Molding of Cylinder Head Materials by the Lost-Wax Casting Process Using a Gypsum Mold

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Abstract

A resin cylinder head model was produced using a rapid prototype producing system. The resin model was used in the lost-wax casting process instead of a wax model. The casting molded by this method was as precise in both shape and dimensions as a casting produced using a metal mold. This paper describes the manufacturing process of cylinder head material using this method in detail.

***Key words**: Gypsum Mold, Lost-Wax Casting, Rapid Prototyping*

1. Introduction

Cylinder heads are relatively large in size and the molds used for casting them feature complicated core shapes. Traditionally, cylinder heads and similarly complicated castings have been produced by manufacturing wooden patterns that model the shape of the required product, creating sandmolds which are the inverse of the wooden patterns, combining these to form a casting cavity, and finally pouring aluminum or some other molten metal into this cavity to produce the required casting. Creation of wooden patterns in this process requires a considerable amount of time as it involves time-consuming jobs such as designing casting plans and making wooden pattern manufacturing data.

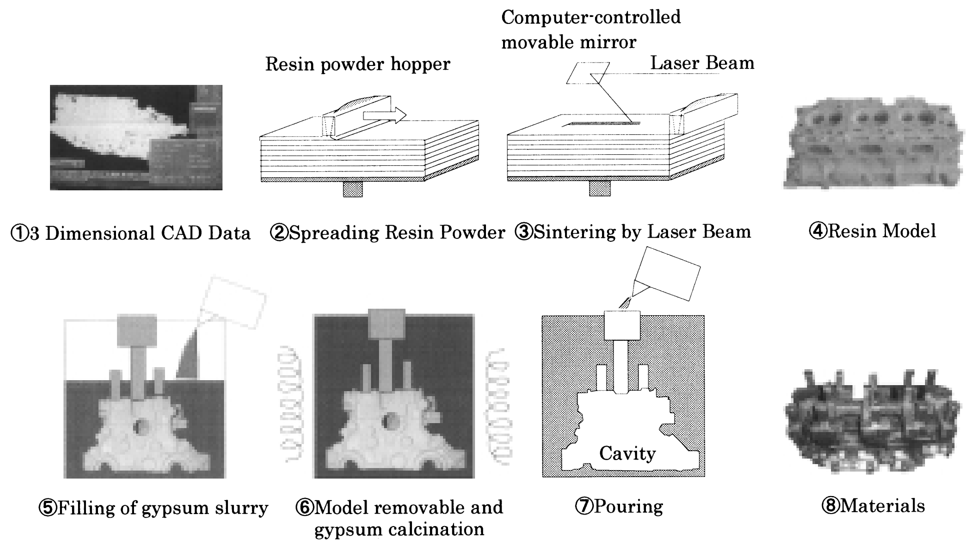

Fig. 1 Main process steps

In recent years, machinery manufacturers have market-released a wide variety of rapid prototyping machines which use three-dimensional, computer-aided design data in the creation of the models, and these machines are being put to use in the field of electrical appliances to make resin case prototypes and, in the field of automobiles, to create models of small resin components in order that development periods may be shortened. Meanwhile, it is possible to use models produced using these machines as lost-wax models from which gypsum molds may be created, and this method is actually applied to the production of small cast-component test samples. However, it is generally standard for accuracy attainable by this method to be restricted to a level of approximately ± 1 mm when it is used in the production of cylinder heads or other similarly complicated components with weights in excess of 10 kg. For this reason, this process has not been used for the production of cylinder head materials whose intake and exhaust ports require an accuracy of ± 0.5 mm. Recently, Mitsubishi Motors successfully resolved this accuracy-related problems by forming individually the parts of a resin model and devising measures for limiting deformation encountered in the production of gypsum molds. This paper will introduce the new method that has been established to rapidly produce advance materials of cylinder heads in small quantities to the same accuracy as available with metal molds.

