Die Cast Prototyping using Plaster Casting with Pressurized Vibration Casting Machine

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ABSTRACT

This work is concerned with the development of a new plaster die-casting process that combines pressurization and vibration for the prototyping of die-castings, and also with a plaster die-casting machine that has a structure quite similar to that of an ordinary die casting machine. The machine utilizes an air cylinder for pressurization and a magnetic actuator for vibration. A rapid prototyped pattern is made by the LOM process to prepare a plaster mold. In the process, a plunger in the developed machine simultaneously pressurizes and vibrates the molten metal to fill the plaster mold completely and to facilitate the creation of nuclei in the molten metal, respectively. The developed machine produced a prototype of an end clutch cover with a remarkable improvement in mechanical properties.

Keywords : Rapid prototyping, plaster die-casting, die-casting, vibration, pressurization

1. Introduction

Conventional prototyping of die-casting requires costly steel tools and considerable time to make the tools. In the past even though die casters understood the need for prototyping of die-casting, the cost and time for making and repairing steel tools prevented them from prototyping die-castings. After the development of rapid prototyping processes that could optimize designs and incorporate changes of a part in the prototyping stage, die casters realized that prototyping of die-casting could be competitive [1,2]

The combination of rapid prototyping and plaster die-casting has provided a useful means of making prototypes of die-casting. Plaster die-casting can produce metallic castings, such as aluminum, zinc, and magnesium castings, with dimensional accuracy and good surface quality. Unlike in standard die casting, however, in plaster die casting molten metal is poured into a plaster mold without additional pressure, gravity, and the mold cools much more slowly than a die cast mold. In this way, plaster castings have much larger and coarser grain structure than standard die-castings. In addition, the gravity pour of plaster die-casting can cause incomplete filling of thin walls of the mold cavity. Because of the poorer mechanical properties of plaster castings, which mainly stem from their large grain structure, and incomplete filling of the thin walls, plaster castings are not suitable for the prototyping of die casting [3].

The purpose of this study is to propose a new plaster die casting process to improve the prototyping of die casting, and to develop a plaster die-casting machine implementing the proposed process. Laminated object manufacturing (LOM), a rapid prototyping process, is employed to make the patterns to prepare plaster molds. In addition, in the process the molten metal is pressurized and vibrated simultaneously to fill the mold completely and to facilitate the creation of nuclei in the molten metal, respectively. Preliminary experiments examined the effects of pressurization and vibration on the quality of castings [4]. Based on the data obtained from the experiments, a plaster die-casting machine employing pressurization and vibration has been developed that has a structure similar to that of a conventional die casting machine The machine utilizes an air cylinder for pressurization and a magnetic actuator for vibration.

2. Problems in conventional prototyping of die-casting

Generally, plaster castings have inferior mechanical properties in a range of 70 to 80 % of the die-castings due to some differences in the processes. Table 1 shows a comparison of mechanical properties between plaster castings and die-castings [5].

Table 1 Comparisons of mechanical properties between die-castings and plaster castings

Properties \ Process	Die-castings	Plaster castings
Yield strength (%)	100	70 ~ 75
Tensile strength (%)	100	70 ~ 85
Surface roughness (μm)	0.8 ~ 0.2	2.0 ~ 3.3
Porosity (high density)	Interior	Exterior

In die casting, molten metal is forced into a steel mold by high pressure and velocity, and is held under pressure during solidification so that the molten metal fills the mold completely and rapidly. On the contrary, plaster die casting produces castings with low pressure and longer filling time. Therefore, at pouring, the plaster mold should be kept at a relatively high temperature in order to reduce heat losses and maintain fluidity of the molten metal. Because of their very low heat conductivity of under 0.5 W/mk, plaster molds prevent outward heat transfer from the castings. This slows down the cooling rate of the castings. Slow cooling rate typically yields large grain structure during solidification of metals. Obviously, plaster castings have larger grain structures than those of die-castings, as shown in Fig. 1.

