

Application of Thermoplastic Resin Molding to Control Unit of General Purpose Engine

Ryuichi KIMATA* Yoshinori MAEKAWA*
Shinichi KUWASAKO** Takao TAMECHIKA*

ABSTRACT

The majority of electrical components utilized in general purpose work equipment are manufactured by potting employing thermosetting resins, taking into account their water, chemical and vibration resistance properties. The research discussed in this paper adopted a different approach, and attempted to mold these components using thermoplastic resins in order to reduce the size and weight of general purpose engines. Thermoplastic resin molding is typically only utilized when manufacturing small electrical components, due to the characteristics of the injection molding process. Molding conditions were optimized to enable the procedure to be employed for a large electronic circuit for engine control, a process which involved the study of resin materials and the layout of the electronic components, in addition to resin flow analysis. Manufacturing components using these optimized conditions enabled a 20% reduction in height and 50% reduction in weight of the control unit, in addition to reduction of the time required for the molding process.

1. Introduction

Electrical parts for general-purpose equipment utilized as work equipment, like general-purpose engines, are required to have high heat resistance characteristics as well as vibration and water resistance, because of their system requirements. Potting solidification using thermosetting resins has been conventionally used for this protection. Two liquid component epoxy resins are frequently used for this application. The electrical components such as Printed Circuit Board (PCB) are put into plastic or metal cases, which are then potted with resin and thermal processing is performed according to prescribed hardening requirements. Thermal processing, which differs according to the type of resin,

requires not only equipment investment and management of the heat curing furnace, but the process also involves a considerable amount of time and effort. For example, the cases need to be placed in the furnace from 3 to 10 hours at 100 °C in a controlled environment.

Products that use epoxy resin potting, for example PCBs, require cases with sufficient depth to cover the tallest installed components and enough resin to fill the cases. Therefore, the amount of resin used naturally increases, making the size and weight of the units larger than necessary and incurring excess costs for the resin.

On the other hand, reductions in size, weight and costs are continual requirements for electrical equipment; therefore, this molding method which focuses on thermoplastic resin

* Asakahigashi R&D Center

**Honda Engineering Co., Ltd.

characteristics, as a method for achieving better environmental performance of electrical equipment, an effective method that would replace thermosetting resin potting was investigated.

This paper describes the knowledge obtained during development and application of a molding method using thermoplastic resin to control units for general-purpose engines.

The thermoplastic resin molding method is one that replaces conventional thermosetting resin potting and has been called “hot melt molding technique” for the last several years. In Japan, the procedure has been used for sealing extremely small circuit boards, sensors, and wire harnesses for residential applications, in order to enhance reliability and reduce costs. This technique, as compared to the temperature and pressure requirements of injection molding using normal thermoplastic resins of 240 – 300 °C and 40 MPa – 130 MPa, requires much lower temperature and pressure conditions, roughly 200 °C and less than 5 MPa, for insert resin molding of circuit boards and sensors.

As injection pressures are low, a simple aluminum mold can be used for the mold, thus greatly reducing the cost of the mold and the injection machine, in addition, the mold tightening device can be greatly simplified. There are also several advantages compared to thermosetting epoxy resin potting, the main procedure used up until now; however, the thermoplastic resin mold method has previously not been used with this large of a circuit board (roughly 100 mm × 70 mm).

2. Basic Structure and Target Requirements

Throttle valve control is one of the features of the new general purpose engine “iGX440” (Fig. 1)⁽¹⁾ that uses a control unit where this method has been applied. The ECU that performs this control is integrated into the top of the carburetor, together with the gear case and the motor that drives the throttle valve. As the ECU is placed on top of the gear case, motor wiring has been simplified. In addition, the endothermic effect of the carburetor has a mitigating effect on the heat of the motor and engine.

