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AZ31 합금의 온간 부풀림 성형시 결정립 변화에 관한 연구

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Grain Evolution during Bulge Blow Forming of AZ31 Alloy

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Abstract

In the present study, blow forming characteristics of commercially rolled AZ31 alloy sheets were investigated. Two different kinds of AZ31 sheets were originally fabricated by using direct casting and strip casting methods respectively. Both sheets have similar grain sizes of about 7μm with a relatively equiaxed structure after rolling. A series of tensile tests were carried out to get flow behavior in terms of temperature and strain rate. Also, grain size effect was investigated by annealing as-received sheet at elevated temperatures. Elongation increased with temperature increment as well expected. However, the differences in tensile test condition did not give much difference in elongation even at the temperature range where a large elongation would be expected with such as fine grain of 7μm. Blow forming experiments showed that forming condition did not result in higher difference in dome height. However, the interesting feature from this study was that formability of this AZ31 alloy got different with stress condition. Firstly, biaxial stress condition might result in lower temperature and strain rate dependencies compared to uniaxial tension results for both DC and SC sheets. Secondly, DC showed slower grain growth in uniaxial tension than in biaxial stress state while SC has much higher grain growth rage in uniaxial tension than in bulging.

Key Words : Blow forning, AZ31, superplasticity

1. Intorduction

Mg alloys have drawn a lot of attentions in the field of transportation and consumer electronics industries since it is the lightest alloy which could be industrially applicable. However, industrial application of wrought Mg alloys seems to be still quite limited while cast Mg parts seem to find a wide range of application. There have been a lot of research activities on the wrought alloys and their plastic forming process recently.

Most works have been focused on warm forming including stamping or deep drawing processes carried out in temperature range of between 200℃ and 300℃. There are several scientific explanations on why this temperature range leads to a relatively better formability. However, warm forming at this temperature regime is such a difficult job done successfully since dies need to be heated and followed by unwanted dimensional change. So, it is very hard to warm form a relatively large scale product like panels for passenger car with thin Mg sheets. Most thin Mg sheets have a very fine grain structure which gives superplastic behavior under a certain condition with elevated temperature and optimum strain rate. In terms of die design and part precision, superplastic forming would give a better chance to apply Mg alloy sheets into practical engineering field.

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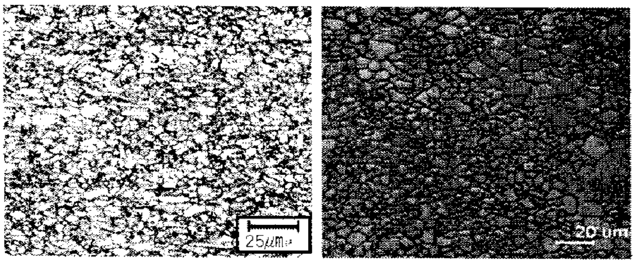
2. Experimental Procedure

Currently, two different kinds of Mg sheets are commercially available, which were rolled from cast billets with direct chill casting (DC) and strip casting (SC). In the present study, both DC and SC AZ31 sheets with same grain size of about 7μm as shown in Fig. 1. The microstructures of Fig. 1 were taken with as-received condition. DC sheet shows a higher content of twin boundaries and less uniform grain size distribution compared with SC sheet.

A series of tensile test was carried out with a variation of temperature and strain rate for both DC and SC AZ31 sheets. For a successful blow forming tensile elongation was measured carefully. After tensile tests, blow forming experiment was performed with dies of diameter of 100mm.. Usually, blow forming of superplastic materials tends to be carried out at an optimum strain rate regime where strain rate sensitivity shows maximum value. Then, pressure cycle with time needs to be determined to maintain an optimum strain rate throughout the forming stage. In the present study, however, a constant pressure test was done since a difference of forming characteristics between both DC and SC sheet need to be understood.



