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Development of the Electromagnetic Continuous Casting Technology for of Magnesium Alloys

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Abstract

Currently, magnesium billets produced by ingot casting or direct chill casting process, result in low-quality surfaces and low productivity, Continuous casting technology to solve these problem has not only high-quality surface billets with fine-grained and homogeneous microstructure but also cost down. The latent heat of fusion per weight (J/g) of magnesium is similar to other metals, however, considering the heat emitted to the mold surface during continuous casting in meniscus region and converting it to the latent heat of fusion per volume, magnesium will be rapidly solidified in the mold during continuous casting, which induces subsequent surface defect formation. In this study, electromagnetic casting and stirring (EMC and EMS) techniques are proposed to control solidification process conveniently by compensating the low latent heat of solidification by volume and to fabricate magnesium billet with high-quality surface. This technique was extended to large scale billets up to 300 mm diameter and continuous casting was successfully conducted. Then magnesium billet was used for the fabrication of prototype automobile pulley.

Introduction

The use of magnesium alloys for structural components is attractive due to their excellent specific strength to weight ratio [1]. Die casting is the typical process for magnesium component production, and wrought magnesium alloys have gained a great attention due to its potential use for vehicle mass reduction and performance improvement. However, the cost of wrought magnesium products remains still expensive because of the low quality of casting billets. Currently, important issues for improving the quality of magnesium alloy billets are these such as surface defects, segregation, and inclusions. Especially, the latent heat of magnesium alloy is low compared with aluminum alloys, resulting in surface defect, during continuous casting [2-4].
Continuous casting in conjunction with electromagnetic field is very effective not only in improving productivity, but also in refining grain size, eliminating surface defect and segregation, stabilizing the temperature distribution during solidification and enhancing the casting speed. In previous study, high quality aluminum billets were successfully fabricated by applying electromagnetic casting and stirring (EMC and EMS) technique. In this study, the electromagnetic casting and stirring techniques is proposed to fabricate magnesium alloy billets of high-quality surface. The casting of magnesium billet was scaled up to large billets up to 300 mm diameter. Then magnesium billet was forged for the fabrication of prototype automotive engine pulley.

Experimental

The equipment for the continuous casting of magnesium alloy billet with electromagnetic field consists of a melting furnace capable of producing about 40 kg of molten metal for magnesium, a tundish to supply the molten metal into the mold, a mold, an electromagnetic casting and stirring devices. After melting the magnesium alloy in a melting furnace, the furnace was tilted and the molten metal was poured into the tundish. A stopper was used to control the flow of molten metal from the tundish into the mold so that a fixed amount would be supplied. The continuous casting experiment was carried out by changing the EMC and EMS conditions when the supplied molten metal reached a certain height.
In the previous study of aluminum electromagnetic continuous casting, it was possible to improve the casting speed and quality characteristics by spraying cooling water directly on the billet surface that comes out of the mold. Analogous technique was applied to electromagnetic continuous casting process of the magnesium billets; however, for the molten metal of magnesium alloy, there are difficulties in the process because a strong and violent reaction occurs when molten metal comes in direct contact with water. To solve this problem, the surface of the molten metal was solidified completely while the magnesium was cast continuously so that explosive reaction was avoided even if the billet surface came in direct contact with water at the mold separation area. Two types of mold: 150 and 300 mm in diameter, was used in this study.
The schematic diagram of experimental apparatus is described in Fig 1. Through direct cooling using a cooling spray on the billet surface in the mold separation area, the cooling effect on the billet surface area was doubled. The EMC coil located at the upper part of the mold can apply a high frequency electromagnetic field to the molten metal inside the mold. The EMS system was installed at the lower part of the mold so that the microstructure in the billet can be improved by electromagnetic stirring during casting process. The experimental conditions of this study are as shown in Table 1. To prevent oxidation and ignition of the molten magnesium during casting, a mixture of CO_2 and SF_6 gases were supplied to the melting furnace, tundish, and the molten metal of the mold. The billet was forged into automotive engine pulley.

Table I. Parameters of experiment

Parameter	Conditions
Alloy	AZ31, AZ31+1%Ca
Mold	Copper, Length 150mm , Diameter 150 mm, 300 mm,
EMC	Frequency 20 kHz, 0~1400 A
EMS	Frequency 15 Hz, 0~150A
Casting Speed	5~40 cm/min.

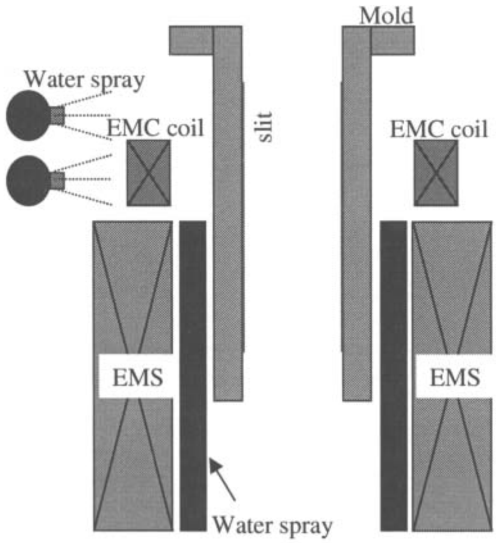

Figure 1. Schematic diagram of continuous casting apparatus combined with electromagnetic field for magnesium alloy billet

