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Mg 합금의 성형성에 미치는 결정립 크기의 영향

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Grain Size Effect on Formability of Mg alloys

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Abstract

Magnesium alloys still have a lot of technical challenges to be solved for more applications. There have been many research activities to enhance formability of magnesium alloys. One is to design new alloy composition having better formability. Also, low formability of wrought alloys can be improved by optimizing the processing variables. In the present study, effect of process variables such as forging temperature and forging speed were investigated to forgeability of three different magnesium alloys such as AZ31, AZ61 and ZK60. To understand the effect of process variables more specifically, both numerical and experimental works have been carried out on the model which contains both upsetting and extrusion geometries. Forgeability of magnesium alloys was found to depend more on the forging speed rather than temperature. Forged sample showed a significant activity of twinning, which was found to be closely related with flow uniformity

Key Words : magnesium, hot forging, crack, finite element simulation

1. Introduction

Since magnesium alloys have the highest specific strength among the industrially available alloys, application of magnesium alloys in the field of transportation and consumer electronics industries has increased significantly recently. Because of its light weight property, magnesium alloys are likely to have huge possibilities if process variables are optimized. Especially, forging of Mg alloys can be more beneficial to cope with light weight demand compared with thin sheet forming with a relatively low weight.

In the present study, effects of process variables such as forging temperature and forging speed were investigated to understand hot forging behaviors of magnesium alloys like AZ31, AZ61 and ZK60 alloys. All materials used in the present study were cast billets which have quite coarse microstructure. Usually, coarse grained structure might have a very poor formability. On the other hand, extruded billets of Mg alloys surely have a refined grain sizes followed by higher formability. In the present study, however, a feasibility of cast Mg billets was checked for forging stock considering that cast Al billets have been widely used for hot forging stocks.

For this purpose, a model die configuration was suggested in which both upsetting and extrusion could be exerted throughout forming stage. Firstly, a series of compression tests was carried out to get flow behaviors with temperature. To understand the effect of process variables more specifically, numerical simulations have been carried out on the model geometry. Finally, forged microstructures were observed to find out how Mg alloys evolved with strain accumulation.

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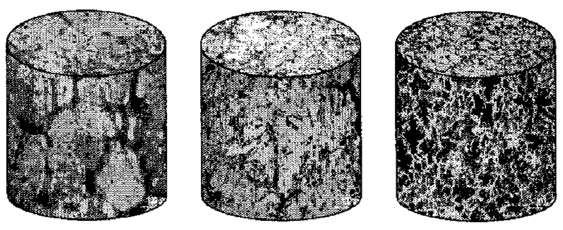
2. Experimental Procedures

Magnesium alloys used in this study were received with the cast and homogenized condition as shown in Fig. 1. All the samples carried cast structures and average grain size or primary dendritic arm spacing was measured 380, 580 and 200μm respectively. Firstly, flow behaviors of three magnesium alloys were obtained using compression test with Gleeble machine. Compression tests were carried out in the temperature range of from 250 to 400°C and strain rate of between 10^{-2} to 50/s. All flow curves were used for finite element analysis of hot forging of three magnesium alloys. Because most Mg alloys shows an extensive microstructural evolution such as recrystallization or recovery with strain accumulation at the elevated temperature, microstructural observation was carried out on the compressed samples.

Two different billet sizes with a cylindrical shape were prepared with diameters of 30mm and 36mm. All the magnesium billets were heated at the target temperature for more than 30mins. To enhance formability die and punch were heated with halogen lamp before forging up to 100°C. DEFORM-2D program was used to investigate the effect of processing variables, temperature and strain rate. Initial temperature of die and punch was given as 100°C as controlled in the experiment.



(a) (b) (c)

Fig. 1 Microstructure of Mg alloys , (a) AZ31, (b) AZ61 and (c) ZK60

3. Results and Discussion

Fig. 2 represents example of hot forging experiment taken from AZ31 billet of Φ36mm at the punch speed of 1mm/min. Formability at certain condition was determined as good, moderate and bad respectively depending on whether external crack opens and how severe crack is. As temperature rises, formability was found to be generally enhanced independent of billet size. Billet size influenced formability as listed in Table 1. Outer surface of smaller diameter billet needs to be flow farther to fill die, which in turn induce more strain and crack initiation. Depending on alloy type, the maximum strain to be applied seems to differ. In the present study, ZK60 alloy seems to have the highest formability. However, it is not true that ZK60 has the highest formability since ZK60 has the finest dendritic arm spacing of 200μm. So, more careful study needs to be carried out which alloy system has better formability for hot forging process. Table 2 showed the effect of forming speed on hot forging formability. Even though it is not clear in Table 2, overall tendency of forming speed was that higher forming speed leads to a slightly better formability.

Fig. 3 shows a general failure pattern occurring during hot forging of coarse grained magnesium alloys. It is clear that the first crack initiated from orange peel-like surface relief which was caused by localized slip due to both HCP structure and coarse grain sizes. As shown in Fig.3, a distribution of surface relief is dependent on alloy composition. Surface of ZK60 specimen looks relatively clean compared to both AZ31 and AZ61 alloys. Also, location of initial billet gives folding type defect like region 2 type defect.

