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Effect of water content of frozen mold on fluidity of aluminum alloy

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Abstract

The frozen mold that is fabricated by refrigerating the mixture of sand and water has many advantages to improve the working environments such as noise, vibration, dust and bad smell. The fluidity might be the key issue to spreading this technique to light metals such as aluminum and magnesium because a frozen mold has the possibility to accelerate solidification due to its large cooling ability. In this study, the fluidity of an aluminum alloy (AC4CH) cast in the frozen mold, and the effect of water content of frozen mold on the fluidity was investigated. It is revealed that the AC4CH aluminum alloy has better fluidity against the frozen mold rather than the conventional green sand mold. The flow length of aluminum alloy cast into the frozen mold was influenced by the water content of frozen mold, and increased with decrease in the water content. The good fluidity can be achieved by the mold with the low temperature decrease property.

Introduction

A frozen mold is a kind of sand mold which is produced by freezing the mixture of sand and water. In the mold, the frozen water acts as binder and provides a sufficient mold strength. Thus, no organic binder and curing agents are needed. Therefore, the casting process using the frozen mold generates no harmful gas and bad smell that arise from organic binder and curing agents. The frozen water in the mold unfreezes by the heat of melt after casting. As a result, the frozen mold loses the bonding force of the sand and naturally collapses. So, no equipment is needed to break the mold. Accordingly, such problems as vibration, noise and dust resulting from the breakup process of molds are relieved dramatically. As mentioned above, the frozen mold casting process has the remarkable industrial advantages compared with the conventional casting processes. This casting process using the frozen mold was developed in United Kingdom in the early 1970's [1], and several studies about frozen mold have been reported in Japan [2-6]. However, this technique was not applied in engineering due to the high cost. This process required liquid nitrogen in order to freeze a sand mold. Recently, the advanced freezing method in which the cold air was ventilated through the sand mold was developed [7]. This method enabled to provide frozen mold in a short time with low cost, so the industrial trial of frozen mold casting process has been started. Actually, the frozen mold is now applied to iron and bronze casting in Japan [8, 9].
The frozen mold has a great cooling ability because the frozen mold is at low temperature (about 240K) and includes much frozen water which has large heat of solution. It was reported that the frozen mold casting showed high cooling rate and fine microstructure of cast compared with the green sand mold casting [10]. However, this large cooling capacity of frozen mold might become demerit to fluidity because it has the possibility to accelerate solidification. The influence of this disadvantage seems to be remarkable especially to metals like aluminum alloys and magnesium alloys which have low melting point and low heat of solidification. So the fluidity might be the key to applying this process to light metals. To the authors best knowledge, there has been no reports on the fluidity of light metals cast in the frozen mold. In this present work, the fluidity of aluminum alloy (AC4CH) cast in the frozen mold was studied.

Experimental procedure

The silica sand (R6) was used to fabricate the frozen mold in this study. Water of 3-10 mass% was added to this silica sand, and it was blended for 180 seconds by a mixer. Then, the sand mold for fluidity test which has a cavity of spiral shape was formed using a wood mold as shown in Fig.1. The cavity size of spiral shape is as

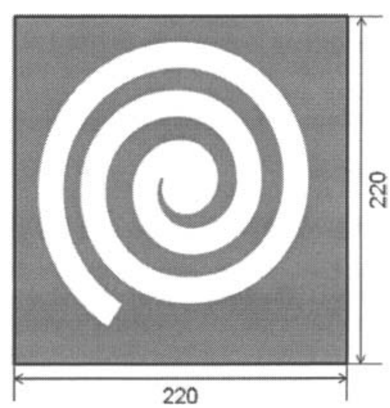

Fig.1 Schematic illustration of the wood mold used for fabrication the fluidity test mold.