The actual layout is shown in Fig. 2. Utilizing this method’s feature of being able to form the external shape of the mold freely, as space can be used effectively, the motor in the gear case and tall parts such as capacitors and transformers in the ECU were mounted so that they mesh together. The gear case is of waterproof construction with a grommet inserted between the aluminum gear case and the ECU, in addition to a metal plate inserted from the outside for sealing and impact protection. This enables the use of

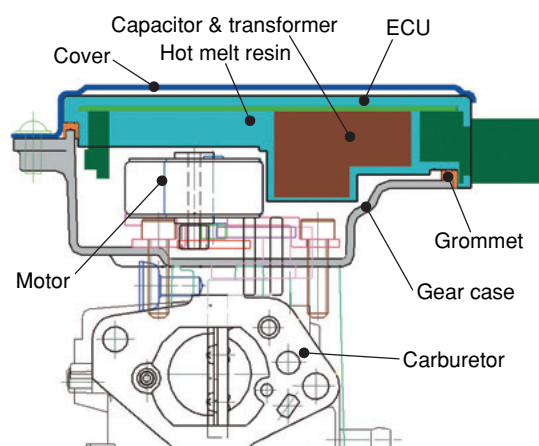


Fig. 2 Layout around ECU

small, non-waterproof parts for the motor and connectors, in addition to adding a dustproof countermeasure to the internal gear.

The following target conditions are required for ECUs that employ this method as described above.

Making the mold thinner (space efficiency).

- (1) Fixation of the circuit board.
- (2) Covering the surface of the circuit board completely (water resistance).
- (3) Ensuring the bonding performance of connectors with surface components (water resistance).
- (4) Maintaining flat seal area surfaces (seal ability).

3. Investigation of Resin Materials

While focusing on the chemical and water resistance properties of the copolymerization polyester resin during development of this method, and in repeating mold shape and environmental performance testing on test circuit boards, requests for changes to resin characteristics were made with a resin manufacturer assisting with joint development, and all of these factors accordingly have contributed to the selection of the resin currently being used. Copolymerized polyester resin has more than an order higher melt viscosity compared to that of the polyamide resin that had been investigated. It was expected that a lot of work would be required for mold and flow control. The fundamental characteristics of the resin used for this method are shown in Table 1⁽²⁾. When the investigation of this method first began, the resin used was different from that of the current resin and was a dymer acid polyamide, a resin that had frequently been used in this method. However, from the results of environmental performance testing required for general purpose electrical equipment, and in evaluating gasoline resistance, chemical resistance, water resistance, and so on, it turned out that an enhancement in performance was required. Investigation was then initiated for a resin that would meet these requirements accordingly.

4. Mass Production Equipment

With respect to the balance between preserving circuit functionality and resin insert molding, control of the resin temperature and injection pressure are important.

First, with respect to resin temperature, focusing on the correlation between resin temperature inside the mold and resin



Fig. 1 External view of iGX440

Table 1 Resin characteristics for hot melt molding

	Properties	Unit	Condition	Spec	Test Method
1	Specific gravity	—	RT	1.05	JIS K 7112
2	Hardness	(Shore A)	RT	70	ASTM D2240
3	Melting point	(°C)	RT	155	DSC
4	Brittle point	(°C)	RT	< -65	JIS K 6261
5	Tensile strength	(MPa)	RT	4.3	JIS K 6251 *1
6	Elongation	(%)	RT	1300	JIS K 6251
7	Flexural strength	(MPa)	RT	0.63	ASTM D790 *2
8	Flexural modulus	(MPa)	RT	9	ASTM D790
9	Shear strength	(MPa)	RT	2.0 <	ASTM D732
10	Coefficient of expansion	(K ⁻¹)		1.9×10^{-4}	TMA
11	Volume resistivity	($\Omega \cdot \text{cm}$)	RT	$1.0 \times 10^{11} <$ (dry condition)	ASTM D257 *3
12	Dielectric strength	(kV/mm)	RT	20 (dry condition)	JIS C 2110

*1 Dumbbell No.3 Tensile rate 500 mm/min

*2 Sample: 100 × 12.5 × 6.5mm Flexural rate 3mm/min

*3 Dry condition: 60°C × 8hours drying under <0.1MPa atmosphere

temperature at the end of the injection gun, the resin temperature at the end of the injection gun is used as a control parameter for mass production. Also, the temperature was established considering solder's melting point and the heat dissipation of the mold.

With respect to the injection pressure, as pressure can have the effect of deforming some of the components, injection at the lowest pressure possible was targeted. With optimization of the injection gate layout and an increase in the injection gate thickness, both methods that have been used for normal injection molding, a reduction in the injection pressure was achieved.

