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Effects of melt temperature and mold preheating temperature on the fluidity of Ca containing AZ31 alloys

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The effects of melt temperature and mold preheating temperature on the fluidity of Ca containing AZ31 alloys were evaluated under various casting conditions. The flow lengths of AZ31-xCa alloy melt increased with increasing the melt temperature due to lower viscosity and longer time to fill the mold cavity. The increment of the flow lengths of AZ31-xCa alloy melt with increasing the mold preheating temperature was not large due to large diameter of circular cross section of mold cavity. The fluidity of AZ31-xCa alloy melts was affected more forcefully by melt temperature than by mold preheating temperature under casting conditions used in this study. Also, the flow lengths of AZ31-xCa alloy melt were affected by grain size of primary solid particles solidified during filling mold cavity and surface oxide film due to addition of Ca.

1. Introduction

The magnesium alloys have high reactivity with oxygen in the air. Therefore, ignition or combustion occurs rapidly when they are in contact with oxygen in the molten state, which results in pollution and loss of melt. So the reaction between magnesium alloys melt and oxygen must be prohibited using a proper melt protection method in order to decrease the loss of melt and improve the quality of products. In general the fluxless method using the mixed gas of air, CO_2 and SF_6 gases is widely used in order to protect the magnesium alloy melt from ignition or combustion. But CO_2 and SF_6 gases are green house gases being the source of global warming, so their usage will be reduced or prohibited in near future. The new melt protection method decreasing the environmental pollution must be developed in order to apply the magnesium alloys to structural parts continuously and widen their application fields. There are some methods being developed as new melt protection methods including application of new protection gases [1, 2] and addition of alloying elements [3–8]. The addition of alloying elements has some benefits in respect of processing because special equipment for blowing protection gas on the melt surface during melting and casting is not needed. Ca and Be are known to be effective for improving the oxidation resistance of magnesium alloys melt [3–8]. Especially, the alloys with above 1 wt%Ca did not burn at temperature above liquidus temperature by 50°C [7, 8]. There have been many researches on the microstructures of oxide layers and mechanical properties of Ca containing magnesium alloys [1–10] but the results on the castability or formability of Ca containing magnesium alloys have not reported yet in respect of manufacturing process of products.

In this study the effects of the melt temperature and mold preheating temperature on the fluidity of Ca containing AZ31 magnesium alloys were examined in order to evaluate the possibility of non-combustible Ca-containing magnesium alloys to be applied to the casting process such as die casting and horizontal continuous casting.

2. Experimental procedures

2.5 kg of AZ31B alloy was inserted into a steel crucible and heated to 720°C. Ca pellet was added into a molten AZ31 alloy and the melt was cooled or heated to the temperatures of 680∼760°C and then held isothermally

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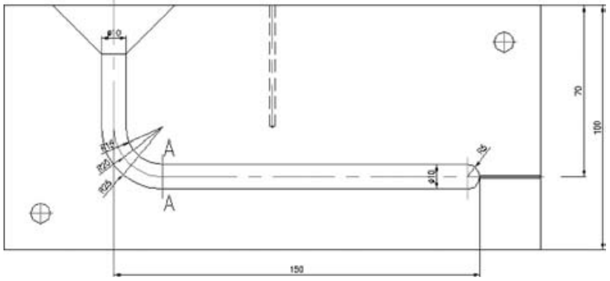


Figure 1 Schematic drawing of mold for fluidity test.

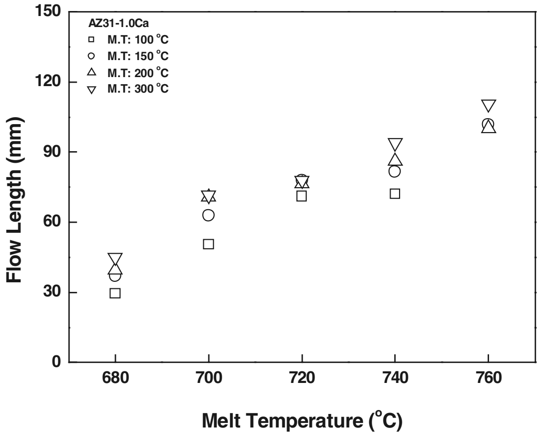


Figure 2 Change of the flow length of AZ31-1.0Ca alloys with melt temperature.

for 30 min in order to homogenize the melt temperature. The amount of Ca added into AZ31 alloy was changed from 0 to 5 wt% (nominal composition). After homogenization, the melt was poured into the mold as shown in Fig. 1. The preheating temperatures of the mold were changed in the range of 100∼300°C. The melt of AZ31-xCa alloys was poured into the mold three times at the same condition. After complete solidification, the lengths of solidified AZ31-xCa alloys from the origin at A were measured and the flow lengths of AZ31-xCa alloys poured at various conditions were determined as average value of these results.