follows; length: 820 mm, width: 10 mm and height: 5 mm. The sand mold was put into the freezer held below 240K, and was frozen by ventilating the cold air into the sand mold for more than 3.6 ks. After freezing, the frozen mold was wrapped in a plastic bag in order to prevent drying, and was kept in the freezer again.
A commercially available cast aluminum alloy (AC4CH) was used in fluidity tests. The specimen with weight of about 170 g was charged to a graphite crucible (69 mm (upper) - 60 mm (lower) in inner diameter and 106 mm in height). A hole (10 mm in diameter) was made in the bottom of graphite crucible, and stopper was inserted in this hole. The crucible was put in an electric furnace, and was heated up to 1003K. Then, the crucible where the molten metal was put in was moved from the furnace, and placed on the stand right above the frozen mold, as shown in Fig.2. In order to prevent thawing, the frozen mold was kept in the freezer until just before casting. The graphite crucible where the molten aluminum was put in was covered by heat-insulating ceramic boards to decrease the cooling rate of melt. When the melt temperature was 983K, the molten aluminum alloy was cast

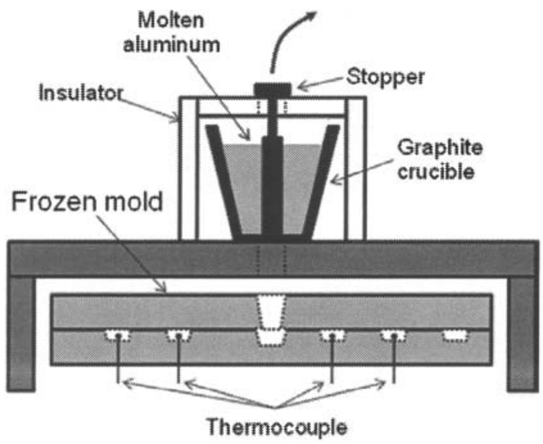

Fig.2 Setup for fluidity test.

into the frozen mold by withdrawing a stopper. In order to measure the temperature of melt which flowed in the spiral cavity, four thermocouples were inserted in the 50, 150, 250 and 350 mm position of the cavity, as shown in Fig.2. For comparison, the fluidity test using green sand mold (green sand, clay, other additives and 2.6 mass% water) was also carried out.

Results and discussion

Frozen mold vs. green sand mold

Fig.3 shows the fluidity test specimens cast into the frozen mold and green sand mold. The flow length of AC4CH aluminum alloy cast in the frozen mold was 551 mm and it was about 1.4 times the flow length comparison with that in the green sand mold (393 mm). It had been deduced that the frozen mold might have a bad influence on the fluidity of aluminum alloys because of its large cooling capacity. However, the present experiment indicated that the frozen mold has good fluidity compared with the green sand mold for the aluminum alloy.

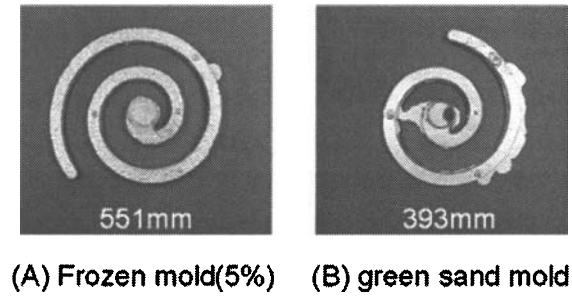

Fig.3 Fluidity test specimen cast in the (A) frozen mold and (B) green sand mold.

Fig.4 shows the typical temperature profiles of melt during the fluidity test. Before casting, temperature indicated mold

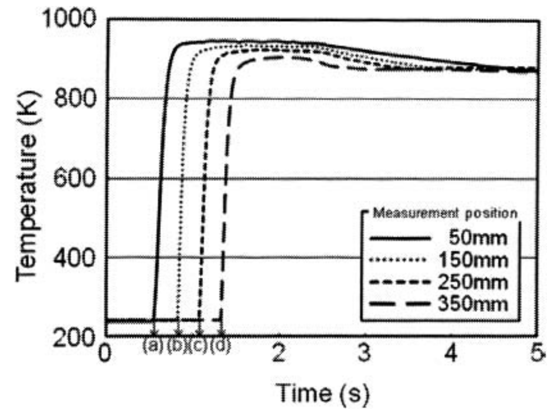

Fig.4 Typical temperature profiles of AC4CH aluminum alloy melt during the fluidity test.

temperature (= about 240K). By arriving the melt at measurement point, temperature rose rapidly by the order from 50 mm to 350 mm. The flow speed of each section (50-150, 150-250 and 250-350 mm) calculated by the arrival time interval of melt was shown in Fig.5. In both molds, the flow speed of melt in the 150-250 mm

