Forging Characteristics of AZ31 Mg Alloy

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Characteristics of open die forging in an AZ31 Mg alloy and a relation between microstructure and mechanical properties of the forged alloy have been investigated for an as-received specimen and an extruded specimen, where the as-received specimen consisted of both elongated coarse grains and equiaxed small grains, and the extruded specimen consisted of only equiaxed small grains. Each specimen was forged at 323 to 673 K. In addition, tensile tests of the forged specimens were carried out at room temperature and the microstructure was observed using an optical microscope. In the forging tests, the specimens could be forged from 18 mm to 2.5 mm in thickness at forging temperatures of more than 423 K. In particular, the specimen could be forged without surface cracks when the grains were refined by extrusion prior to forging. However, for the as-received specimen, some cracks were observed at the edge of the specimens forged at less than 573 K. Therefore, it is suggested that the microstructure of the pre-forged specimens needs to be homogeneous, in order to attain a good surface quality, when forging is carried out at temperatures less than 573 K. The grain size of the forged specimens decreased with decreasing forging temperature. It should be noted that a very small grain size of about 3 μm was attained by forging at 473 K. The tensile strength and the 0.2% proof stress of the forged specimens increased with decreasing forging temperature due to grain refinement by forging.

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1. Introduction

Magnesium alloys are the lightest alloys used as structural metals and they have some advantages concerning to specific strength, specific elastic modulus and so on. Therefore, large demands, in which they are applied to the structural materials for automobile and airplane, are expected. At the present time, most of Mg products are fabricated by casting processes such as die-casting1,2) and thixo-casting.3) Recently, large amounts of studies concerning to the casting processes of Mg alloys have been reported.4–12)

However, it is often difficult to fabricate large Mg products with high strength and high ductility for vehicles by the casting processes because of coarse grain sizes. Therefore, development of plastic forming process is essential to fabricate large structural Mg products exhibiting high strength and high ductility. In general, Mg alloys show poor plastic formability due to HCP structure. Recently, however, it was reported that grain refinement is attained by hot deformation, which is extrusion13–15) and ECAE16,17) process, due to dynamic recrystallization in Mg alloys13–17) and that grain refinement leads to improvement of plastic formability and excellent post-deformation mechanical properties.13–17)

The present paper describes open die forging of an AZ31 Mg alloy. The studies about forging of Mg alloys are very few.18–21) In the present paper, characteristics of open die forging and a relation between microstructure and mechanical properties of the forged Mg alloy are investigated.

2. Experimental Procedures

Open die forging tests were conducted on a commercial magnesium alloy AZ31. Two kinds of specimens for open die forging tests were prepared to investigate effects of microstructures on characteristics of open die forging; one was the as-received specimen and another was the extruded one. For the as-received specimen, cylindrical ones with a diameter of 18 mm and a height of 18 mm were cut from a commercial AZ31 Mg alloy block which was bought from Morimura Bros., Inc. For the extruded specimen, the commercial cylindrical Mg block was extruded at a temperature of 573 K and an extrusion ratio of 5 : 1 in air and then cylindrical specimens with a diameter of 18 mm and a height of 18 mm were cut from the as-extruded bar. Microstructures of each specimen are shown in Fig. 1. In the as-received specimen, both of elongated coarse grains and equiaxed small grains were observed. The mean size of the small grains was about 20 μm. On the other hand, grains were almost equiaxed in the extruded specimen. No elongated coarse grains were observed and microstructure of the extruded specimen was homogeneous. The grain size of the extruded specimen was about 6 μm. Each specimen was forged to a thickness of 2.5 mm at an initial strain rate of 4 × 10–3 s–1 over a temperature range of 323 to 673 K with a step of 50 K.

The post-forging mechanical properties were investigated by tensile tests. Specimens for tensile tests were machined from the forged specimens, as shown in Fig. 2. The tensile specimens had a gage length of 10 mm, a gage width of 3 mm, and a gage thickness of 2.5 mm. With a constant velocity of 1.0 mm/min, tensile tests were carried out at room temperature.

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Microstructure was observed by an optical microscope. Specimens for the observation were etched using a solution of 20 ml acetic acid, 3 g picric acid, 50 ml ethanol and 30 ml distilled water. The grain size was given by multiplication of the mean size of grains by a constant (= 1.74).