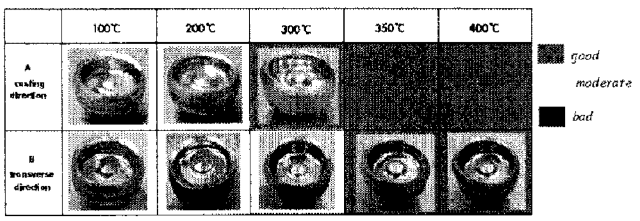


Fig. 2 Hot forging of AZ31(A different temperature with the billet of Φ36).

Fig. 4 shows damage distribution taken from finite element simulation of hot forging of Mg alloys. A fracture area on forged part seems to correspond with the highest damaged area as shown in Fig. 3 and 4. In the present study, Cockcroft and Latham model implemented in DEFORM-2D was used. This model tells that damage level gets higher where higher tensile stress is exerting. These areas might be related with where slip trace gets agglomerated and orange peel –like surface relief prevails.

Table 1 Hot forging in the casting direction with the punch speed of 1mm/min

	AZ31		AZ61		ZK60	
	D30	D36	D30	D36	D30	D36
100℃	-	Δ	-	X	X	Δ
200℃	-	Δ	-	Δ	O	Δ
300℃	X	O	X	Δ	O	O
350℃	Δ	O	Δ	Δ	O	O
400℃	Δ	-	Δ	Δ	-	-

Table 2 Effect of forging speed at the transverse direction with the billet of Φ36 mm.

	Speed (mm/sec)	100°C	200 °C	300 °C	350 °C	400 °C
AZ31	1	Δ	Δ	Δ	O	O
	5	X	Δ	O	O	O
AZ61	1	-	X	Δ	Δ	Δ
	5	-	X	Δ	Δ	Δ
ZK60	1	Δ	Δ	O	O	O
	5	Δ	O	O	O	O

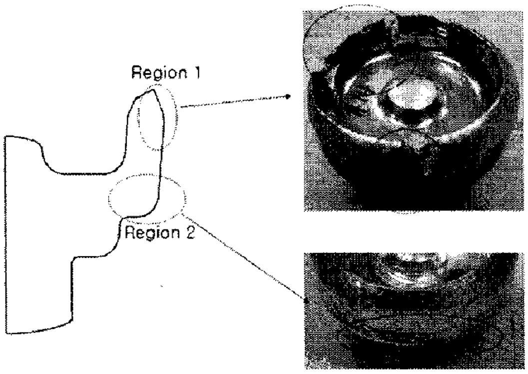
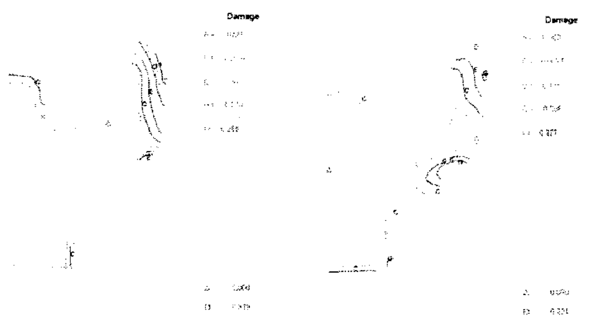


Fig. 3 Failure occurred during hot forming.

Actually, magnesium alloys exhibit plastic anisotropy between tensile and compressive loading. Therefore, the finite element simulation done in the present study could not illustrate a real deformation situation. However, a commercial finite element simulation still could predict where crack would open and tell overall forming behavior.

Fig. 5 shows that microstructure of hot forged part differs depending on the accumulated strain. In the area where shear deformation prevails, very refined grains of less than 3μm seem to be recrystallized. On the other hand, less deformed areas still contain coarse grained cast structure. Due to as-received large grain size, twinning was observed to be quite active throughout the forged sample.



(a) (b)

Fig. 4 Hot forming simulation of AZ31 (a) Φ30 and (b) Φ36.

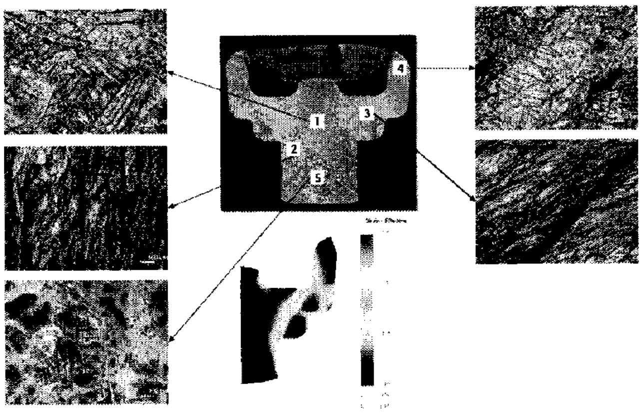


Fig. 5 Hot forged microstructure at various points showing different evolution with strain

4. Conclusion

In the present study, hot forging of three kinds of magnesium alloys with the initial grain size or dendrictic arm spacing of over 200μm was carried out. The flow behavior showed a strain softening after peak stress irrespective of strain rate and temperature. Forgeability of magnesium alloys was investigated in terms of forging temperature, speed and billet size. Even in the coarse grain regime, smaller grain size of ZK60 exhibits better formability rather than AZ31 and AZ61 alloys. Crack was found to start from the surface relief where slip localization occurs to insufficient slip system and coarse grain size. This phenomenon could be predicted using Cockcroft and Latham damage model where higher tensile stress appears. In summary, finer grained billet needs for successful forging of magnesium alloys

Acknowledgments

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