(a) (b)

Fig. 1 Microstructure of AZ31 sheet, (a) direct casting(DC) and (b) strip casting(SC)

3. Results and Discussion

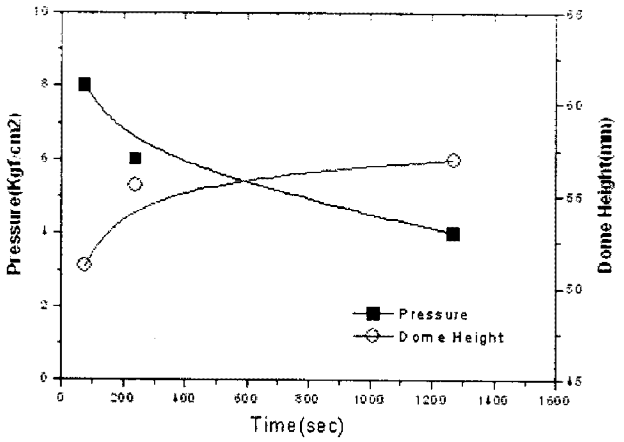
Based on tensile elongation data, the temperature of blow forming was chosen as 400℃ where enough elongation seemed to be too low below. Constant gas pressure of 4 to 9MPa was applied until diaphragm was failed as mentioned above. Considering sheets of both materials was 1.5 mm thick, the estimated strain rate at dome apex was around 10-3 to 10-2/s. In this study, forming time to fracture and final dome height was measured carefully.

Fig. 2 summaries blow forming experiment conducted at 400℃ with both DC and SC sheets. As well expected, forming height get higher with decrease of forming pressure in both materials. It is found that SC sheet was possible to get higher dome height than DC materials. This phenomenon is an opposite trend with tensile data shown in Fig. 3 that DC sheet showed higher elongation. Also, the slope of dome height to time is higher in SC sheet, which means that the optimum strain rate for blow forming can be higher in SC sheet. Overall, SC sheet might have better formability than DC material.

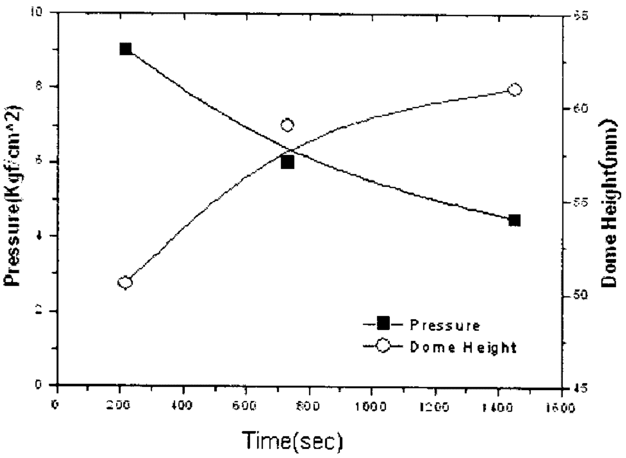
Fig. 3 shows blow forming results conducted with using SC sheet with the grain size of 7 and 14μm. Left vertical axis represents the pressure divided by thickness which is intended to compare stress level on membrane of forming sheet for two grain sizes. As shown in Fig. 3, two different grain sizes were exerted with a similar stress level. As well expected, smaller grained sheet showed higher dome height. However, the forming rate, which is represented as the slope of forming height to time, is quite similar in two grain sizes except an early stage of forming.

Fig. 4 shows the blow formed microstructures at three different area of semi-sphere dome. It is worth noting that DC sheet showed an extensive grain growth at the dome apex while SC sheet did not have such a big growth. It could be quite easily understood that blow formability of SC sheet was better than that of DC considering that deformation induced a high degree of grain growth and lead to earlier failure in the case of DC sheet.

Forming behavior of both DC and SC AZ31 sheets is like to depend on stress condition significantly. This was found to result from the different grain growth pattern between DC and SC sheet. It is believed that the distribution of constituent particles reside in the matrix might explain this trend. As mentioned earlier, SC sheet has the finer and more uniformly distributed particles. Consequently, it leads to higher grain stability in the condition that strain or stress activation for grain growth is lower. However, it is still lacking the reasonable explanation for the overall trend.