3. Results and Discussion

As representative results of the open die forging tests, the specimens forged at 423, 473 and 573 K are shown in Fig. 3. Though the specimens were broken before specimens were forged from 18 mm to 2.5 mm in thickness at forging temperatures of 323 and 373 K for both the as-received and the extruded specimens, the specimens could be forged from 18 to 2.5 mm in thickness above 423 K, as shown in Fig. 3. However, the as-received specimen was not concentrically forged at 423 K and a lot of cracks were observed on the surface. The as-received specimen could be concentrically forged at forging temperatures of more than 473 K, but some cracks were observed at the edge of the specimens forged at 473 and 523 K. The cracks were not observed in the specimens forged at more than 573 K. On the other hand, for the extruded specimens, good surface quality was obtained even at a low forging temperature of 423 K. Therefore, it is demonstrated that microstructure of a pre-forging specimen is required to be refined and homogeneous in order to attain excellent surface quality of a forged specimen when forging is carried out at low temperatures of less than 573 K.

Figure 4 shows microstructures of the specimens forged at 473 K. It should be noted that a very small grain size of about 3 μm was attained by forging at 473 K in both the as-received and the extruded specimens. Recently, Mohri et al. investigated microstructural evolution during hot deformation in a Mg-Al-Zn alloy and they revealed that a fine-grained microstructure was obtained due to dynamic recrystallization. Therefore, it is suggested that grain refinement by forging is attributed to dynamic recrystallization during forging. For the as-received specimens, some coarse grains, which were not recrystallized, were observed even after forging, as shown in Fig. 4(a). The number of the coarse grains after forging decreased with increasing forging temperature.

The grain sizes after forging in the as-received specimens and the extruded ones are listed in Table 1, where the coarse un-recrystallized grains are not measured for the as-received specimens. The grain size of the as-received specimen was almost the same as that of the extruded one when the forging temperature was the same. It is noted that the grain size
decreased with decreasing forging temperature for both the as-received and the extruded specimens.

Figure 5 shows the variation in ultimate tensile strength (UTS) and 0.2% proof stress of the forged specimens as a function of forging temperature. The tensile strength and the 0.2% proof stress increased with decreasing forging temperature for both the as-received and the extruded specimens. It is accepted that the 0.2% proof stress of Mg alloys strongly depends on the grain size and it remarkably increases by grain refinement. Therefore, the fact that the tensile strength and the 0.2% proof stress increased with decreasing forging temperature is likely because that the grain size decreased with decreasing forging temperature.

The variation in elongation to failure of the forged specimens as a function of forging temperature is shown in Fig. 6. The elongation decreased with decreasing forging temperature. It should be noted that the extruded specimen showed larger elongation than the as-received specimen when the forging temperature was the same.

The results of Figs. 5 and 6 revealed that the 0.2% proof stress and the elongation of the extruded specimen were larger than those of the as-received specimen when the forging temperature was the same. The differences between as-received specimen and the extruded specimen are likely to be related to the coarse un-recrystallized grains in the as-received specimens. The improvement of the 0.2% proof stress may be due to the homogeneous grain refinement for the extruded specimen and the improvement of the elongation may be due to the lack of un-recrystallized grain which originates the fracture. The experimental results in the present investigation indicate importance of grain refinement and homogeneity for good forging properties. Anyway, the fact that grain refinement was attained by hot forging suggests that mechanical properties of Mg alloys can be improved by forging.

4. Conclusions

Forging characteristics of AZ31 Mg alloy were investigated by open die forging tests. In addition, microstructures and mechanical properties of the forged Mg alloy have been investigated by an optical microscope and tensile tests at room temperature. The following results have been obtained.

(1) The specimens could be forged from 18 to 2.5 mm in thickness at forging temperatures of more than 423 K. In particular, the specimen was forged at 423 K without surface cracks when the grains were refined by extrusion prior to forging. However, for the as-received specimen which consisted of both elongated coarse grains and equiaxed small grains, some cracks were observed at the edge of the specimens forged at less than 573 K. Therefore, it is suggested that microstructure of a pre-forging specimen is required to be refined and homogeneous in order to attain good surface quality of a forged specimen when forging is carried out at low temperatures of less than 573 K.

(2) The grain size of the forged specimens decreased with decreasing forging temperature. It should be noted that a very
small grain size of about 3μm was attained by forging at 473 K.

(3) The tensile strength and the 0.2% proof stress increased with decreasing forging temperature. This is likely to be related to grain refinement by forging. Therefore, it is suggested that mechanical properties of Mg alloys can be improved by forging because of grain refinement.

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REFERENCES


