

Application of Rapid Heat and Cool Molding to High Strength Outer Parts without Painting Treatment

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ABSTRACT

Glass fiber reinforced plastic of polyamide is applied as one of the materials used for the high strength exterior parts of a motorcycle, such as a rear grab rail or a carrier, to which both strength and good exterior appearance are required. However, Glass Fiber reinforced Polypropylene (PPGF), which is relatively inexpensive material, has a property that the contained glass fibers are prone to be exposed at the surface and, therefore, the requirements for good appearance are hardly met by using PPGF. In this study, Heat and Cool molding method (H&C molding) was employed to realize a cost reduction by using PPGF yet without applying painting process, and the established method was applied to mass production while fulfilling the requirements for a good exterior appearance. In H&C molding, the metal molds are heated up by steam and cooled down by water after molding. This process works for making superior surface appearances and the appearance quality is determined by the temperature control of the molds. H&C molding has been generally applied to the parts with a flat shape and straight piping with a diameter of around 10 mm is arranged close to the surface of a metal mold cavity to get a good efficiency of temperature control. However, when this method is applied to a motorcycle part that is structured by three dimensional surfaces, these conventional piping arrangements cannot satisfy the requirements for a short molding cycle time and an even distribution of mold surface temperatures at the same time. In our study, a piping arrangement design by which the pipes are located along the three dimensional cavity surfaces was investigated. The piping arrangement design was determined based on the measurement results on test pieces and the molding cycle time of 100 seconds was eventually achieved. Furthermore, a proof testing to examine the material strength and the weather resistances is conducted as well.

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INTRODUCTION

Historical Background of Conventional Molding Methods Applied for High Strength Exterior Parts of Motorcycles

While various materials, such as iron, aluminum and plastics, are used for motorcycle body parts, plastics are frequently applied because of their flexibility in designing and superior degree of freedom in shape forming especially when they are used for exterior parts. In spite of that, steel and aluminum are still widely used from the viewpoint of cost-performance balance if the parts should meet the requirement of high strength. Our development was particularly targeted to the parts with relatively large sizes and, as a consequence, with a large possibility of weight reduction among the parts which are applied for exterior of motorcycles and require high strength. In addition, we aimed at the development of a production method that enables a low cost production of plastic parts with light weight and good exterior appearance.

Carrier, rear grab rail and foot peg holder are some of the examples of motorcycle parts that used as exterior parts and require a high strength (Figure 1). Among these parts, rear grab rail is under a strict demand for strength and excellent exterior appearance because this part should bear a considerably large force applied by a rear passenger and is located at a highly conspicuous position. Rear grab rail used to be made of a steel pipe to get a necessary strength (Figure 2). For that reason, it could be manufactured at low cost but had little freedom of design in the shape. After that, grab rails made of casted aluminum were applied to enhance flexibility of designing and freedom. However, aluminum die casting method requires many processes to finish the products. Accordingly, the application of plastic injection molding method has been considered to get better productivity and to get further degree of shape design freedom in addition to superior design flexibility and light weight. On the other hand, plastic parts molded by conventional methods cannot satisfy the requirements for strength and stiffness. Therefore, the methods of molding plastic over a metal insert or reinforcing plastic parts by strengthening with reinforcing fibers have been studied.



