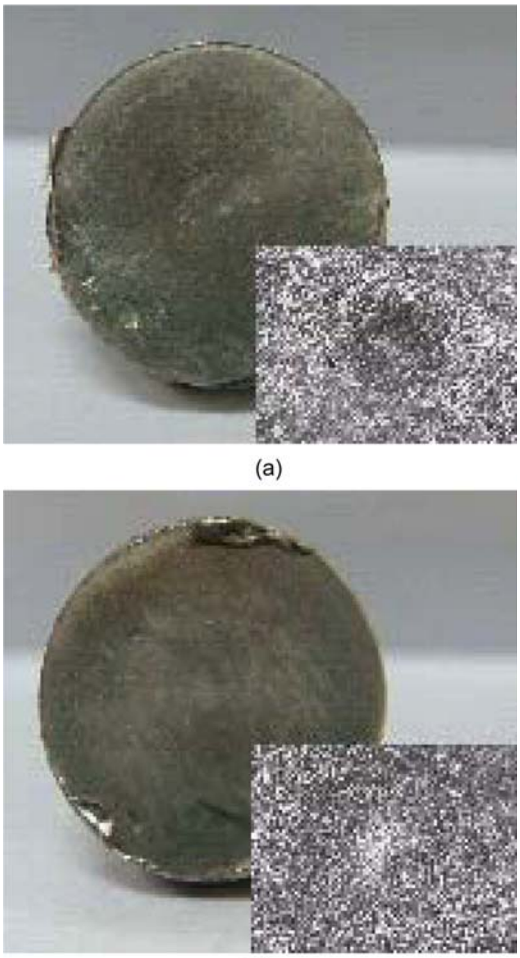
(a)

(b)

(c)

(d)

Fig. 7. Peripheral damages obtained from FEM analyses with the friction coefficients of (a) 0.3 and (b) 0.7 at 300 °C and (c) 0.3 and (d) 0.7 at 350 °C.



(a)

(b)

Fig. 8. (a) Effective strain and (b) peripheral damages with the friction coefficients of 0.3 on the front side and 0.7 on the back side at 350 °C.

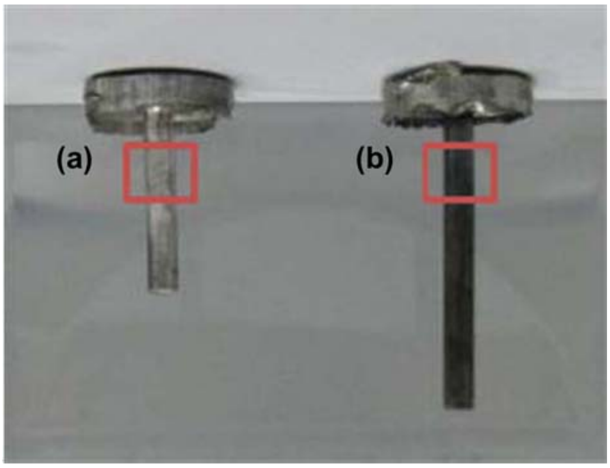


Fig. 9. Experimental boss forming results without lubrication at (a) 300 °C and (b) 350 °C after holding for 300 s.

given in Fig. 8 clearly show a reduction of shrinkage cavity and also a decrease in peripheral damage when compared to