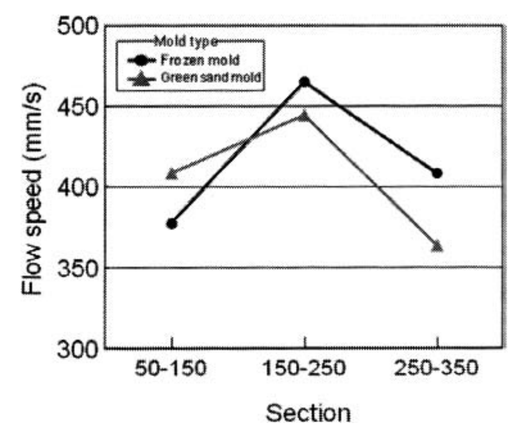

Fig.5 Effect of the mold type on the flow speed of AC4CH aluminum alloy.

section was faster than that in the 50-150 mm section. Then, the flow speed in the 250-350 mm section decreased compared with that in the 150-250 mm section. These results indicate that the aluminum melt flowed acceleratively at first, and then decelerated. In the 50-150mm section, the flow speed of melt cast in the green sand mold was faster than that cast in the frozen mold. In contrast, in the 150-250 mm and 250-350 mm sections, the flow speed of melt cast in the frozen mold was faster than that cast in the green sand mold. It should be noted that the flow speed of melt cast in the green sand mold was significantly slowed down in the 250-350 mm section.

Fig.6 shows the amount of temperature decrease of melt in the 50-150 mm section ($T_{a\text{-}b}$). $T_{a\text{-}b}$ was calculated by formula (1) based on the following assumption; the melt of 50 mm position flowed to 150 mm position while the melt front flowed 100 mm (from 250 mm to 350 mm).

$$T_{a\text{-}b} = \alpha - \beta \quad (1)$$

where $\alpha(T)$ is melt temperature of 50 mm position when the melt front reaches in 250 mm position, $\beta(T)$ is melt temperature of 150 mm position when the melt front reaches in 350 mm position. In the case of green sand mold, the melt temperature decreases by 36K while the melt flowed 100 mm (50 mm to 150 mm). In contrast, the temperature decrease of melt cast in the frozen mold was 17K, i.e., less than half of that cast in the green sand mold. Incidentally, the melt temperature α of frozen mold and green sand mold was 944K and 947K, respectively. It is considered that this low temperature decrease in the frozen mold led the low flow speed degradation (Fig.5) and excellent flow length (Fig.3).

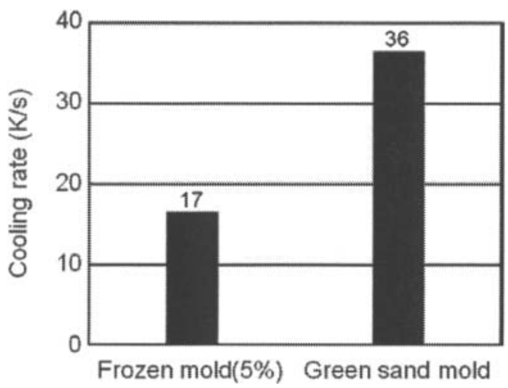

Fig.6 Comparison of cooling rates of AC4CH aluminum alloy on different molds.

Effects of water content on fluidity

Fig.7 shows the flow length of AC4CH aluminum alloy cast into the frozen mold as a function of water content of frozen mold. It can be seen that the fluidity of the aluminum alloy in the frozen mold is closely related to the water content of frozen mold. The

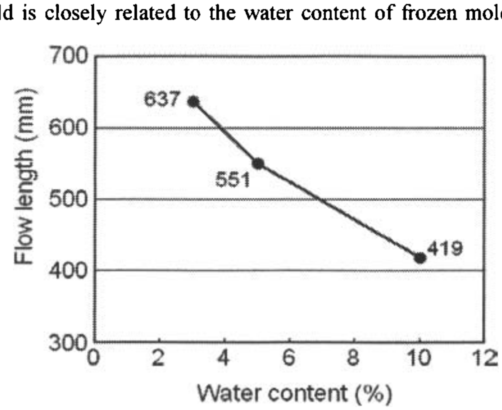

Fig.7 Flow length of AC4CH aluminum alloy as a function of water content of frozen mold.

flow length decreases with increase in the water content. Within the range of water content in the present study, the flow length and water content exhibits a linear relation, and the flow length reduces by 30-40 mm by the increase in 1 mass% of the water content. When the water content is as high as 10 mass% (maximum value of this study), the fluidity of the aluminum alloy is comparable with that cast in the green sand mold.