The cooling rate also affects the surface roughness of the castings. Due to the rapid cooling rate, die-castings have finer surface roughness than plaster castings. Because most die cast parts have fine sections and details, the prototyping of die casting using plaster casting can result in incompletely filled casting prototypes.

(a) die-casting (b) plaster casting

Fig. 1 Typical microstructures of die-casting and plaster casting

3. Plaster die-casting combined with pressurization and vibration

Previous work has shown that the application of vibration to solidifying metals in molds is beneficial to their mechanical properties in many ways [6,7]. The applied vibration prevents the growth of columnar and dendritic grains and facilitates the formation of fine equiaxed grains during solidification. As a result, the diameter of critical stable nuclei size of the solidifying castings decreases and consequently the castings have improved mechanical properties.

In the preliminary experiments, an end clutch cover, a typical die cast part, has been cast in pure aluminum using the plaster die casting adopting pressurization and vibration [4]. A test apparatus was made to perform the plaster die casting process. In order to examine the effects of pressurization and vibration on the quality of castings, preliminary experiments were carried out for two end clutch covers: one by conventional plaster die casting and the other by the developed plaster die casting. Preliminary experiments found that the applied vibration during the solidification of castings facilitated the creation of nuclei in the castings and resulted in finer grain structure. Furthermore, the pressurization increased the filling rate of the castings.

Based on the results of the preliminary experiments, a new plaster die-casting machine was developed. Pressurization and vibration were applied to the molten metal in the machine, which has a structure quite similar to that of a typical die-casting machine

3.1 A plaster die-casting machine employing pressurization and vibration

Fig. 2 shows the configuration of the developed plaster die-casting machine. It is composed of two parts: a magnetic vibration component and a pneumatic pressurization component.

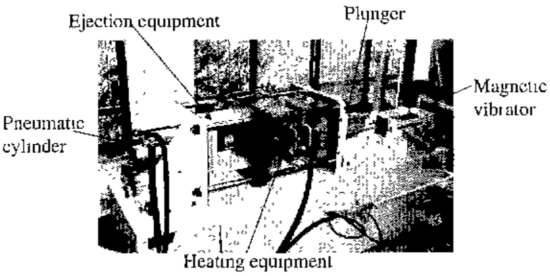


Fig. 2 A plaster die-casting machine employing pressurization and vibration

The casting procedure of the proposed plaster die casting process is as follows. First, the heating equipment applies heat to the surface of the plaster mold, which is loaded onto the steel casings beforehand, each half of the mold to each casing. Since plaster molds have low heat conductivity, it is necessary to heat the mold surface directly. After the surface temperature of the mold reaches a set temperature, the pneumatic cylinder on the left side pushes the left half of the mold and closes the mold. Next, immediately after the molten metal is poured into the cylindrical shot chamber on the right, the plunger pressurizes and vibrates the molten metal simultaneously. Fig. 3 shows how the plunger operates during the process. As a double action air cylinder controls the plunger, the plunger moves to the left at a low speed, 300 mm/sec. The slow movement of the plunger avoids damaging the plaster mold. The plunger holds the molten metal under pressure and continues to vibrate it during solidification. The magnetic vibrator oscillates according to horizontal sinusoidal signals generated by a signal controller. After a while, the mold is opened and the ejector pushes the casting out of the mold. The PLC controller of the machine controls all the operations automatically.

3.2 Prototyping of end clutch cover

Fig. 4 describes the prototyping procedure of an end clutch cover. The first step is to create a three-dimensional CAD model of the end clutch cover. From the CAD model, the graphic software can generate easily the CAD models of the upper and lower halves of the mold, which have a negative shape of the end clutch cover. Secondly, according to the CAD models of the mold, laminated objected manufacturing (LOM), a rapid prototyping process, is employed to make two physical models of the mold: the upper and lower molds. After some post