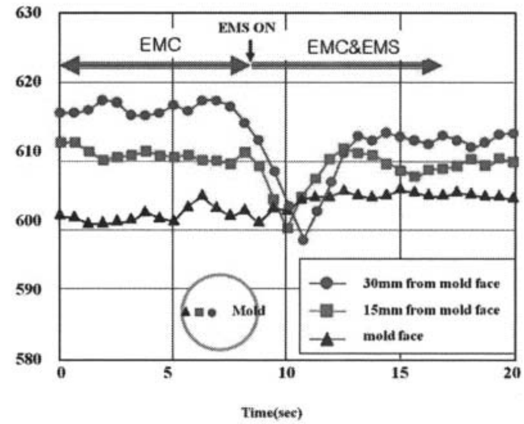

Figure 2. Temperature distribution on the molten magnesium during EMC and EMC+EMS casting

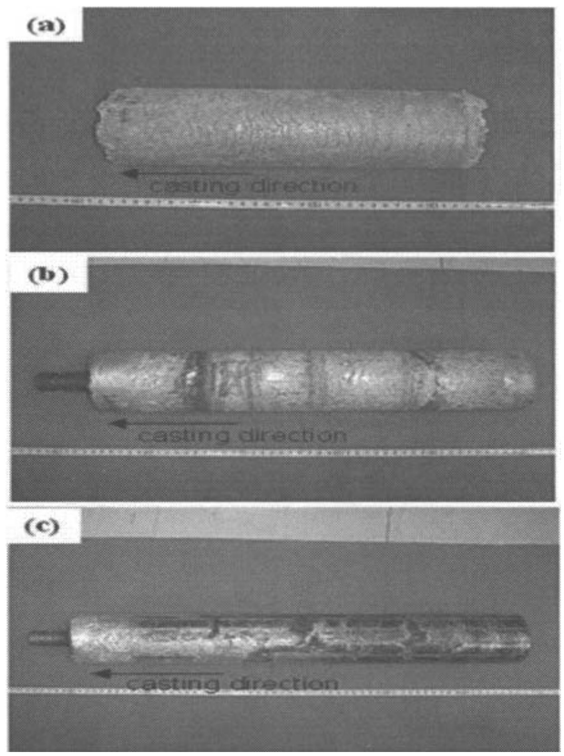

Figure 3. Appearance of magnesium billet with various experimental conditions; (a) applied 600A currents on EMC, 0.2 m/min casting speed with 50L/min (b) applied 650A currents on EMC, 0.3 m/min casting speed with 20L/min (c) applied 920~1134A currents on EMC, 0.3~0.4 m/min casting speed with 20L/min

Results and discussions

The temperature distributions of molten metal surface when only EMC was applied and when both EMC and EMS were applied simultaneously are shown in Fig 2. The initial part describes the temperature change when only EMC was applied. The temperature difference between different positions which were separated by 10 mm and 50 mm from the mold surface, was very large as 20~30°C. However, the difference was greatly reduced to about 10□ while EMC and EMS were applied simultaneously, as shown in Fig 2. This indicates the temperature of the molten metal becomes uniform because the molten metal is mixed homogeneously by the electromagnetic stirring. It was expected that a uniform temperature distribution of the molten metal plays an important role in reducing the cracks inside the slab by suppressing the creation of dendrite structure and promoting the creation of fine-grained structure. In addition, it was possible to increase casting speed up to 0.4 m/min with a billet diameter of 100 mm and up to 0.2 m/min for a diameter of 150 mm.

Occasionally, the breakout of magnesium billet was observed during continuous casting. Fig 3(a) is applied 600A currents on EMC, 0.2 m/min casting speed with 50L/min. Fig 3(b) is applied 650A currents on EMC, 0.3 m/min casting speed with 20L/min. And fig 3(c) is applied 920~1134A currents on EMC, 0.3~0.4 m/min casting speed with 20L/min. The example of breakout billet is shown in Fig 3(a). If the high power EMS is applied to molten metal, the stirring is excessive so that the circulation of molten metal affect on the solidifying surface and shell. It is important to find optimized process condition for EMS and EMC. The lack of cooling water also causes the breakout of magnesium billet. As the casting speed is increased, the more cooling water is required. If the cooling water is not sufficient, the breakout of billets can occurs. The amount of cooling also can be an important factor for the production of billets. By optimizing these conditions, 1.2m-length magnesium billet with high casting speed was successfully cast as shown in Fig 3(b) and (c).

Fig 4 shows the microstructure of the AZ31+1wt% Ca alloy billet of applying EMC only and applying both EMC and EMS. The grain size of only EMC applied specimen is about 48-60 μm, while it is about 40-50 μm for the specimen of applying EMC and EMS. It indicates that the grain size has been decreased as both EMC and EMS are applied. It is noticeable that the grain side has become significantly smaller and the microstructure refinement was achieved by applying EMC and EMS. The microstructure refinement may be due to the combination of effects of direct cooling, electromagnetic stirring, and the addition of Ca.