Figure 1. Examples of high strength exterior parts of motorcycles

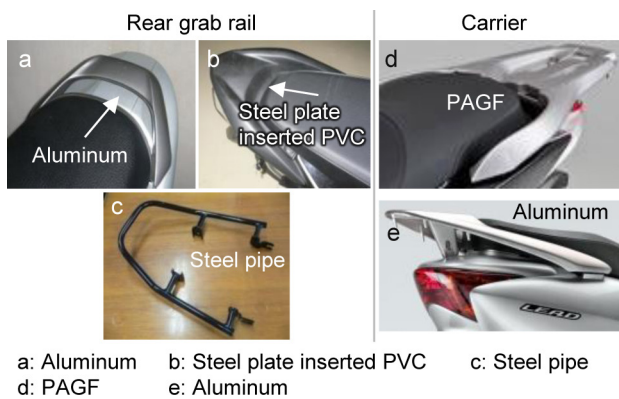


Figure 2. High strength exterior parts made of various materials

As a method of inserting a metal core, the method of overmolding resin on steel plates, which works as strengthening members and mounting members, is employed for mass productions. For using this method, there is a benefit that various tactile sensations and exterior appearances can be imparted to the parts' surfaces because the hardness of the overmolded plastic is flexibly adjustable. However, this method needs to have many manufacturing processes and that leads to a disadvantage in productivity. In addition, as metal inserts are necessary, they usually weigh heavier than a part made by aluminum die casting. With this reason, the application of an injection molding method for a fiber reinforced plastic has been investigated to realize a better product efficiency than the methods using aluminum die casting or resin overmolding. Moreover, development of a practical method applying this method has been long pursued to produce high strength exterior parts at a lower cost.

Application of Fiber Reinforced Plastics and Associated Issues

Fiber reinforced plastics are composite materials that have enhanced physical properties with higher strength and higher modulus of elasticity by mixing fibers with superior strength and stiffness than those of the matrix resins. Materials used for reinforcing fibers are various materials such as glass fiber (GF), organic fiber (e.g. aramid), carbon fiber (CF) or metal fiber (e.g. stainless steel). The diameter of

mixed fibers and their lengths within a produced part after molding have a significant influence on the properties of the parts.

Accordingly, there are many kinds of reinforced plastics with different fiber materials. One of the examples is a reinforced plastic with long uncut carbon fibers that is usually used for aircrafts or hydrogen containers. Another example is a plastic containing chopped fibers with lengths of 3 to 5 mm. Various other methods of mixing those fibers are also proposed.

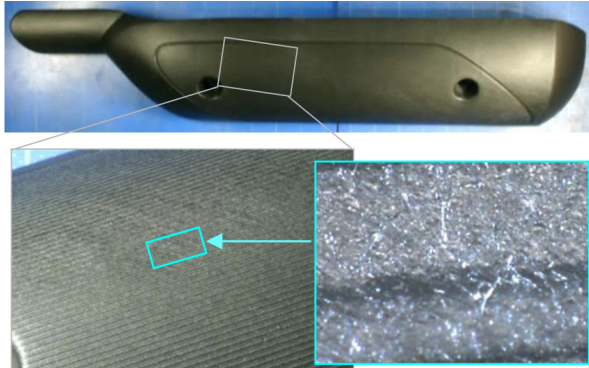
Chopped glass fibers are commonly used as reinforcing fibers for applications of general industrial products including automobile parts because of the balance between reinforcing effectiveness and cost. As the matrix resins that have thermoplasticity and applicable for fiber reinforced plastic, various kinds of resins are used, e.g. polyamide (PA), polypropylene (PP), polyphenylene sulfide (PPS), polybutylene terephthalate (PBT), polyoxymethylene (POM) or polyether ether ketone (PEEK), depending on their applications and material properties. In the applications for motorcycles, glass fiber reinforced polyamide (PAGF) and glass fiber reinforced polypropylene (PPGF), which are using PA or PP respectively as matrix resin, are widely used because of their good balance among cost, strength, stiffness and heatproof temperature. However, glass fiber reinforced plastics generally exhibit poor transferability to a metal die cast as the contained glass fibers are apt to stay exposed on the molded part's surface. Moreover, there is a tendency for the part surface to look whitish with the exposed glass fibers and associated minute irregularities appearing on the surface. In addition, the transferability is inferior for textured surfaces as well leading to another issue of exterior appearance (Figure 3, Figure 4). Accordingly, when a glass fiber reinforced plastic is used for a high strength exterior part of a motorcycle, the requirements for the exterior appearance are hard to be satisfied in its primary condition, and mending treatments, such as covering up by painting and/or an improvement of the property of the plastic, are usually applied.



Figure 3. Surface appearance of a molded part of glass fiber reinforced resin (PPGF) by conventional injection molding

Among various glass fiber reinforced plastics, PPGF is less expensive than that of PA because its matrix resin of PP needs to have fewer synthesis processes in its production. However, it is difficult to apply painting on PP. Therefore, it is generally considered to be impractical to cover up the exposure of glass fibers on the surface. As a consequence, PA is usually selected as the matrix resin when painting is expected as the cover up treatment method. On the other hand, methods of painting on PP also have been studied for long time. For

example, the method of applying fine dispersion of elastomer to the paint contacting interface is already practically applied to the production of bumpers for automobiles [1]. Nevertheless, when this method is applied, the strength and the modulus of elasticity decline. Therefore, the application of this method to a part that requires high strength is actually not practical.



