研究速報
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MANUFACTURING OF MOLDING DIE BY CASTING INTO CERAMIC PERMEABLE MOLD

——Report 3 : Aluminium Alloy Molding Die——

通気性セラミック型への鋳造による金型の製造
——第3報：アルミ合金型——

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1. Introduction

As a kind of new material for molding die, aluminium alloy has been adopted progressively in resent years for its light weight, rust-free, excellent thermal-conductivity. Especially, the molding dies having elaborate patterns, which are usually produced with some high cost and long delivery working process, such as etching, electrocasting, have become much more expensive along with increasing of the manufacture of diversified products in small lots. This study was carried out by authors, in which aluminium alloy molding die for injection was produced by sucked casting with ceramic permeable mold at low cost for rapid delivery. And high-quality elaborate patterns and improved surface hardness are obtained.

2. Casting experiment

2.1 Alloys used in the experiment

The alloys used in the expreiment are shown in Table 1. They respectively belong to hypoeutectic alloy (AC4D) which is added with Si, Cu, Mg to result in solid solution strengthening and precipitation hardening, eutectic alloy (AC3A) which has a very narrow solidifying range, and hypereutectic alloy (AC23H) which contains a lot of Si appearing as a form of primary phase.

Table 1 Alloys used in experiments

Name of Alloys	Element Composition (wt%)				Liquidus Temp.(°C)	Solidus Temp.(°C)	Solidification Range(°C)
	Zn	Al	Cu	Si			
ZAS-C	90	4.5	5.2	／	390	378	12
ZA-27	70	27	2.5	／	500	440	60
AC3A	0.3	88	0.2	11	585	575	10
AC4D	／	93	1.2	5.0	625	580	45
AC23H	／	72	1.6	23	750	575	175

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2.2 Permeable mold used in the experiment

The casting molds used in experiment, named "green mold", are only vacuum-dried at 76 cmHg, 100°C for 3~6 hours instead of sintering at high temperature to improve thermal shock resistivity in casting and collapsibility after casting. And they have also very good permeability for more than 40% porosity.

2.3 Method of the experiment

The device used in experiment is the same with report 1[1].

In order to evaluate transprinting attribute of sucked casting to elaborate patterns, several kinds of triangle wave patterns, which are different in angle and pitch, are combined into a mold. The triangle wave contours of casting mold and cast molding die are respectively measured with a surface texture measuring instrument and the effect of sucked casting is compared with non-sucked casting. The detail of this method has been introduced in Report 2[2].

Another group of experiments are carried out to investigate the effect of "Rapid cooling in casting". The excellent permeability is used to precool and cool the casting mold by making the cooling medium (Air, cold nitrogen even water) flow in the pores. Hardness on cast molding die surface in different cooling condition are measured and compared.

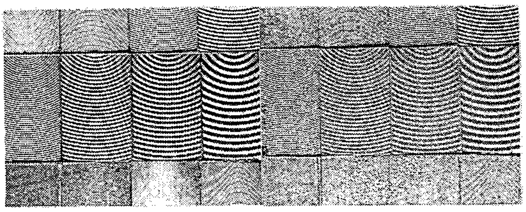

Fig. 1 Comparison between sucked and non-sucked casting (Photograph)

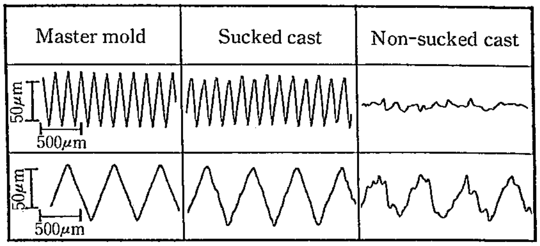

Fig. 2 Comparison between sucked and non-sucked casting (Measured contours)

3. Result of experiment

3.1 Effect of sucked casting

The effect of sucked casting are shown in Fig. 1 and Fig. 2. The sample sucked is much better than non-sucked one in not only transprinting attribute, but also surface luster. As showing of measured contours, the small triangle waves are transprinted very clearly and completely by sucked casting, comparing with this, the non-sucked ones are almost not transprinted, the contours appear very shallow and disorderly. Even the large triangle waves also can not be transprinted satisfactorily on the non-sucked occasion, which were transprinted somewhat fair when Zn alloy was cast in non-sucked for its larger spesific gravity, and the surface of triangle waves is quite rough even if their contours are recognizable. It can be observed clearly that grains on surface are so coarse that the surface become rough and undulant. This can be considered that there is a layer of air and gas between molten alloy and casting mold in case of non-sucked which affects heat-conduction obviously from molten alloy to casting mold so that slow solidifying rate results in coarse grains. But in sucked casting, the air and gas at interface are drawn away by vacuum pump and molten alloy keeps hold of casting mold. Thus, the heat of molten alloy is taken away rapidly and fine grains and smooth surface are obtained. It is evident that the sharper the shape of pattern is and the smaller the specific gravity of alloy is, the poorer the transprinting is, in other words, the higher the vacuum pressure must be for getting satisfactory transprinting.

3.2 Effect of rapid cooling in casting

The effect of rapid cooling casting on surface hardening is investigated by means of using the ceramic permeable mold which can be cooled rapidly for its excellent permeability and thermal-conductivity. It will be mainly reported here through a kind of Al alloy (AC4D).