2. Method overview

Fig. 1 presents an overview of the above-mentioned process. In this process, three-dimensional computer-

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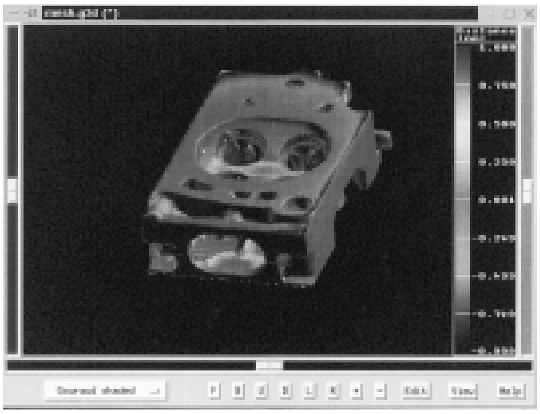

Fig. 2 Results of dimensional measurement on divided polystyrene resin model

aided design data are used to create a resin model (part ① of **Fig. 1**). First of all, a laminate of fine polystyrene powder is laid down with an arbitrary thickness on a platform (Part ② of **Fig. 1**). Next, a laser beam is scanned across the surface of the resin powder layer in accordance with slice-shape data which has been obtained by correcting the desired shape data with the shrinkage rates for both resin model forming and casting, and the resin powder is thus sintered (Part ③ of **Fig. 1**). When the first layer has been completely sintered, another thin layer of fine plastic powder is formed, and laser beam scanning is again used to sinter the layer, thus forming a new sintered layer on top of the first sintered layer. By repeating this layer-forming procedure, a resin model is formed (Part ④ of **Fig. 1**). Next, sprues, heads, and chillers are added to this resin model, and wax is then applied to the model to improve the adhension of the resin model and the gypsum slurry.

Following this, the resin model is setup within a depressurized molding flask, and gypsum slurry is then poured into the molding flask and allowed to harden (Part ⑤ of **Fig. 1**). Next, the gypsum mold is removed from the molding flask, and by placing this into an oven, the resin model can be melted and removed, and the gypsum mold can be calcined (Part ⑥ of **Fig. 1**). The mold is then cooled down to the pouring temperature, and molten aluminum is poured into the mold (Part ⑦ in **Fig. 1**). After cooling and mold removing, the casting is subjected to solution treatment to modify the metal structure of the combustion chamber walls, and then artificial hardening treatment (T6) is carried out, thus completing the cylinder-head material (Part ⑧ of **Fig. 1**).

3. Measures for assurance of dimensional accuracy

3.1 Resin model forming

One-piece resin model forming was initially tried, but the cleaning of polystyrene from the water chamber was extremely troublesome; accordingly, it was decided to form the resin model in two pieces, one parted from the other at the water chamber. Warping of the joint surfaces of these separately formed models was corrected using sand paper, and they were joined

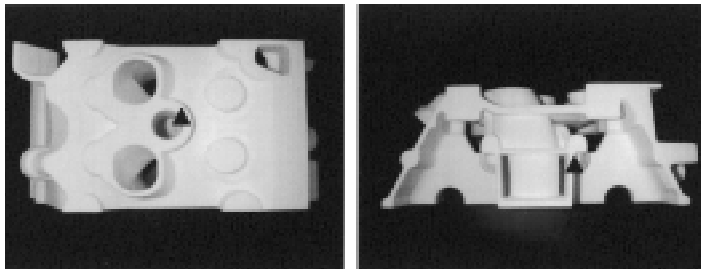

Fig. 3 Forming into shells of thick-wall portions

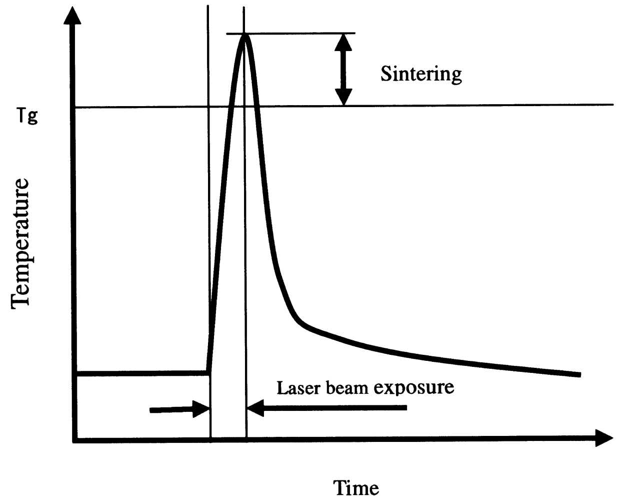

Fig. 4 Heating pattern of resin powder sintering

together using a polyvinyl-acetate emulsion type adhesive. The shape dimensions of the assembled model were measured using a three-dimensional measurement device, which revealed that shrinkage of material at thick-wall sections led to warping of the entire model. It was concluded that this resulted from the buildup of heat from radiated laser beam in thick-wall sections, thus raising the sintering temperatures at these sections and leading to a larger degree of shrinkage than occurring in thinner sections. The following solution was devised in order to resolve this problem.