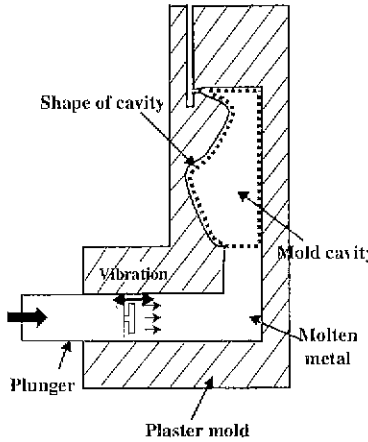


Fig. 3 Schematic diagram of plaster die-casting using pressurization and vibration

processing, each mold made by LOM is placed in an open acrylic box. Liquid silicon is poured over each mold in the acrylic boxes. The obtained silicon molds have the positive shape of the end clutch cover.

Finally, the LOM molds in the acrylic boxes are replaced with the silicon molds over which plaster slurry is poured. When the plaster molds are solidified, they are

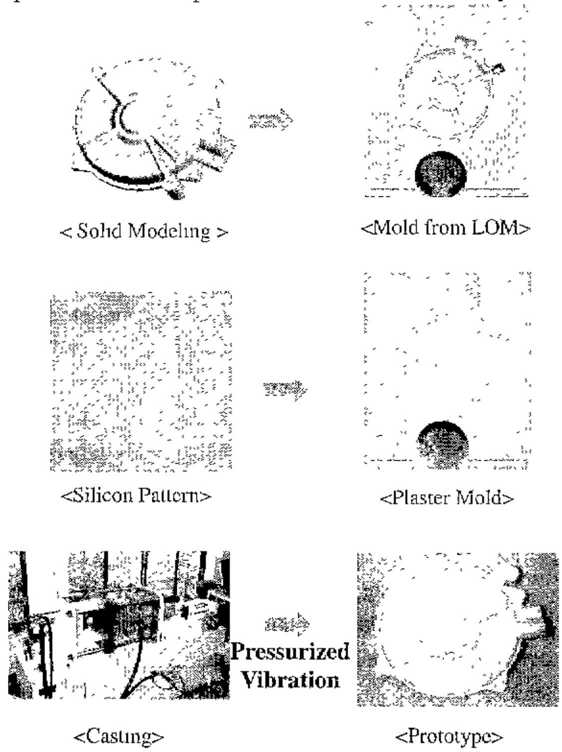


Fig. 4 Steps of plaster die-casting process with pressurization and vibration

baked in an oven to remove moisture remaining in the interior. Then the plaster molds are loaded on to the developed plaster-casting machine and the machine pressurizes and vibrates the molten metal to be poured into the mold.

3.3 Comparisons of properties between prototypes of end clutch cover

In this section, mechanical properties and microstructures of the prototypes, which were made in the preliminary experiments and by the developed plaster-casting machine, are compared. Table 2 shows the experimental conditions used in both cases. As shown in Table 2, the injection speed of the developed plaster die-casting machine is 6 times faster than in the preliminary experiments. In the developed casting machine, the injection speed is controlled by the plunger, which forces the molten pure aluminum with a temperature of 800℃ into the mold. Because of the increased injection speed, the temperature of the mold surface can be lowered from 300℃ to 200℃.

To measure the surface roughness of the prototypes, four specimens were taken from each prototype. The locations from where the specimens were picked are shown in Fig. 5. As shown in Table 3, the prototype made by the developed process has a much more improved surface roughness than the prototype from the preliminary experiments. The lower temperature of the mold surface and shorter injection time resulted in the notable improvement in surface roughness.