Enlarged photo shows exposed glass fibers shining bright

Figure 4. Textured surface of molded part made of glass fiber reinforced plastic (PPGF)

In addition, a mending method for exterior appearance that does not use painting is also investigated for PAGF. In conventional injection molding, including molding of PPGF, the temperature of the metal molds is usually set around 40°C that is lower than the crystallization temperature of 115°C while the temperature of the molten resin is about 220°C when it is in molding process. However, the resin that has reached the cavity surface of the mold is immediately cooled and transformed into solidification and/or crystallization. In the case of glass fiber reinforced plastic including PPGF, the contained glass fibers block the flows of the matrix resin and the resin cannot fully reach the contacting surface between the resin and the mold cavity surface. This is the reason why the glass fibers stay exposed at the surface. Accordingly, if the solidification and crystallization can be retarded, the resin can fully reach the surface of the cavity and the exposure of the glass fibers is made suppressed. Based on this principle, the other type of glass fiber reinforced polyamide has been developed that provides better exterior appearance. It was achieved by applying copolymerization of different monomers, such as polyamide 66 plus an aromatic polyamide, where conventional polyamide 6 or simply polyamide 66 alone used to be applied. This type of plastic is used for a grab rail and a carrier in motorcycle application and for a door handle in automobile application. On the other hand, there is no practical method for PPGF because its crystallization speed is too fast to be controlled by copolymerization or other methods applicable through polymer arrangement. As a consequence, suppression of glass fiber exposure for PPGF is difficult by applying the same method as that for PAGF. With these technical backgrounds, when exterior appearance matters, PPGF could not be applied for high strength parts. Based on the aforementioned reasons, so far, PAGF is primarily used for high strength exterior parts because it is paintable for covering up and also has other applicable method without applying paint to realize a good exterior appearance.

Investigation on Molding Method Applicable to PP

The percentage that material cost accounts for in the total cost of a part manufacturing is quite large especially for motorcycles produced in large numbers in developing countries. For that reason, it is strongly desired to establish a production method using a plastic material that is less expensive than PA for high strength exterior parts as well. To respond that demand, the establishment of a molding method by which a good exterior appearance can be achieved without applying painting for the parts requiring high strength made from inexpensive glass fiber reinforced plastic using PP was endeavored to realize the cost reduction of high strength exterior parts. As for the molding method, application of Heat and Cool (H&C) molding method, in which the metal mold temperature is controlled during the molding process, was investigated to control the crystallization speed of PPGF by metal mold temperature. In the investigations for applying H&C method, uniformity of the temperatures on the mold cavity surfaces is one issue, and reduction of the time needed for mold temperature control to get a shorter molding cycle time is another issue to be tackled. To solve those issues, parameters needed to define molding temperature control specifications were to be determined. In the early stage of the development, an evaluation using simulation model was examined. However, it was not doable without experimental data with high accuracy to construct that simulation model. Consequently, in this study, the establishment of the temperature control specifications was conducted based on experiments using test pieces and the test results yielded through them.

Meanwhile, application of H&C molding method had been almost limited to the parts used indoors so far and the weather resistance performance under outdoor use had not been a requirement. To the contrary, when it is applied to high strength parts for motorcycles, weatherability is one of the key requirements. Accordingly, the adaptability of H&C method for the parts critically requiring weather resistance performance was also investigated to firmly define the specifications of the material that fully comply with outdoor requirements.

In addition, as this method has been already applied to one of the mass production parts, the results of proof testing on that actual production part are also reported in this paper.