Table 2 shows 4 conditions used in this experiment and their results about cooling rate and surface hard-

Table 2 Experimental condition and results of AC4D

No	Condition	Mold temp.	Cooling method after casting	Other conditions	Cooling rate(°C/min)		Hardness(H_RB) L=100kg				
					625~580°C	660~150°C	A	B	C	D	E
210	Rapid cooling(1)	−90°C	with water by sucking as soon as casting	Room temp. 14~18°C	26.5	75.0	103	126	139	148	151
204	Rapid cooling(2)	−60°C	with cold N gas 2 min. later than casting	Pouring temp. 660°C	11.5	29.8	101	120	134	143	148
213	Slow cooling(1)	15°C	Cooling naturally (Plaster casting mold)	Alloy weight 1.0~1.3kg	7.6	10.5	90	116	127	137	148
212	Slow cooling(2)	300°C	in an electric furnace. (300°C heated) 2 min. later than casting	Sucking pressure 60~70cmHg	16.1	2.2	83	83	84	85	148

ness. And relation beween the cooling rate and the surface hardness is illustrated in Fig. 3. Curves A,B, C,D,E are surface hardness which are respectively measured 2 days later, 12 days later, 24 days later than casting, after tempering (155°C 8 hours), after quenching (525°C 12 hours, 100°C water) + tempering (155°C 8 hours). The hardness increases with the increasing of cooling rate for all of the curves except E. Especially the increasing rate has the maximum near the cooling rate of 10°C/min. But at the slow cooling point (2.2°C/min) the surface hardness has no change following the several treatments (A~D) untill the quenching + tempering (E) is carried out. On the other hand, there is almost no difference between "tempering only (D)" and "quenching + tempering (E)" in case of rapid cooling (>30°C/min). From above phenomena, it can be considered that oversaturated solid solution from rapid cooling and precipitation from aging or tempering result in the hardening, but these effects are invisible in case of slow cooling because the oversaturated solid solution does not exist. So it is obvious that rapid cooling in casting with ceramic permeable mold can be used to improve the surface hardness simply and avoid oxidation or deformation resulted from quenching, which is very important for the molding mold that there are elaborate patterns on surface.

Fig. 4 shows microstructure on cast surface with ceramic permeable mold and plaster mold. As the plaster mold can not be cooled effectively, the cooling rate is much lower than ceramic permeable mold, so that the grain size is finer with rapid cooling by using ceramic permeable mold than plaster mold (AC4D) and the fine-grained and dispersed Si cells are observed (AC23H). The hardness is also different as it should be.

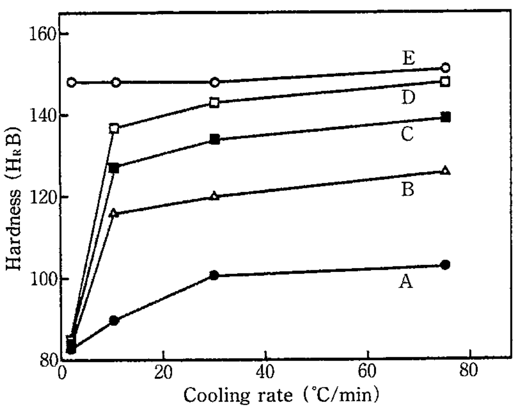

Fig. 3　Relation between cooling rate and surface hardness

3. 3　Unsuitable alloys for this process

a) Alloys that there are obvious differences in specific gravity and melting point between the elements contained. As shown in Table. 1, ZA-27 is a kind of Zn alloy which contains 27wt% Al. But volume ratio of Al is about 50vol% for its specific gravity is only 2.7 to 7.133 of Zn. And the melting point of Al (659°C) is quite higher than Zn (420°C). So as soon as casting, the part where Al is rich floats up to upper side of molten alloy and solidifies earlier. On the other hand, the part where Zn is rich sinks down to lower side of molten alloy and solidifies later. Therefore, defects like shrinkage cavity, shrinkage sponge are concentrated at the bottom of molten alloy so that precision transprinting becomes impossible (Fig. 5). Even if the sucking is used, but the trouble can not be solved as the sucking power can not overcome contracting power when alloy solidifies.

b) Alloys which have a wide solidifying range. A close attention has to be paid in casting with this kind of alloys. As these alloys do not solidify rapidly after pouring, different cooling condition in molten

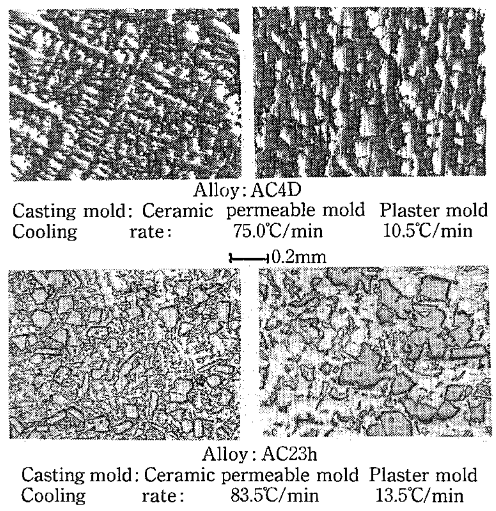

Fig. 4　Comparison of micro structure on cast surface

Fig. 5 Defect on the transprinted surface of ZA-27

Fig. 6 Inner defect of AC23H

alloy forms a temperature gradient. So defects like porosity, shrinkage hole occur usually at the central zone of cast where the solidifying is the latest (Fig. 6). Therefore, measures which can promote directional solidifying have to be used to make the defects disappear or go to the top of cast which will be cut away.

4. Conclusion

a) Sucking is absolutely nesessary to transprinting elaborate pattern with this process, especially when light alloys like Al alloys are used, because air and gas at interface between molten alloy and casting mold can not be removed by dead weight of molten alloy.

b) Rapid cooling casting with this process can obtain a "quenching effect" for solution heat treatment alloys to avoid surface oxdation and deformation resulted from quenching, which are very harmful to the transprinted elaborate pattern.

c) Not all of kinds of alloys can be used into this process, such as the alloys which is easy to produce the "gravity segregation", and a close attention has to be paid for the alloys which have wide solidifying range.

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References

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