

Technology for Rapid Manufacture of Prototype Molds for Instrument Panels

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ABSTRACT

A method has been developed enabling rapid manufacture of prototype molds for instrument panels used in test vehicles in the automotive development process.

The new prototype molds are produced using polypropylene injection molding, as used for mass-produced parts, enabling manufacture in a shorter period. The master model transcription method is used, obviating the necessity for heavy machining or electrical discharge machining. Carbon fibers have been used in the material for the new resin molds (known as “carbon molds”) resulting in outstanding strength and durability.

The new method was employed to manufacture prototype instrument panels for the new model INSIGHT, which were used in crash tests. The use of the new method has enabled prototype molds to be produced at the same cost as conventional ZAS molds, but with a 20% reduction in production time.

1. Introduction

Crash safety is an important automotive performance parameter. Crash safety laws and regulations become increasingly stringent year-by-year, and automakers are responding by increasing the safety of their vehicles. The instrument panel plays a role in occupant protection in a crash, and it is therefore necessary to create prototype

instrument panels of the same level as mass-produced instrument panels to be used in crash tests during new vehicle developments.

To enable the instrument panels to be tested using mass-production materials during the vehicle development period, molds are produced more quickly and at lower cost than mass-production molds, and used to manufacture prototype instrument panels by injection molding.

Conventionally, simple molds for prototype use, of the type shown in Fig. 1, have been manufactured using zinc alloys (these will be referred to as “ZAS molds” below), and the molds have been used to produce the number of prototype instrument panels required for crash tests.

2. Reduction of Period for Creation of Prototype Mold

The reduction of the period required to create a mold for the body of the instrument panel, which is lengthy in comparison with other resin parts, represented an issue in enabling response to today’s demand for reductions in the period for new vehicle development.

A development project for a new prototype mold (Fig. 2) was therefore undertaken in order to reduce the time for production of the mold against the conventionally-used ZAS molds.

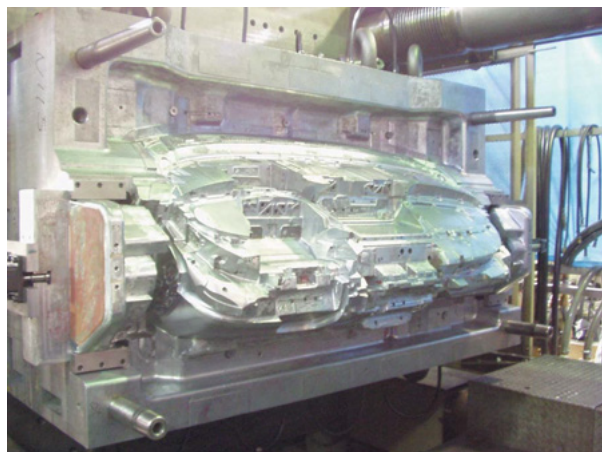


Fig. 1 ZAS mold

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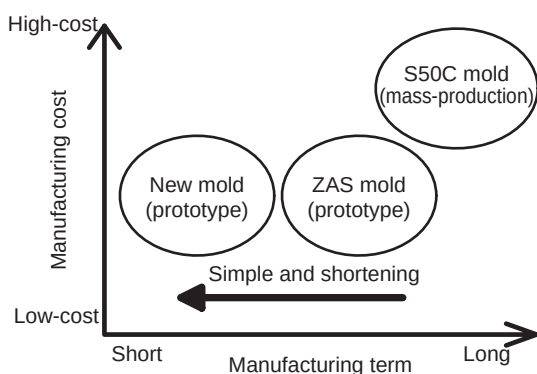


Fig. 2 Development concept for prototype mold

3. Development of New Prototype Mold

The creation of a form requires working of material. Whether carving or modeling in clay, a new form is created by adding or subtracting material. Mass-produced parts are manufactured through transcription from a mold, but it is necessary to add or subtract materials to create the form of the original mold. This project examined the mold manufacturing method and selected appropriate materials to enable the time required for this working of materials to be reduced, resulting in the development of a technology for rapid manufacture of prototype molds.