(1) Separated polystyrene model forming

In order to reduce the total amount of incoming laser beam during forming, the forming of the model was further subdivided by parting it not only at the water chamber but also between combustion chambers by providing joint margins. The separation surfaces were corrected while maintaining the flatness and perpendicularity of the joint sections thereby matching the accuracy of the port-to-port pitch to the target value. **Fig. 2** presents the results of dimensional measurements on the separated polystyrene model.

(2) Application of shell structure in thick-wall sections

Shells structure was were applied in sections with thick-walls in order to restrict the localized build up of heat which can occur at these locations. **Fig. 3** presents a separated polystyrene model in which shell structure has been adopted in such sections.

(3) Optimization of laser sintering temperature

Fig. 4 illustrates the pattern of heating during the

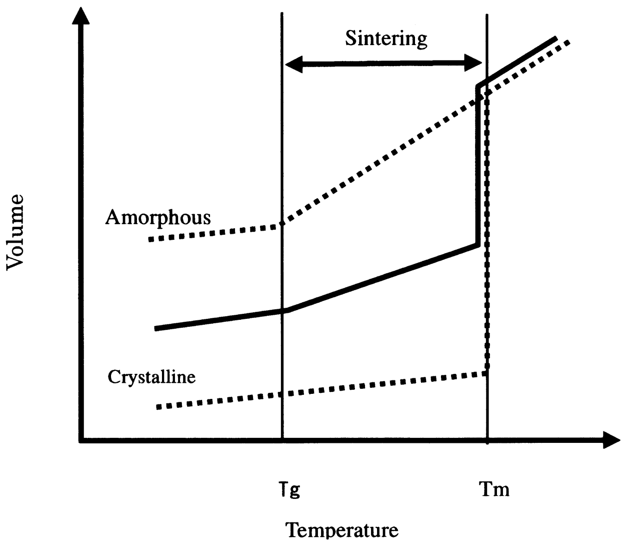

Fig. 5 Thermal expansion of resin

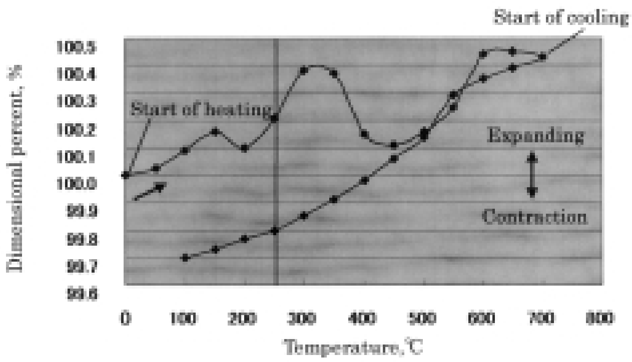

Fig. 6 Expansion and contraction that takes place during formation of gypsum mold