3. Results and discussions

Fig. 2 shows the change of the flow length of AZ31-1.0Ca alloy poured into the mold preheated to 100∼300°C as a function of melt temperature. The flow length of AZ31-1.0Ca alloy increased linearly with increasing the melt temperature at all of mold preheating temperatures investigated in this study. It is well coincided with the equation of $L_f \propto \Delta T$, where L_f and ΔT are the flow length and the superheat, respectively [11, 12]. The increase of flow lengths of AZ31-xCa alloy melt was mainly resulted from the decrease in the viscosity of melt and the increase in filling time. The viscosity of melt decreases with increasing the melt temperature, which results in increase of fluidity because the fluidity is the inverse of viscosity [13]. Also, the time for being remained as liquid and flowing into the mold cavity increases with increasing the melt temperature when the melt is poured into the mold preheated to the same temperature.

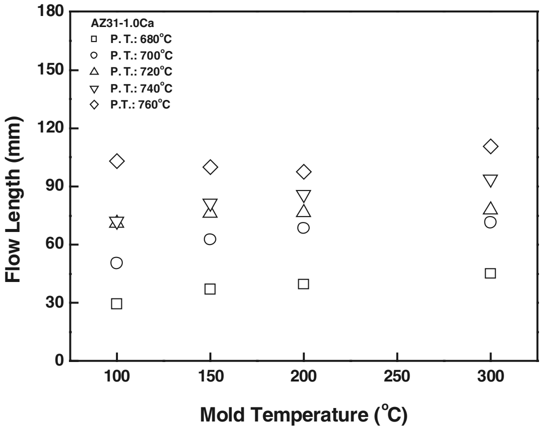


Figure 3 Change of the flow length of AZ31-1.0Ca alloys with mold temperature.

Fig. 3 shows the change of the flow length of AZ31-1.0Ca alloy poured into the mold at various melt temperatures of 680∼760°C as a function of mold preheating temperature. The flow length of AZ31-1.0Ca alloy increased slightly with increasing the mold preheating temperature. The rate of temperature change of the flowing melt during filling the mold cavity with circular cross section can be expressed as follow [11].

$$\frac{dT}{dt} = -\frac{2h(T - T_0)}{a\rho_L c'} \tag{1}$$

where ρ_L and c' are density and specific heat of the liquid metal, respectively. T is melt temperature, T_0 mold temperature, a diameter of circular cross section and h is mold-metal interface resistance to heat transfer. As shown in Equation 1, the rate of temperature change of the flowing melt is proportional to the difference between the melt temperature and the mold temperature and is inversely proportional to the diameter of circular cross section. So a little change of the mold temperature can be resulted in large temperature drop of the flowing melt in the case of small a, which makes the fluidity of the melt be more sensitive to the mold temperature. But the temperature change of the flowing melt is not sensitive to T-T_0 in the case of large a. So it was seemed that the increment of the flow length due to the increase of the mold temperature was not large in this study due to large a (= 10 mm).

Fig. 4 shows the change of the flow length of AZ31-xCa alloys poured into the mold preheated to 300°C at melt temperature of 700°C as a function of Ca content. The flow lengths of AZ31-xCa alloys increased slightly up to 0.5 wt%Ca but changed little above 1 wt%Ca. The increase of flow length in Ca containing magnesium alloys could be resulted from the grain refinement because Ca is the effective element to suppress the grain growth during solidification [14]. Fig. 5 shows the change