3.1. Selection of Manufacturing Method

The injection-molding molds used in mass-production are manufactured by NC machining of S50C and other steels. Only several hundred units will be produced from prototype molds, and they therefore do not need to display the durability of mass-production molds. Zinc alloy is currently used for prototype molds because it enables a rough form to be cast more easily than steel, and the speed of NC machining and other forms of processing is faster than it is for steel. The manufacturing method for the molds is well matched to its purpose in creating molds for prototypes, enabling injection molding of resins as in mass-production, but without the need for the level of durability achieved using steel.

In order to enable molds to be manufactured more rapidly than these conventional ZAS molds, the present project selected a manufacturing method enabling simple creation of a form.

It was determined that the mold would first be produced using a transcription method enabling the form to be transferred. Traditionally, a wooden pattern – a method in use since ancient times – has been used, but more recently, the material has been changed from wood to resin to produce what is known as a “master model.” The process of adding and subtracting material to create a form is easier using resin than metals. It was decided that the rough form of the instrument panel would be

produced using a master model.

The next procedure would be rapid prototyping, as exemplified by stereolithography. The detailed forms of the instrument panel would be produced using stereolithography, and these would be incorporated in the master model.

The mold form shown in Fig. 3 was created using these two methods.

The transcription method can also be used to transfer surface designs. Texturing of the mold is therefore possible simply by using a texture sheet or the like on the master model and transcribing. This reduces the time required for texturing from the four weeks required for conventional ZAS molds to only one week.

3.2. Selection of Mold Materials

Plaster or silicon rubber are generally employed as materials for molds used to transcribe forms. However, in the molds used for the injection molding of polypropylene to mass-produce instrument panels, high pressures are applied to high-temperature molten resin. In addition, the transcription process would require several days, and these materials therefore did not offer an advantage in terms of reducing manufacturing time against the ZAS molds.

The following conditions were therefore considered in the selection of materials:

- (1) Mold manufacturing process
 - Able to manufacture molds using existing equipment
 - Completion of transcription process within two days
- (2) Mold performance
 - Able to withstand molding pressures of 30 MPa
 - No damage resulting from contact with molding resin at 200°C
 - Heat conduction to enable cooling of molded resin

Based on these conditions, a thermosetting resin was selected as the mold material. This would mean that a resin would be used to form a resin; however, the polypropylene used in the mass-production of instrument



Fig. 3 Master model

panels is a thermoplastic resin. If a thermosetting resin displays heat resistance and does not melt at the melting temperature of a thermoplastic resin, it can be used as a mold material. Such molds, generally termed “resin molds,” are formed from epoxy resins mixed with aluminum powder, and are in use as a method of injection molding prototypes. However, the majority of these prototypes are cellular phones or objects of a similar size, and there are cases in which the mold is unable to resist the molding pressure and breaks when a large part such as an instrument panel is being formed.

The following points were therefore established as development aims:

- (1) Mold strength: Able to mold instrument panel
- (2) Durability: Sufficient durability to manufacture several hundred prototypes
- (3) Properties of molded part: Equivalent to part manufactured in ZAS mold
- (4) Accuracy: Equivalent wall thicknesses and external dimensions to mass-produced part

3.3. Method of Strengthening Mold Materials

The mold materials were strengthened to enable the development of a resin mold that was sufficiently durable to produce instrument panels.

The standard method of strengthening thermosetting resins is to use fibers to create a compound material known as a fiber reinforced plastic (FRP). In the present project, the conditions for the selection of materials, as discussed above, were also taken into consideration in the selection of the fibers to be used. It was decided to employ carbon fibers, and to create the mold using a carbon fiber reinforced plastic (CFRP).