INVESTIGATIONS ON APPLICATION OF H&C MOLDING METHOD TO MOTORCYCLE EXTERIOR PARTS

Issues Associated with Application of Conventional Heat and Cool Method

Overview of Heat and Cool Molding Method

H&C molding method is one of the methods by which a resin is filled while the metal mold cavity surface is kept hot and the molded part is removed from the mold after cooling down of the cavity. In a conventional injection molding, the temperature of the mold is maintained at the same temperature, which is lower than the

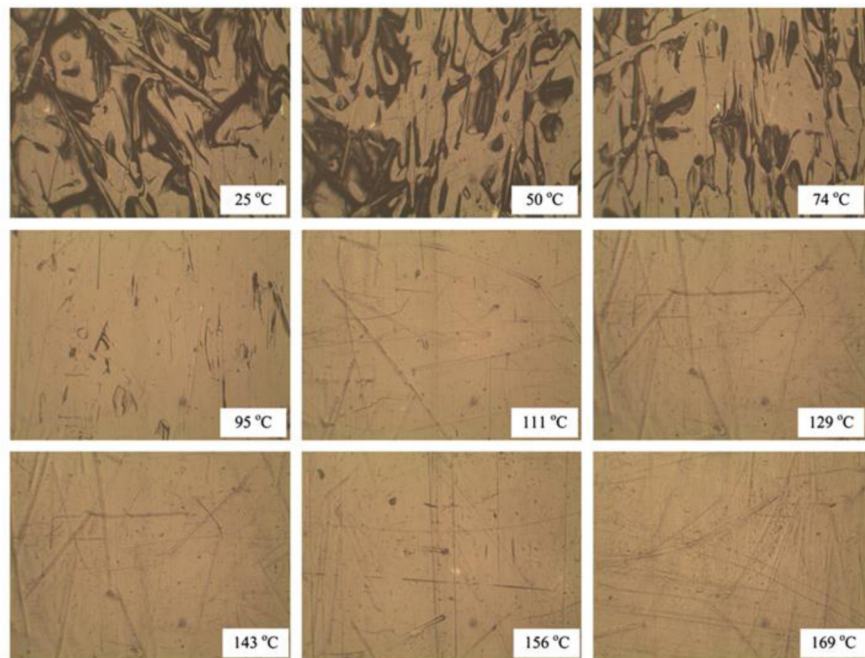
solidification temperature, while the whole solidification process of the resin and the resin that flows inside the cavity is immediately cooled down to a solid state at the interfacing layer with the cavity surface. On the other hand, in H&C molding method, the resin is filled in the cavity while a high cavity temperature is maintained. This alleviates the sudden cooling of the surface layer of the flowing resin and the fluidity is maintained. As a consequence, the transferability to the cavity shape is increased and defective side effects, such as generation of weld lines, decreases yielding a good molded product with a superior gloss and an excellent exterior appearance. Accordingly, molded parts with a high quality appearance, like the high gloss piano-black (i.e. high quality black surface we frequently see on the surfaces of a piano), can be produced without painting and they are applied to some of the electric appliances and electric office equipment, such as outer frames of Liquid Crystal Displays (LCD) and outer cases of printers (Figure 5). In the paper by Zhao et al., it is reported that the same kind of high quality appearances are also producible using fiber reinforced plastics by applying H&C molding method because of their suppression effects against glass fiber exposure on the surfaces (Figure 6) [2]. The exposure of glass fibers and unevenness on the surface are mitigated and the smoothness of the surface is enhanced by increasing the temperature of the mold just before the full filling timing of the resin into the cavity. On the other hand, the mold should be cooled down promptly after the resin filling into the cavity because, if the mold keeps its high temperature, the resin does not

easily cool down and the molded part cannot be taken out of the cavity. Accordingly, when H&C molding method is applied, the mold is heated in advance to the required temperature before filling the resin into the cavity and the mold is cooled down after the resin filling to have the resin cooled down quickly.



Figure 5. Examples of H&C molding applied parts used for electric appliances and office electric equipment

This heating and cooling cycle is repeated. When a molding cycle time of a conventionally applied injection molding is considered, two types of necessary times, the time for heating a mold and the time for cooling a mold, should be taken into account (Figure 7).