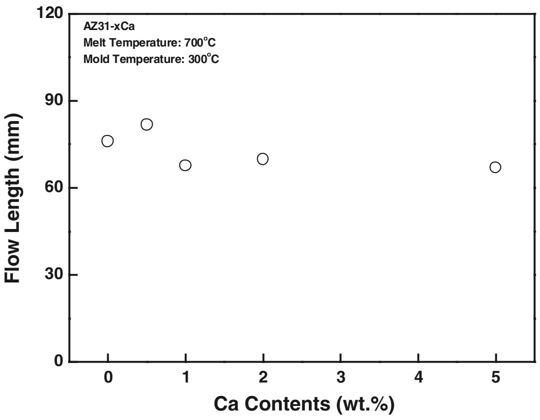


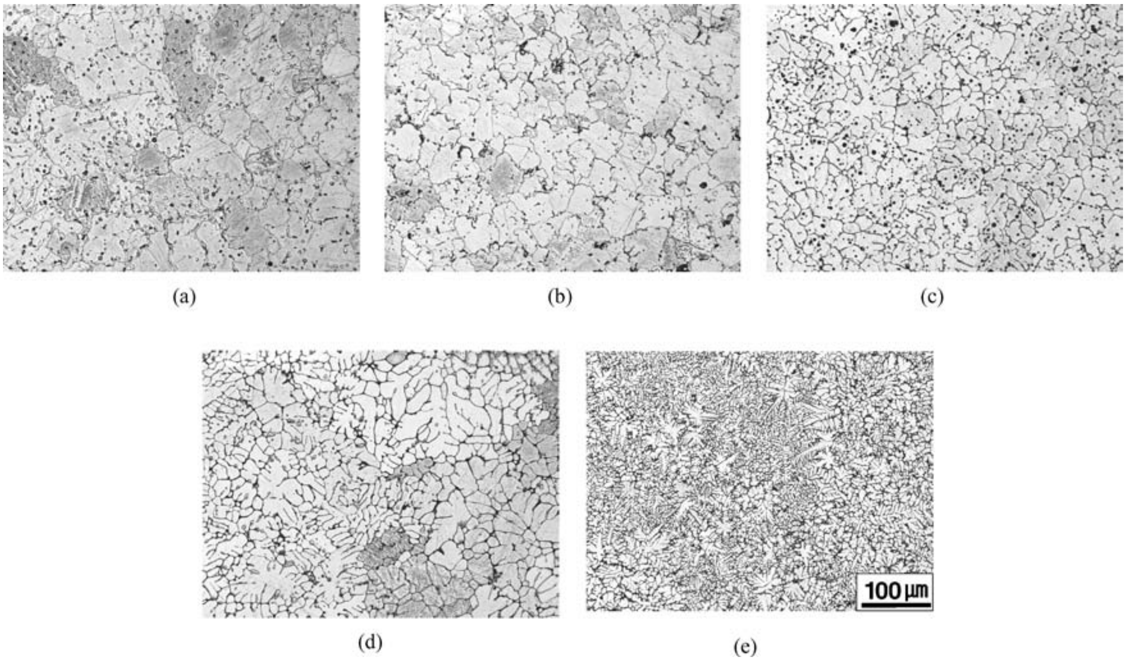
Figure 4 Change of the flow length of AZ31-xCa alloys with Ca content.

in microstructures of AZ31-xCa alloys poured at 700°C into the mold of 150°C. As shown in Fig. 5, the grains were refined with increasing Ca content. In general the grains grow from the mold wall to the center in pure metal and the flow of melt stops after complete solidification. But in the case of alloy, not only solidification from the mold wall but also nucleation and growth of fine dendritic grains occurs in the region of solidification front. So the fluidity of alloy melt will be decreased dramatically when the solid network between the dendritic grains in solidification front will be formed. It was reported that the critical volume fraction of primary solid phase for formation of network was increased with decreasing the average grain size, which resulted in the increase of flow length of the alloy melt [15, 16].

Another factors affecting the fluidity of the alloy melt is the oxide layers on the melt surface [17]. It is well known that the oxide layers on melt surface decreases the fluidity of the alloy melt. In Ca containing magnesium alloy, the formation energy of CaO is lower than that of MgO and the oxide film on the melt surface will be formed more with increasing Ca content, which results in the decrease of the fluidity of melt. So the flow lengths of AZ31-xCa magnesium alloys melt were affected by grain size of primary solid particle solidified during filling mold cavity and surface oxide layers. At low Ca, the increment of flow length by grain refinement was larger than the decrement of flow length by surface oxide layer. With increasing Ca content, grain size decreased but thickness of oxide layer increased. The increment of flow length by grain refinement was compensated by decrement of flow length due to increase of thickness of oxide layer, which resulted in little change in fluidity above 1 wt%Ca as shown in Fig. 4.

4. Conclusion

The flow lengths of the AZ31-xCa alloys melt increased with increasing the melt temperature and mold temperature. The increase of flow length with increasing the melt temperature was resulted from the decrease in the viscosity and longer time to flow into the mold cavity as liquid. The increment of the flow length of the AZ31-xCa alloy melts due to the increase of the mold temperature was not large in this study due to large diameter of channel. The fluidity of AZ31-xCa alloys melt was affected more forcefully by melt temperature than by mold preheating temperature under casting conditions used in this study. The fluidity of Ca containing AZ31 alloy melts increased due to the grain refining effect of Ca but formation of oxide film on the melt surface due to higher Ca was detrimental to the fluidity.



(a) (b) (c) (d) (e)

Figure 5 Change in microstructures of AZ31-xCa alloys poured at 700°C into the mold of 150°C; (a) 0.0Ca (b) 0.5Ca (c) 1.0Ca (d) 2.0Ca (e) 5.0Ca.

Acknowledgments

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