The reason for this choice was that in addition to being generally known to possess a high degree of specific strength and a high specific modulus of elasticity, carbon also displays a low coefficient of thermal expansion, high heat resistance, chemical stability, and is self-lubricating. The selection focused in particular on carbon's high coefficient of thermal conductivity, which would increase the low coefficient of thermal conductivity of the mold material. It was considered that these properties of carbon would enable the development targets to be reached.

The molds employed in injection molding serve the function of absorbing the heat of and hardening molten resin. For this reason, the temperature of the molds increases during casting. A decline in the strength of the mold due to temperature increase, rendering it unable to resist pressure during casting, is thought to be one factor in breakages of large molds when employing conventional resin molds. It was thought that the use of carbon to increase the coefficient of thermal conductivity of the mold material would enable it to rapidly absorb and dissipate heat, thus controlling temperature increase and assisting in preventing a decline in strength.

A test mold was manufactured using carbon fibers and

epoxy resin in order to verify this concept. Molds were produced using cloth fibers and mild fibers, and their performance in injection molding was compared.

The cloth fibers were laminated by means of hand lay up. Because this is a manual method, transcription required four days. In addition, the cloth fibers were unable to trace the detailed forms of the instrument panel. As the mold cross-section in Fig. 4 shows, multiple voids occurred in the mold. The mold was unable to resist the pressure of injection molding, and cave-ins occurred on its surface, as shown in Fig. 5.

In the case of the mild fibers, the fibers and the resin were laminated using a simple spray-up. Figure 6 shows

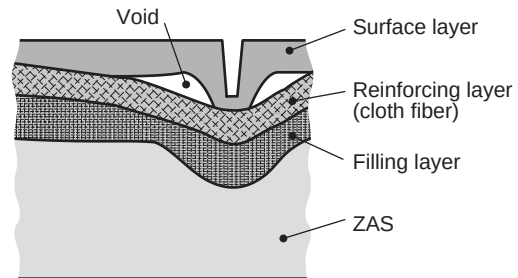


Fig. 4 Void due to lamination defect

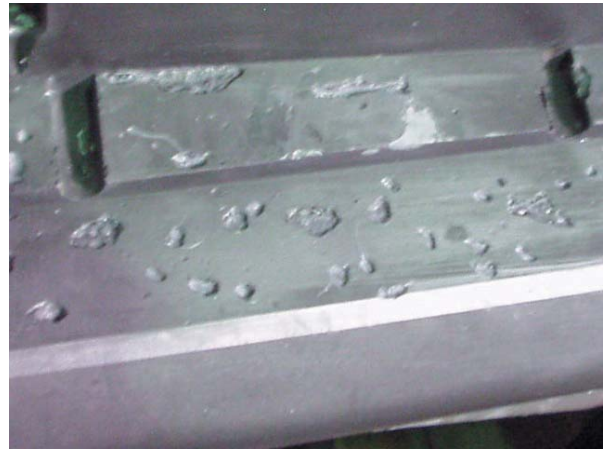


Fig. 5 Cave-in due to void

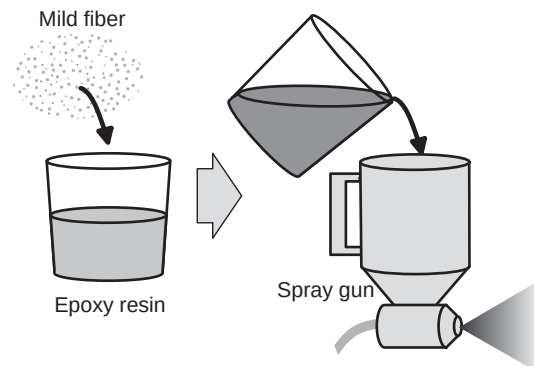


Fig. 6 Simple spray-up of CFRP

Table 1 Comparison of materials

	Unit	Carbon epoxy	Aluminum epoxy	ZAS
Tensile strength	MPa	63.5	52.0	244.0
Tensile elongation	%	10.3	3	4
Rockwell hardness	—	93.1 HRM	35.3 HRM	63.0 HRG

a schematic of this simple method. Mild carbon fibers of 1 mm or less in length were mixed with epoxy resin, and applied from a spray gun. The carbon fibers were able to trace the detailed forms of the instrument panel, and lamination was possible with no voids. In addition, the transcription process required only two days. For these reasons, spray-up lamination of mild fibers was selected as the method used to produce the mold.