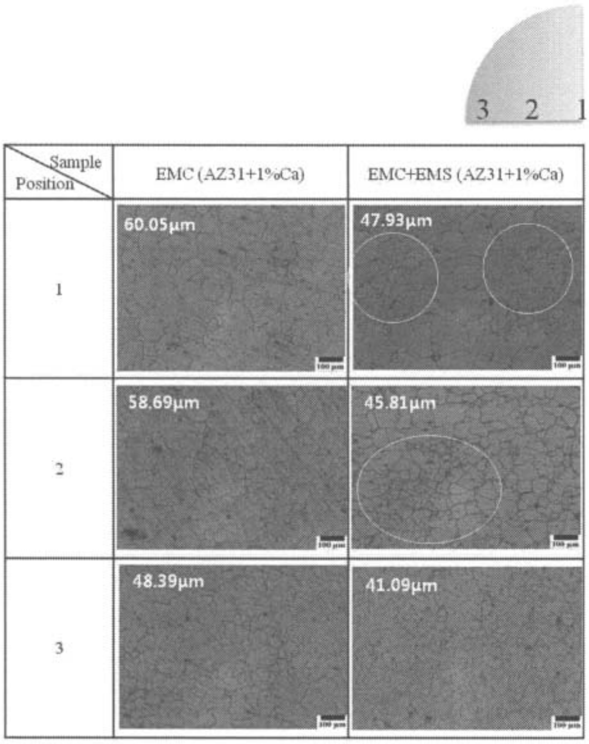

Figure 4. Microstructures of the 1 wt. % Ca-AZ31 billet processed by EMC and EMC+EMS

The casting equipment was scaled up to 300 mm diameter, which enables the production of large scale products. The size of mold was sized up to 300 mm and following apparatus, such as cooling water system, EMC coil, and EMS module were modified for the large scale equipment. Fig 5 shows the magnesium billets of 300 mm diameter made by continuous casting with EMC and EMS technique. The equipment for the fabrication of large scale billets was successfully implemented and operated which means that EMC/EMS can be applied for large scale production.

Fabricated magnesium billets are wrought alloy so that post-processing is required for the final product. In this study, we conducted hot forging process to fabricated automotive engine pulley. An automotive engine pulley made by magnesium billet has a less weight in comparison to aluminum or steel pulley. Forging process was conducted in the temperature range of 230 to 320°C. In the low temperature, the forging process could be finished but the quality of pulley surface is not sufficient. At the high temperature processing with 320°C, there is no crack or defect on the surface of final product. The fabrication process of automotive engine pulley is shown in Fig 6. In the Fig6, second product is forged one and last product is surface-treated one.

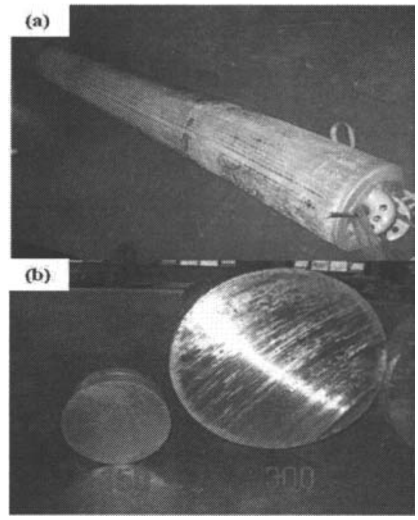

Figure 5. Magnesium billets of 300 mm diameter made by continuous casting

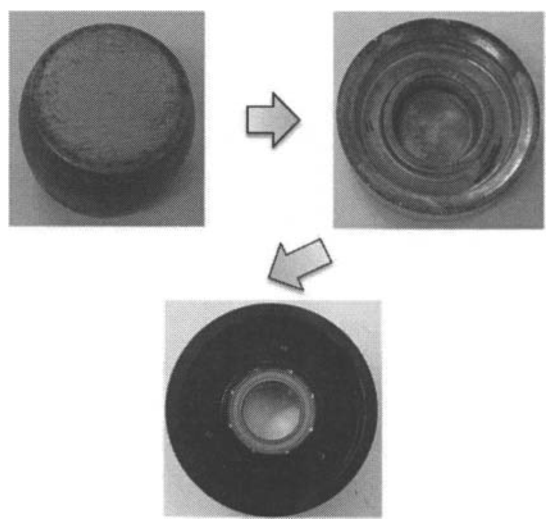

Figure 6. Fabrication of automotive engine pulley with magnesium billets.

Conclusions

The following conclusions were obtained in this study;

(1) High quality magnesium billets can be produced by continuous casting with electromagnetic casting and stirring techniques;

(2) The casting speed can be increased up to 0.4 m/min for a billet diameter of 100 mm, and 0.2 m/min for a billet diameter of 150 mm.;

(3) The microstructure of magnesium billet can be refined by applying the electromagnetic stirring technique;

(4) The casting equipment was modified to produce 300 mm diameter billets and successfully demonstrated;

(5) Magnesium billet was hot forged and made into the prototype of automotive magnesium pulley.

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