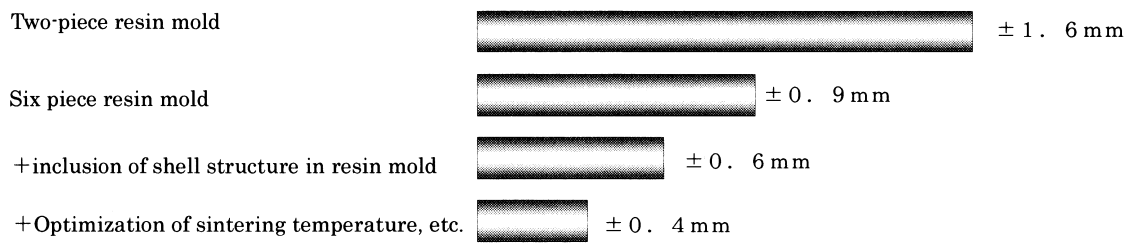

Fig. 7 Accuracy in length of materials produced by different methods

sintering of the fine resin powder. If the laminated sections of fine polystyrene powder layers are preheated using an infrared lamp at just below the glass-transition temperature and then exposed to the laser beam, the temperature of the plastic powder will rise to the range between the glass-transition temperature and the melting point, and sintering of the resin powder will take place. As shown in **Fig. 5**, the rate of thermal expansion is considerably high for resins at a temperature above the glass-transition temperature; accordingly, disparity in the sintering temperature contributes greatly to deformation. Furthermore, the physical properties of the resin powder varies from lot to lot, and it is therefore necessary to adjust the pre-heating temperature, laser output, and laser scanning speed to the optimum values for each individual one. Accordingly, the preheating temperature for the fine polystyrene powder was dropped by approximately 80 ˚C from the initial setting of 84 ˚C, and fine tuning of this temperature was carried out for each individual lot. As a result it was possible to always assure a dimensional accuracy of the resin model to within ± 0.4 mm.

3.2 Lost-wax casting with a gypsum mold

The principal cause of deformation during lost-wax casting process using a gypsum mold is the temperature variation that occurs during the melting and

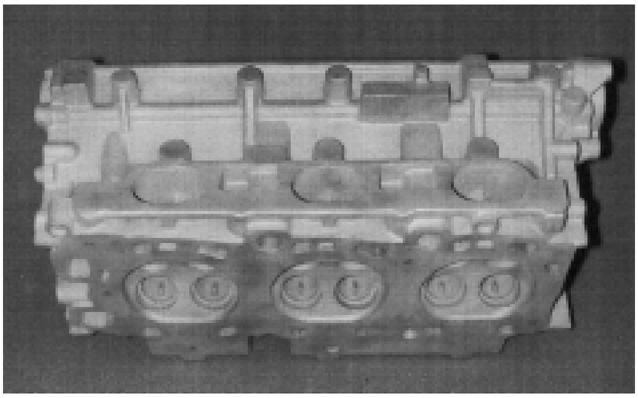

Fig. 8 Finished material

removal of resin model, during sintering of the gypsum mold, and during the cooling of the sintered mold to the pouring temperature. In the case of cooling of the mold in particular, large-scale shrinkage takes place; consequently, cooling was carried out in the oven over a period of at least two hours in order to prevent deformation of the gypsum mold. **Fig. 6** shows the expansion and contraction that takes place during the formation of the gypsum mold.

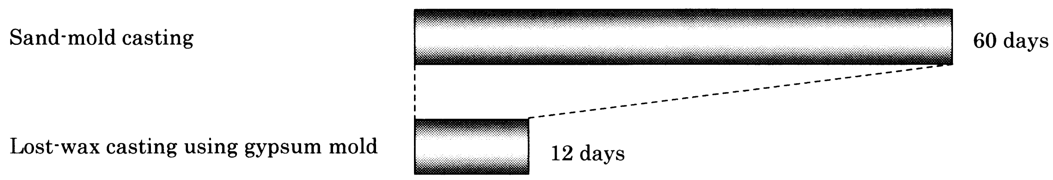

Fig. 9 Comparison of manufacturing periods

4. Dimensional accuracy

Fig. 7 presents a comparison of the contribution to improved dimensional accuracy as achieved using each of the improvement measures. The required dimensional precision of ± 0.5 mm was achieved for the position (and shapes) of the air intake and exhaust ports in the final product. **Fig. 8** provides a photograph of the finished casting.

5. Man-hour and cost comparison

Fig. 9 compares the man-hours required for the gypsum mold, lost-wax process with those for sand-mold process. With the conventional sand-mold method, a period of 60 days is required for wooden pattern manufacture and other tasks before the first product can be obtained; however, when using this new method, the first casting can be obtained after 12 days, thus allowing the development period to be reduced by 48 days.

In the case of cylinder-head materials, the cost involved in producing six units by the gypsum mold lost-wax process is equivalent to that involved in producing one unit by the sand-mold process. It is considered that this process can be adopted for the prototype production in advance of sand-mold casting.

6. Summary

The lost-wax casting method using a gypsum mold has made it possible for cylinder head test samples that are large in size and relatively complicated in core shape to be manufactured with a high degree of dimensional accuracy. Using materials produced by this method, designers can develop cylinder heads efficiently as they can test and check engine performance for a wide range of different port shapes before proceeding to sand-mold casting. From now on, this project will involve the studying of issues such as the reduction of costs for fine resin powder in hope that this method can be applied to testing where larger number of samples are required. Finally, all the project members would like to express their sincere gratitude to all persons from Mitsubishi and other companies who helped in the advancement of this research.

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