Next, test pieces were formed using a variety of spray guns and mild carbon fibers and subjected to tensile strength tests in order to determine whether a mold laminated with mild carbon fibers alone would be sufficiently strong to resist injection molding (Fig. 7).

As Table 1 shows, the carbon epoxy material performed better than the conventional aluminum epoxy resin mold material in tensile strength tests. In addition, it displayed greater elongation than aluminum epoxy or ZAS. The fact that cloth fibers could not be used reduced the rigidity of the material, but the flexibility imparted to the mold by the elongation characteristic of the material would make it less prone to breakage. It was considered that this would increase the resistance of the mold to damage or cracking under injection molding pressures.

The development concept for the new mold was to be sufficiently flexible to resist injection molding pressures. Given that the method was considered to offer sufficient potential for the achievement of development targets, the simple spray-up method was adopted to produce the molds.

This simple spray-up method of lamination using a mixture of mild carbon fibers and epoxy resin was employed to produce the test mold shown in Fig. 8, which incorporated the complex forms of the instrument panel's bosses and ribs.

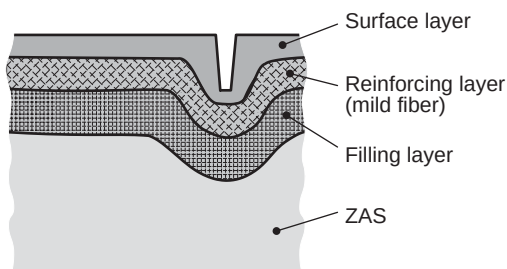


Fig. 7 Voidless lamination using spray

The lengths of the bosses and ribs in this test molding were at the upper limit for lengths in instrument panel design. Successful molding of these elements of the instrument panel form by the test mold would indicate the applicability of the new method to any instrument panel.

In order to determine whether the mold was able to resist molding pressures, an injection molding test was conducted using polypropylene, as used in the mass-production of instrument panels.

Molding of the same type as conducted in ZAS molds was conducted for the molding test. As Fig. 9 shows, an internal pressure of 37 MPa was measured, but the mold did not break. It was therefore judged that the target, a level of strength enabling molding of an instrument panel, had been achieved.

In conventional resin molds, metal inserts are embedded in the detailed forms in order to help prevent breakage of the mold. As Fig. 10 shows, inserts formed by machining aluminum or other metals are embedded in vulnerable sections where the resin mold would be prone to breakage in order to strengthen it. However, embedding



Fig. 8 Test mold

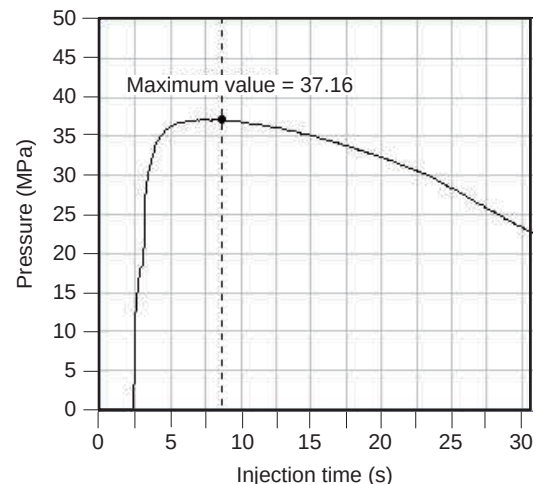


Fig. 9 Internal pressure of mold

inserts in the mold can also cause cracks, and these cracks can become the points of origin of breakage of the mold.