(a)



(b)

Fig. 2 Blow forming of AZ31 sheets under constant pressure at 400℃ (a) DC and (b) SC sheets

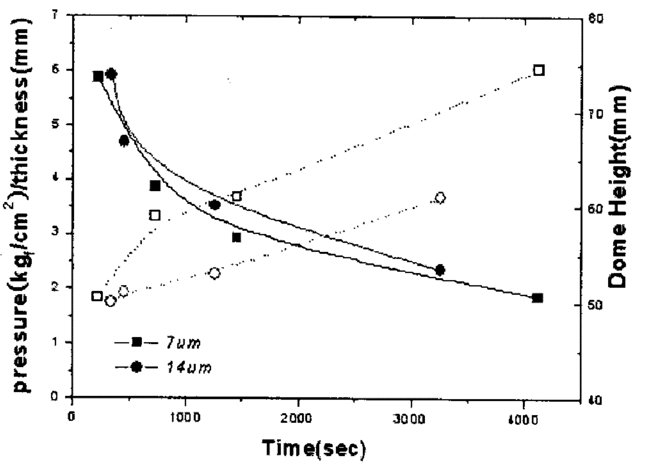


Fig. 3 Blow forming of AZ31 sheets of two different grain sizes of 7 and 14μm.

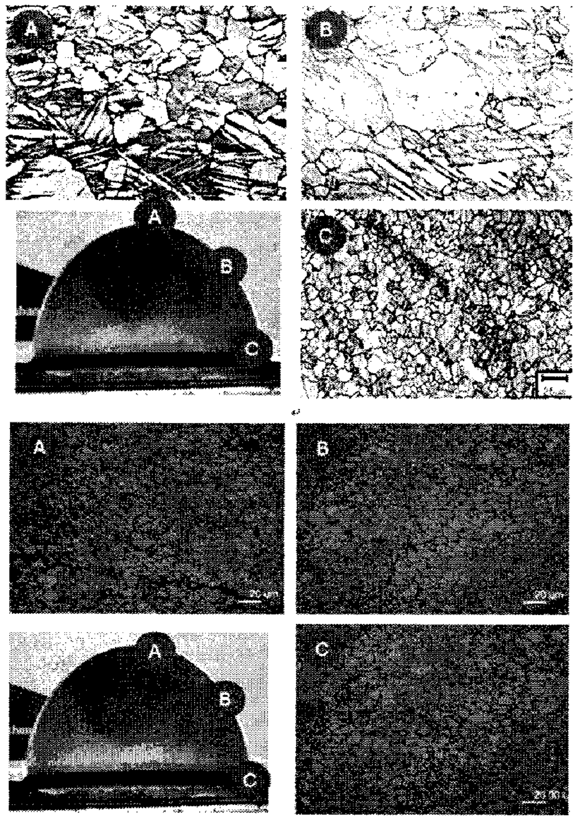


Fig. 4 Blow formed microstructures at three different area of semi-sphere dome(a) DC and (b) SC sheet.

It has been well known that deformation of AZ31 sheet at the elevated temperature above about 200℃ accompanies dynamic recrystallization which in turn causes softening effect. It has been found that AZ31 has a relatively low necking resistance in uniaxial tension condition compared to usual superplastic materials. Easy necking and dynamic recrystallization might be related in some way to lower formability of AZ31. Also, commercially rolled AZ31 sheet has in plane anisotropy even at high temperature like 400℃. From the previous study, anisotropy also gives an influence in necking resistance. So, difference of forming behavior between uniaxial tension and biaxial stress could be originated from necking resistance depending on stress state. But, a quantitative explanation is still under investigation.

4. Conclusion

Blow formability of AZ31 sheets rolled from DC and SC billets were studied by using tensile and gas blow forming tests. It was found that formability of AZ31 alloy fabricated with different processes showed an opposite trend in some sense. In uniaxial tension condition, DC sheet showed a higher elongation even though the difference in absolute value was not so high, which was influenced by grain growth. On the contrary, SC sheet had a higher formability in biaxial condition, which also resulted from slow grain growth rate in biaxial condition. This difference between DC and SC sheets was believed from the constituent particle distribution. SC sheet has a higher solidification rate and consequently a finer and more uniform distribution of particles. Also, stress state might be giving some effect on formability variation along with anisotropy and dynamic recrystallization, which needs a more detailed study.

Acknowledgement

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