Casting Surface of AZ91 Alloy and Its Reaction with Sand Mold

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Due to its light weight and abundance as a resource, the utilization of magnesium is increasing. AZ91 alloy is the most common cast magnesium alloy and is widely used as die-casting material. AZ91 is also used for sand mold casting. In sand mold casting, reaction with mold sand is expected because magnesium is a very reactive element. This study investigated the surface condition of AZ91 castings using sand mold.

Higher pouring temperature promoted the reaction with silica sand, and the surface of castings became rough. Reacting with mold sand, \( \text{Mg}_2\text{Si} \) and Mg and Al complex oxides were precipitated near the casting surface. [doi:10.2320/matertrans.MC200727]

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1. Introduction

Magnesium alloys have been used as a substitute for aluminum alloy and plastic material because of their light weight, recyclability and electromagnetic shield ability.

Die-casting is the main process for magnesium castings, but the sand casting process is also utilized for trial manufacturing or aircraft components, for example. The main reason for surface roughening of the sand mold casting is penetration of melts. In other metal castings, melt does not react directly with mold sand, but reaction in air causes an oxidized melt to react with mold sand.\(^1,2\) Since the magnesium alloy has a low density and a low melting point, therefore penetration does not easily occur, and strength and heat resistivity of mold sand are not important. However, magnesium melt is expected to react with mold sand because of its high reactivity. Generally, magnesium casting is carried out under cover gas in air. Until now, researches on the reaction between magnesium and mold sand has been carried out to understand the mechanisms of sand mold protection by using cover gas on magnesium melts.\(^3-5\) Therefore, the basic reaction between magnesium melt and mold sand has not been studied. This study examines the effect of mold material and pouring temperature on casting surface condition of the AZ91 alloy.

2. Experimental Procedure

The melting material is AZ91D and its composition is 9%Al-0.62%Zn-0.25%Mn. 400 g of AZ91 was melted in a graphite crucible using an induction vacuum furnace under an Ar atmosphere. To study the effect of sand, a sodium silicate/\( \text{CO}_2 \) sand mold having different sand or mold wash was designed to contact with the melt at the same time as shown in Fig. 1. The effect of melt temperature can be ignored since the AZ91 melt contacts the different mold sands at the same time. The effect of mold wash of boron nitride (BN) was studied by coating BN on one side of the silica sand mold wall. Spray type BN was used in this experiment.

The dry sand mold shown in Fig. 2 was made of silica sand to examine the effect of pouring temperature. The green sand mold was made using silica sand, 7 mass% bentonite and 3 mass% water. This green sand mold was dried at 150°C for more than 5 hours to make the dry sand mold. Pouring temperature was varied from 720°C to 910°C and the AZ91 melt was poured into the dry sand mold.

Casting surface and microstructure were examined by optical microscope, XRD and EPMA.

3. Results and Discussion

3.1 Effect of mold material

Figure 3 shows the effect of the sand. The upper photograph shows the side in contact with the silica sand and the lower, chromite sand. The adherence of sand is seen on the
casting surface in contact with the silica sand, but is not observed on the chromite sand side. The silica sand is seen to be more reactive than chromite sand. Figure 4 shows the surface condition of castings with boron nitride applied or unapplied. The applied casting in the lower photo has a clean surface and the effectiveness of the mold wash is apparent. On the unapplied casting, adherence of sand is observed on the surface.

Figure 5 is the cross section of the chromite sand mold after the casting was removed. A slightly whitened layer can be seen near the surface that had been in contact with the casting. This means that the magnesium melt evaporated and penetrated into the sand mold. This can happen in any sand mold. If the temperature of the sand is high enough, a reaction between magnesium and mold sand will occur.

3.2 Effect of pouring temperature

Figure 6 shows the surfaces of castings produced at four different pouring temperatures. As pouring temperature increases, the casting surface becomes blacker and rougher. Both the casting surface and the sand mold near the casting became blacker.

The casting surface was observed by SEM and the results are shown in Fig. 7. When pouring temperature is low (720°C), the shapes of sand grains are almost the same as before pouring. When pouring temperature is high (910°C), the shapes of the sand grains changed extremely. Many cracks on grains and collapsed grains are observed. When pouring temperature is low (720°C), the sand grains became slightly blacker. This means the same reaction between the melt and the mold sand occurs at these four pouring temperatures.

3.3 Analysis of casting surface

With increasing pouring temperature, the reaction between magnesium and silica sand became more severe, as expected because magnesium is very reactive. XRD and EPMA were used to analyze the structure changes caused by the reaction. The casting surface with pouring temperature of 910°C was selected to analyze, because the reaction is most severe. Figure 8 is the XRD result of the casting surface. As indicated in the figure, SiO$_2$ and Mg$_2$Si were identified, but pure Si was not identified.

$$\text{SiO}_2 + 2\text{Mg} = 2\text{MgO} + \text{Si}$$

(1)

$$\text{SiO}_2 + 4\text{Mg} = \text{Mg}_2\text{Si} + 2\text{MgO}$$

(2)

Reaction (1) did not occur, but reaction (2) occurred.

Microstructures of the castings near the surface at different pouring temperatures are shown in Fig. 9 (790°C) and in Fig. 10 (910°C). At both pouring temperatures, reaction products are observed. In Fig. 9, a brown-color lamellar structure is seen at No. 2. A massive light-blue phase is seen at No. 1. In Fig. 10, a characteristic peninsular shape is observed. This shape indicates that originally there were sand grains at this part. In this peninsular-shaped region, a brown
Fig. 6  Casting surface change with different pouring temperatures.

Fig. 7  SEM images of casting surface poured into silica dry sand mold at 720°C, 790°C, 840°C, and 910°C, and SEM image of mold sand before pouring.

Fig. 8  XRD analysis of casting surface poured into silica dry sand mold at 910°C.

Fig. 9  Microstructure of the casting near the surface poured at 790°C. (1) Light-blue color phase, (2) Brown-color lamellar phase.

Fig. 10  Microstructure of the casting near the surface poured at 910°C. (1) Light-blue color phase, (2) Lamellar structure composed of brown-color phase and light-blue phase.
phase and a light-blue phase form a lamellar structure at No. 2. At the base of this peninsular region, massive light-blue phases are observed at No. 1.

To identify these phases, these structures were analyzed by EPMA. Figure 11 is the EPMA mapping of the microstructure shown in Fig. 9. In the region corresponding to (1) in Fig. 9, only Mg and Si are observed. So, the massive blue phase is Mg$_2$Si. In the lamellar structure, O, Mg and Al are observed. So, the brown lamellar structure is expected to be compounds of Mg oxide and Al oxide.

Figure 12 is the EPMA mapping of the microstructure shown in Fig. 10. The light-blue phase is Mg$_2$Si. In the peninsular region, a lamellar structure is observed containing O, Mg, Si and Al. It is seen that the massive light-blue phase is connected to the lamellar phase. The light-blue lamellar phase is Mg$_2$Si, and the brown lamellar phase is a compound of Mg oxide and Al oxide. Based on optical microscope observations, increasing pouring temperature increases the reaction products.

4. Conclusion

The AZ91 alloy was cast into a sand mold. The following results were obtained.

1. Chromite sand does not easily react with the AZ91 melt as silica sand does.
2. The reaction between the AZ91 melt and the silica sand mold could be suppressed by application of boron nitride as the mold wash.
3. As pouring temperature increases, severe sand adhesion is observed.
4. The reaction between silica sand and AZ91 melt causes the precipitation of Mg$_2$Si and compounds of Mg oxide and Al oxide.

REFERENCES