If the flexibility of the material used in the developed mold (termed a “carbon mold” below) could be exploited to create a mold configuration matching the elements of the form of the instrument panel discussed above, injection molding could be carried out without any requirement for inserts. This insertless molding is another feature of the developed method, and the consequent reduction in the use of machining has also contributed to reducing the time for manufacture of the molds.

3.4. Properties and Accuracy of Molded Parts

The test mold was designed to enable molding of test pieces for tensile and other tests. Test pieces were also molded in a ZAS mold. Comparison of the tensile strength and elongation of the test pieces showed that the properties of the parts molded in the carbon and the ZAS molds were almost identical.

The accuracy of the molded part is affected by the accuracy of the transcription of the master model. The wall thickness and external dimensions of the parts molded in the test mold were within design tolerances. It was demonstrated that the developed mold, while being flexible and able to be produced using a simple transcription process, was able to resist injection molding pressures, and the molded parts fell within the required range of accuracy. These results showed that the project had successfully developed a carbon mold able to mold the bosses and ribs of an instrument panel.

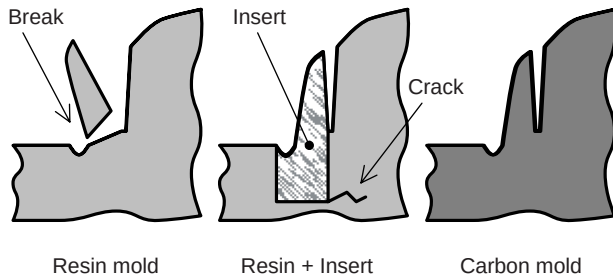


Fig. 10 Insertless molding of vulnerable sites

4. Method of Manufacture of Carbon Mold

As the cross-section in Fig. 11 shows, the carbon mold used in the new manufacturing method is made up of a CFRP layer that forms the molded part, and a ZAS section that reinforces the main mold, i.e., the section of a ZAS mold that forms the molded part has been replaced with CFRP. As Fig. 7 shows, this CFRP layer is composed of three layers: a surface layer, a reinforcing layer, and a filling layer.

In addition to the main mold that forms the instrument

panel, the slide core and the small mold used in the undercut sections are manufactured using a mixture of mild carbon fibers and epoxy resin.

4.1. Main Mold

The master model, which represents the basis of the form of the main mold, is given the form of the desired product by NC machining of a general purpose tooling resin.

The ZAS core is formed in the same way as a conventional ZAS mold, by casting in a sand mold using a disappearing model.

As indicated above, the CFRP layer has a three-layer structure. The surface and reinforcing layers are laminated in the master model. The surface layer is laminated by means of a spray-up of a mixture of epoxy resin and carbon powder. Next, the reinforcing layer is laminated by a spray-up of a mixture of epoxy resin and mild carbon fibers. As shown in Fig. 12, the master model in which these two layers have been laminated is covered by a ZAS core. The ZAS core is manufactured by casting a rough form which incorporates the section that produces the molded part and a 15 mm cavity. The ZAS core is not machined. The filling layer, composed of a mixture of mild carbon fibers and epoxy resin, is injected into the cavity.

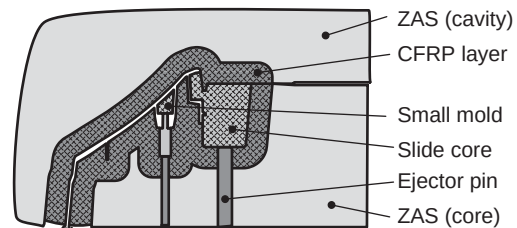


Fig. 11 Section of assembly mold



Fig. 12 Combination of master model and ZAS core

4.2. Slide Core and Small Mold

To produce the slide core and small mold, models are created using stereolithography (Fig. 13), and the material is poured into these models (Fig. 14). As in the case of the filling layer of the main mold, the material used is a mixture of mild carbon fibers and epoxy resin.