Generally divided, mass production equipment consists of a resin injection portion, a mold tightening portion, a product attachment portion, in addition to a product removal portion, making up a vertical rotary molding machine (Fig.3).

The mold tightening portion holds the circuit board and in order to suppress opening due to resin pressure buildup on opposite sides (upper and lower sides in this case), a specification for generating a tightening force 2 times that of the force generated by the theory⁽³⁾ used for injection molding where:

$$\begin{aligned} &\text{The required mold tightening force (ton)} \\ &= \text{average pressure in resin (kgf/cm}^2\text{)} \times \\ &\quad \text{filling projection area (cm}^2\text{/1000).} \end{aligned} \quad (1)$$



Fig. 3 Hot melt molding system

The product attachment and removal parts have specifications that conform to general injection molding equipment.

5. Optimization of Molding Requirements

5.1. Resin Flow Pre-investigation

The item for which thermoplastic resin molding will be used is a PCB. In molding, the following items must be observed while maintaining its shape.

- (1) The heatproof temperature of any of the components must not be exceeded.
- (2) The resistance pressure of any of the components must not be exceeded.
- (3) Any changes in the shape of components are to be within permissible limits.

The circuit board was larger than the one conventionally used, with tall components (roughly 15 mm) such as a capacitor for power supply smoothing and a transformer for ignition power supply on the board making experiential estimation of the flow difficult and resin flow analysis imperative.

Flow patterns that show flow conditions, molding temperature and pressure are flow analysis results that have been obtained (using Toyobo's CAE flow analysis service). An actual example of a flow pattern is shown in Fig. 4.

In the above analysis example, in the center of the lower area (inside gear case), resin filling is late; therefore, the pressure balance between the upper and lower areas is upset and it is anticipated that deformation of the circuit board will occur. In temperature analysis while performing molding, filling temperature results identified the areas on the circuit board at which temperature increases are recognized, and it has specifically been confirmed that these temperatures are below the solder melting point. Using pressure analysis during molding enables the estimation of required resin pressure settings when filling.

By performing the analysis above, the circuit board layout, mold shape and injection gate shape are determined more efficiently, shortening the time and reducing the costs required to actually make the mold.

5.2. Heat and Pressure Resistance and Molding Confirmation

Although temperatures and pressures are low compared to normal resin injection molding, the affect these factors have on electrical parts populated on the circuit board can not be ignored, when comparing to sealing with conventional thermosetting epoxy resin potting. As an example, temperature and pressure resistance for all of the electrical parts used in the current engine control unit were determined. Characteristics are summarized below.

- (1) Explosion proof construction of large electrolytic capacitors makes them weak under pressure, and the external resin film has poor heatproof performance.
- (2) The heatproof temperature of the film used for the film capacitor is lower than that of the melting point of solder.
- (3) Parts other than this capacitor will basically not have an issue as long as the temperature is held under that of the melting point of solder.

Temperature comparisons and verifications were performed while molding each electrical component on the circuit board with the standards above.

In order to prevent obstruction of the flow path injection gate, an extremely thin, wire diameter thermo-couple was used to measure the temperature of several locations on the circuit board. The temperature measurement locations were based on the results of the resin flow analysis, and with the location nearest the injection gate used as standard, the surface temperatures of vital components were measured. The temperatures at all locations were below each

standard and thus verified that there were no issues (Fig. 5).

On the other hand, stress applied to the circuit board during molding was measured. From this measurement, it can be seen that stress is applied on the circuit board at the time of initial injection pressure application and holding pressure application that comes after the completion of resin filling (Fig.6).

5.3. Bonding Performance of Resins with Circuit Board and Electrical Parts

Judging from the characteristics of the resin being used, a certain level of bonding performance with the circuit board and electrical components was expected; however, with the actual molding, from the temperature of each of the areas during injection molding, the resin temperature was found to be slightly lower than necessary to obtain sufficient resin bonding performance. For the current circuit board, the resin temperature could not exceed the melting point of solder which is 180 °C. Due to the small temperature difference with the melting point (155 °C) of the resin being used, strong bonding performance, similar to that obtained when molding is performed using thermosetting epoxy resin, can not be expected. It was necessary to work with the external shape of the mold, in order to ensure water resistance of the ECU.