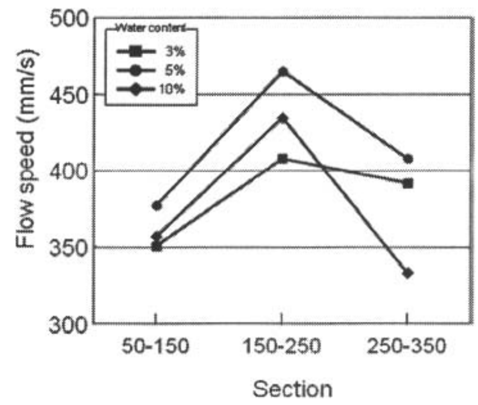

Fig.8 Effect of the water content of frozen mold on the flow speed of AC4CH aluminum alloy.

The flow speed of aluminum alloy cast into the frozen mold with different water content was shown in Fig.8. In all sections, the melt cast in the frozen mold with 5 mass% water has the fastest flow speed. Although the flow speed in the frozen mold with 3 mass% water was slower than that in the frozen mold with 10 mass% water in the range of 50-150 mm and 150-250 mm, in 250-350 mm range, the flow speed in the frozen mold with 3% water was earlier. The tendency of flow speed (the flow speed increased from 50-150 mm to 150-250 mm section, and then decreased from 150-250 mm to 250-350 mm section) was independent of the water content. However, the degree of flow speed degradation in 250-350 mm section was influenced by the water content, and increased with increase in the water content.

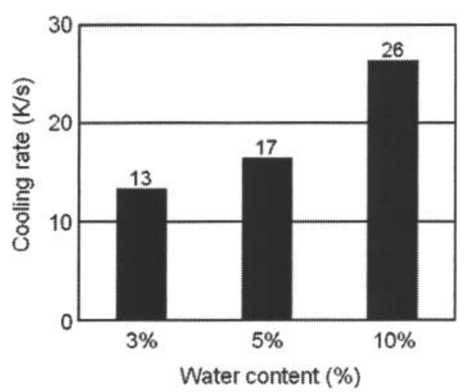

Fig.9 Comparison of cooling rate of AC4CH aluminum alloy on different water content of frozen mold.

Fig.9 shows the amount of temperature decrease of melt in the 50-150 mm section (T_{a-b}) . T_{a-b} decreased with decrease of the water content. T_{a-b} in the frozen mold with 3 mass% water was 13 K, and about half in the frozen mold with 10 mass% water.

It is clearly seen that the amount of temperature decrease of melt (T_{a-b}) during flowing in the cavity correlated with the degree of flow speed degradation. Furthermore, T_{a-b} also correlated with the flow length. That is to say, the great fluidity of aluminum alloy was led by the low temperature reduction during flowing in the cavity. When the aluminum melt is cast in the frozen mold, the frozen water of the cavity surface is heated up and evaporated instantaneously. So the layer of water vapor generates between the cavity surface and melt. Because this layer has low heat conductivity, they prevents the heat transfer from melt to mold and leads to a good fluidity and low temperature decrease.

Conclusions

The fluidity of AC4CH aluminum alloy cast in the frozen mold, and the effect of the water content of frozen mold on the fluidity have been investigated, and the following conclusions have been derived.
The fluidity of AC4CH aluminum alloy cast in the frozen mold is greater than that cast in the green sand mold.
The fluidity of aluminum melt cast in the frozen mold is affected by the water content of frozen mold. The flow length of aluminum melt increases with decrease in the water content.
The fluidity correlates with the amount of temperature decrease of melt during flowing in the cavity. The good fluidity is can be achieved by the low temperature degradation condition.

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