When the material has hardened, the casting is demolded from the stereolithographic model and the small mold is removed. There is no requirement for machining or electrical discharge machining.

After the completed slide core and small mold have been coated with a demolding agent, they are placed in the master model of the main mold, and a pocket shape



Fig. 13 Model for rapid prototyping



Fig. 14 Casting of core

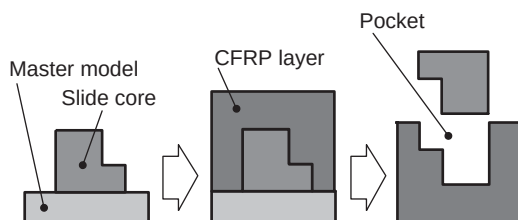


Fig. 15 Non-machined pocket

in which the slide core will be fitted is transcribed to the main mold by lamination of the CFRP layer (Fig. 15). The fact that there is no requirement for machining or lapping of the pocket shape reduces the time required to manufacture the mold.

5. Example of Application of Carbon Mold

The carbon mold prototype manufacturing method was employed during the development process for the 2009 year model INSIGHT (Fig. 16). The use of the new mold reduced mold manufacturing time by 20% against conventional ZAS molds. The bodies of the instrument panels were molded using equivalent injection molding pressures to those used in ZAS molds, and the panels were used in a variety of tests, including crash tests.

The use of the method in the INSIGHT development process also served as a durability test. Two hundred instrument panels were produced in different batches, but no breakage of the mold was observed, and the method was able to supply the prototype parts required for the new vehicle development process.

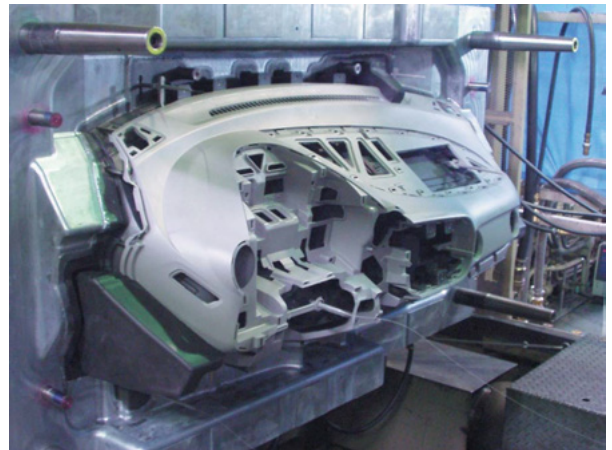


Fig. 16 Carbon mold for INSIGHT prototype

6. Conclusion

A carbon mold has been created specifically for the molding of instrument panels, which are large parts with complex forms. The cost of manufacturing the molds is the same as that for conventional ZAS molds, but 20% less time is required for manufacture, enabling the new method to supply prototypes in a shorter period. If the parts to be produced are small, even if their forms are complex, a carbon mold can be manufactured by transcription from a rapid prototyping model alone, without the need to create a master model by NC machining.

Another advantage presented by the carbon mold is the ease with which the mold can be altered and additionally

worked, a feature that is unique to resin molds. Adding to or subtracting from a ZAS mold necessitates welding and heavy machining, while a carbon mold can be worked as easily as using putty to add and a chisel to subtract. The mold can even be altered without removal from the molding machine.

7. Afterword

The project for the development of a prototype manufacturing technology discussed in this paper provided an opportunity for reflection on the importance of production engineering development, and for consideration of what precisely is evaluated using prototype parts, what the performance requirements of the prototype parts are, and what factors make a prototype manufacturing tool easy to use. The development of prototype manufacturing technologies will continue, to enable the process of new vehicle development to be accelerated.

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