5.4. Ensuring Mold Quality

As a step to establish target molding requirements for mass production equipment, of the test circuit boards, dummy PCBs populated with large components (large electrolytic capacitors, transformers, connectors, power transistors, LED, film capacitors) were used to determine limitations on conditions where molding can be performed using resin temperatures and initial injection pressures as parameters.

Concerning high resin temperatures, all components were populated on a similar circuit board that was made operable and whether or not the circuit board could be operated was also tested (Fig.7).

With the current manufacturing method, in order to maintain the quality of molding, it is necessary to prevent the melted viscosity of used resin with a large effect from obstructing the resin flow path. The following items must be considered.

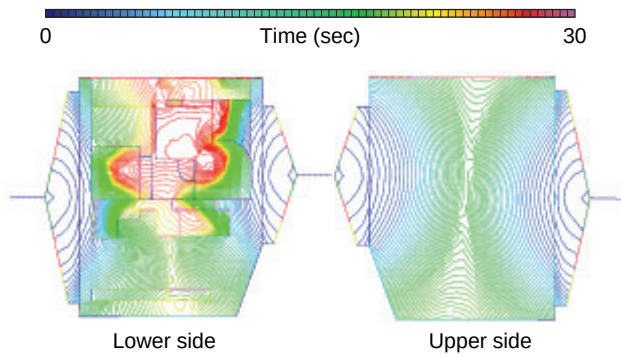


Fig. 4 Flow pattern

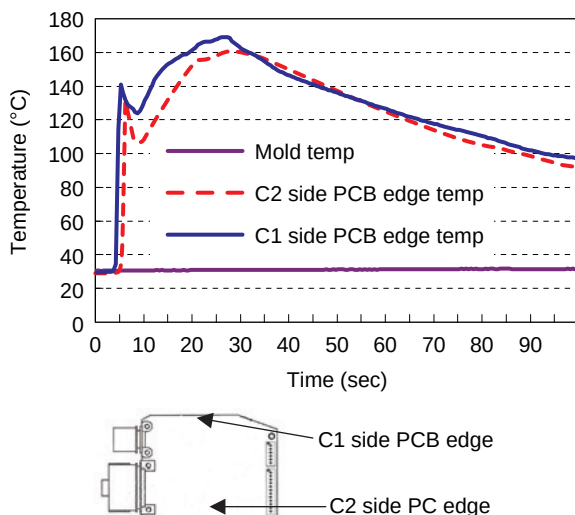


Fig. 5 Thermal transition on PCB surface and resin

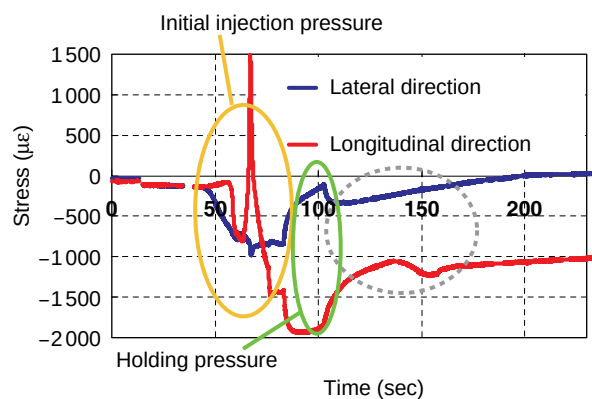


Fig. 6 Stress on PCB with resin injection

- (1) Resin temperature: while keeping electrical part and solder temperature requirements in mind, use as high a temperature setting as possible.
- (2) Use part shapes and layouts designed so that pressure is not concentrated in the same location.
- (3) Design such that resin flow is not concentrated from the resin flow gate.
- (4) In order to maintain somewhat of a balance of resin flow above and below the parting line, do not place components in a manner that would severely obstruct the flow to one side.

Also, for a molding shape, bonding between the resin and parts is not all that strong; therefore, using a configuration where resin covers the parts and not one with resin just being a simple adhesion surface with parts populated on the circuit board is desirable. Figure 8 shows an external view after molding.