Table 2 Comparison of experimental conditions

Process / Conditions	Preliminary experiment	Developed casting
Frequency (Hz)	15	30
Max. amplitude (mm)	0.5	0.3
Injection speed (mm/sec)	50	300
Ejection time (min)	5	1
Mold temp. (℃)	300	200

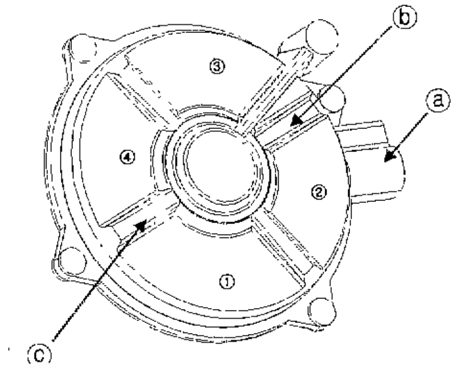


Fig. 5 Locations for acquiring specimens to examine grain size and surface roughness:ⓐ - ⓒ, and surface roughness:① - ④

Because of the lower mold temperature, molten metal is solidified rapidly from the surface facing the mold cavity. The lesser amount of air trapped in the casting, especially on the surface, is due to the filling of the molten metal from bottom to top, which contributes to improved surface roughness.

Table 3 Comparison of surface roughness

Process / Location	Die casting Ra(μm)	Preliminary experiment Ra(μm)	Developed casting Ra(μm)
①	1.63	3.89	1.09
②	3.23	4.92	1.57
③	0.70	4.90	0.94
④	2.66	3.27	1.43

Table 4 shows the average size of grain diameter measured from each prototype. The reasons for the remarkable decrease in the grain size of the prototype made by the developed process are lower mold temperature and vibration. Especially the vibration from the plunger during solidification activated the creation of nuclei of the casting.

To examine the surface hardness of the prototypes, three specimens were taken from the locations shown in Fig. 5. A Rockwell tester of C scale probed the surface hardness of each prototype five times.

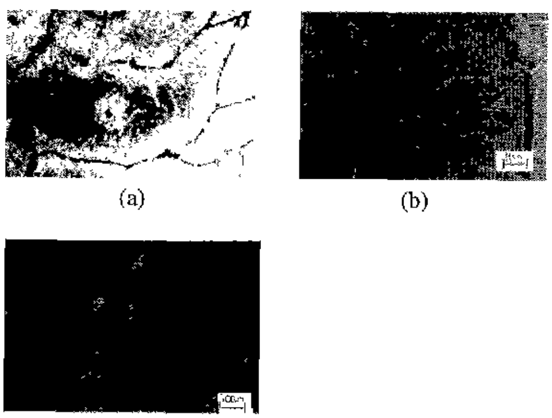
Table 4 Comparison of grain size

Process / Location	Casting without vibration	Preliminary experiment	Developed casting
	Diameter (㎛)	Diameter (㎛)	Diameter (㎛)
ⓐ	400	200	60
ⓑ	300	100	50
ⓒ	300	130	70

Table 5 shows the average values of surface hardness. The lowered temperature of the mold surface, reduced grain size, and increased density hardened the prototype made by the developed process.

Table 5 Comparison of surface hardness

Process / Location	Casting without vibration	Preliminary experiment	Developed casting
	R_c	R_c	R_c
ⓐ	28	30	35.5
ⓑ	29.5	31.5	37
ⓒ	27	30.5	36



(a) (b) (c)

Fig. 6 Microstructures of prototypes made by (a) conventional plaster casting, (b) preliminary experiment, and (c) developed casting

4. Conclusion

A new plaster die-casting process employing pressurization and vibration has been proposed for the improvement of the prototyping of die-casting. Based on the results obtained from preliminary experiments that had been performed to examine the effects of pressurization and vibration on the properties of a prototype of an end clutch cover, a plaster die-casting machine was designed and manufactured to have a structure similar to that of a conventional die-casting machine. The developed plaster die-casting machine generated a prototype of an end clutch cover which has much finer surface roughness and microstructure than those of other prototypes made by conventional plaster die casting and made in the preliminary experiments. The improvements in surface roughness, surface hardness, and microstructure of the prototype are attributed to the vibration that facilitates the creation of nuclei during solidification, and also to the pressurization that lowers the temperature of mold surface and shortens injection time. As stated above, using the developed plaster die-casting process and machine prototypes of die-castings can be produced more effectively.

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