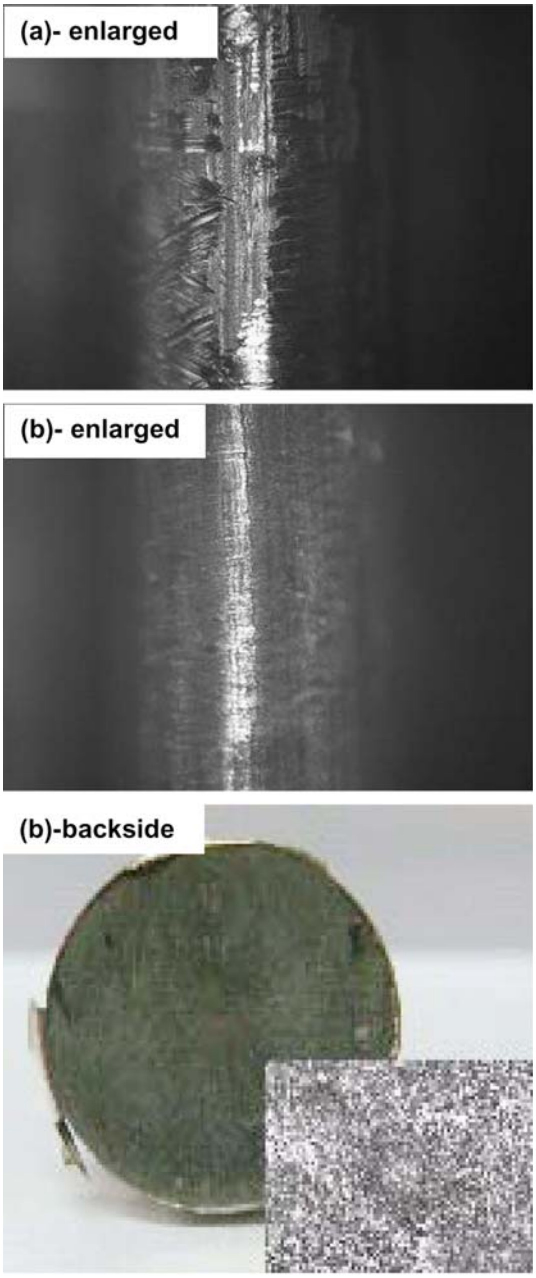


Fig. 10. Bosses formed holding for 300 s after compression at 350 °C (a) without and (b) with lubrication only on the front side, respectively.

Table 1. Boss heights obtained with the various forming conditions

(mm)	Lub.*	0 s	30 s	60 s	300 s
250 °C	Non	-	-	-	3.81
	f-side	-	-	-	5.36
300 °C	Non	-	-	-	7.62
	f-side	-	-	-	15.32
	a-side	4.88	-	-	14.77
350 °C	Non	4.47	9.27	9.83	12.21
	f-side	13.67	17.02	17.67	20.01
	a-side	-	-	-	20.68

*Non : no lubrication
f-side : lubrication only on the front side
a-side : lubrication on the all side
-: not tested

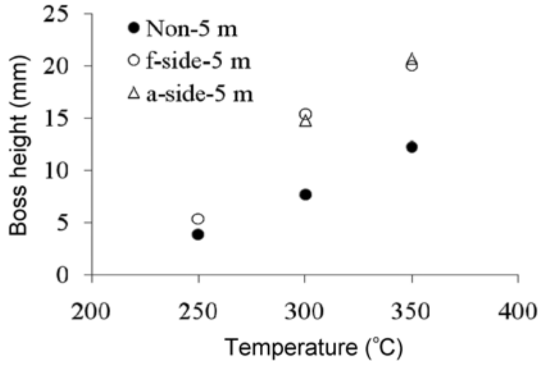


Fig. 11. Boss heights after holding for 300 s plotted in terms of temperatures.

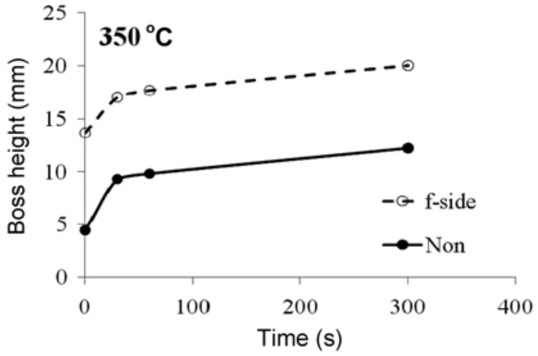


Fig. 12. Boss heights plotted in terms of holding times at 350 °C.

Figs. 5(b) and 7(d), respectively.

3.2.3. Experimental boss forming

Boss forming was first carried out without lubrication. The results shown in Fig. 9 exhibit an obvious reduction of shrinkage cavities compared to results shown in Fig. 4, as already predicted by the FEM analysis.

The peripheral damage in the boss forming without lubrication is observed to increase for a higher friction coefficient as shown in Figs. 10(a) and (b). A modified forming process of lubrication only on the front side was therefore applied, as has been suggested by the FEM analyses. These results of reduced damage and shrinkage cavity can be observed more clearly from the enlarged parts also given in Fig. 10. The boss height is also seen to increase significantly when formed with lubrication on the front side, as shown in Fig. 10, implying also an improvement of boss formability. The boss heights obtained with the various forming conditions are listed in Table 1. The boss heights were found to increase with temperature, as plotted in Fig. 11, in good correspondence with the formability of AZ31 Mg alloy [8].

The boss formability is also seen to improve, as shown in Fig. 11, when the mould was lubricated. The boss formability was not so different between the two cases of lubrication only on the front side and on both sides. The boss heights are also observed to increase with the holding times together with a tendency of a more slowly increasing rate after 60 s at 350 °C, as shown in Fig. 12.

4. SUMMARY

A series of boss forming tests has been performed at elevated temperatures. Shrinkage cavities similar to those generated during a typical metal forming process were observed to form with lubrication, as was confirmed also from FEM analyses with the friction coefficient of 0.3 [10]. The formation of shrinkage cavities appears to be caused by strain concentration in the mid-part and is thus prevented by increasing the friction coefficient without lubrication. The peripheral damages caused by higher friction coefficients were also observed to be reduced by decreasing the friction coefficient, which could be achieved by applying the lubrication only on the front side. This modified boss forming process of lubrication only on the front side was found to produce a sound quality of boss without defects.

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