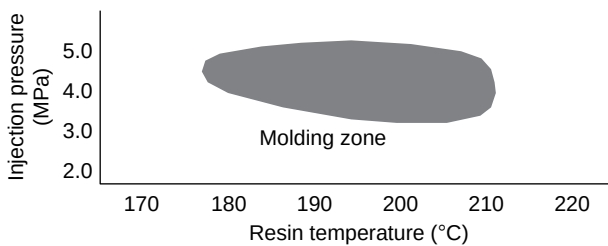


Fig. 7 Practical molding conditions



Fig. 8 Outside view of a hot melt molded ECU

6. Durability and Reliability

This manufacturing method differs from that of the normal thermosetting epoxy resin potting method. In this method, pressure is applied for the molding while resin is flowing. Therefore, there was concern for the effect of high temperature resin flow and that of molding pressure stress on solder areas of the parts that have a lot of electronic elements such as the ECU. In addition, this is the first time that an ECU was installed directly on a general-purpose engine and high reliability and durability requirements of the ECU were needed. In order to provide such features, temperature and vibration-related testing was mainly performed.

With this method, as the effect to the solder junctions was expected to be large, thermal shock testing was performed extensively for verification. A sample was taken at each prescribed cycle of the thermal shock test and solder condition of CPU attached portion was confirmed using x-ray CT equipment. The results are as shown in Table 2. There were no cracks that developed in the solder joints due to the expansion and contraction of the resin relative to thermal stress. In order to understand limitations, the verification of solder conditions was performed for a number of cycles exceeding the test requirement; however, development of cracks large enough to obstruct circuit operation was not seen.

Table 2 Solder conditions of micro-processor and capacitor

Function	Micro-processor	Capacitor
500 Cycles	Crack growth rate 0% 	Crack growth rate 0%
700 Cycles	Crack growth rate 13% 	Crack growth rate 0%
1 000 Cycles	Crack growth rate 23% Minimum pass on soldering junction	Crack growth rate 0%

In order to establish overall reliability in a short amount of time, a temperature humidity cycle and vibration energizing test was conducted, but no issues were found.

Changes in vibration, cooling and heating, and humidity do not affect the populated electrical parts or the circuit board, and it was also verified that this unit has equivalent reliability and durability as a unit manufactured using a conventional thermosetting epoxy resin potting method. This unit fully satisfies requirements of the molded unit that is used for a general-purpose engine.

7. Conclusion

A thermoplastic resin molding method, that replaces the conventional thermosetting epoxy resin potting method used for environmental performance of electrical equipment installed on motors, was developed such that it can be applied to a control unit used for general-purpose engines.

In addition, the following knowledge has been obtained in conjunction with this research.

- (1) If a PCB is molded using this manufacturing method, as the resin temperature can not exceed the heatproof temperature of electrical components or the solder melting point, while on the other hand, the temperature needs to be set as high as possible to provide mold quality, resin temperature and pressure conditions must precisely be controlled.

- (2) Resin flow changes dramatically with shape and placement of components as well as shape and location of the injection gate, and as this easily affects molded product quality, a CAE resin flow analysis performed prior to making test samples is extremely effective.
- (3) Unit height has been reduced by 20%, weight has been reduced by 50% and a 2-order enhancement in molding work processing time has been achieved.

As a sealing method for electrical equipment, starting with control units for general-purpose engines, application of this method will be expanded.

Acknowledgements

In conjunction with this research, especially with development of the resin material and CAE flow analysis, we express our thanks to TOYOBO Co., Ltd. and to all others who have assisted.

References

- (1) Ito, K., Honda, S., Saito, T., Kurata, M., Naoe, G.: Development of Electronically Controlled Multi-purpose Engine iGX440, Honda R&D Technical Review, Vol. 17, No. 2, p. 44-51 (2005)
- (2) TOYOBO Vyroshot Technical catalog, p. 8 (2004)
- (3) Basic injection metal mold, Nikkei mechanical, Engineer training Visual mechanism series, Vol. 2

■ Authors ■



Ryuichi KIMATA



Yoshinori MAEKAWA



Shinichi KUWASAKO



Takao TAMECHIKA