With a high cavity temperature, less glass fiber exposures are observed

Figure 6. Microscopic surface images of parts molded with different cavity surface temperatures at full packing of injected resin (PPGF)

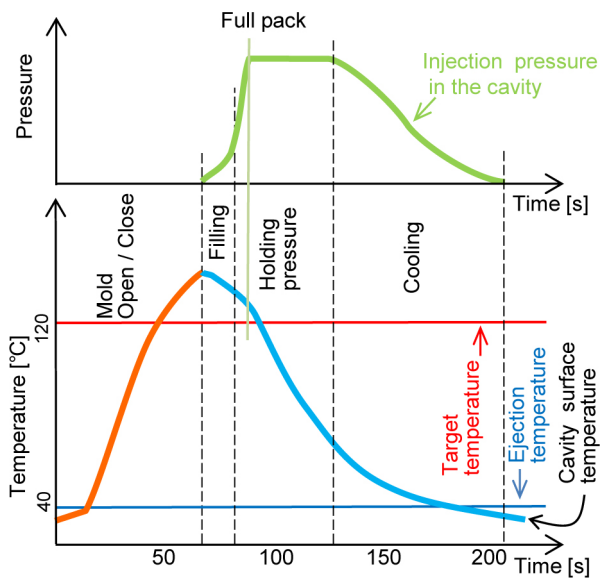


Figure 7. Example of molding process cycle with changes of control parameters

Effects on Exterior Appearance Brought by Heat and Cool Molding

As shown in Figure 6, the enhancing effects on the exterior appearance are realized by H&C molding method. The resin is solidified at the interfacing surface to the cavity but the solidification becomes slow when the mold temperature is high. With this delayed solidification, fluidity of the resin at the surface of a molding part is maintained for a certain period and the resin flow can fully reach the cavity surface to transfer the shape of the cavity enough to get a high quality appearance. In the case of glass fiber reinforced plastic molding, the injected matrix resin is blocked by the glass fibers in the cooling process of molding and the resin is solidified before fully reaching the interfacing surface to the cavity. As it is previously described, this is the reason why glass fibers are exposed on the surface. Accordingly, if the cavity temperature is raised higher than the temperature at which solidification of the resin starts, the resin in fluid state at the interfacing surface layer maintains its molten status and the resin can fully reach the cavity surface. Thus, the exposure of glass fibers can be suppressed (Figure 8). Therefore, to avoid the exposure of glass fibers on the entire surface of the molded part, the cavity temperature must be kept beyond the required temperature during the period between the point just before the resin is filled into the cavity and the point that the resin is fully packed by prolonged pressurizing. PP is a crystalline resin and the solidification process of the packed resin within the cavity makes progress rapidly when it is cooled down to a lower temperature than the crystallization temperature. It is understood from the things mentioned above that the glass fiber exposure would be successfully suppressed if the cavity surface temperature were set beyond its crystallization temperature. Based on this scheme, in Figure 7, an example of parameter changes required for a molding procedure that is designed for suppressing the glass fiber exposure is shown. The process from filling of the resin into the cavity to the full packing, by prolonged pressurizing, is completed while the cavity temperature is maintained above the specified temperature to

meet the requirement. After that, the cavity surface temperature is cooled down from the required temperature to a lower temperature that allows removal of the molded part.

Molding Defects Frequently Occur in Heat and Cool Molding

Cavity temperature in resin filling process in H&C molding is generally higher than that in conventional injection moldings. Burrs, gas burns and sinks are apt to occur as these types of defects are more likely to happen at high temperature. Especially, burrs and gas burns should be seriously considered in H&C molding. In the resin filling process of H&C molding, the mold temperature is raised to the temperature at which the resin hardly solidifies. As a consequence, the resin with high fluidity easily penetrates into the parting lines of the mold resulting in more generations of burrs than in conventional injection molding. To prevent generation of burrs, the mold mating surfaces should be fabricated with higher precision and the gas release vents should be designed to be much narrower. On the contrary, to prevent gas burns, the gas release vents should be designed larger. As the cavity temperature is higher in H&C molding, gas burns occur rather easily compared to the conditions in conventional injection moldings and the gas release should be considered more carefully and gas release should be applied as possible. In summary, if the gas release is prioritized, many burrs occur. If the prevention of burrs is prioritized, many gas burns occur. To prevent both burrs and gas burns at the same time, thin gas vents with high accuracy should be provided at the parting lines on the molds. In addition, from the aspect of molding conditions, the maximum range of target temperature of the mold should be set at the lowest allowable temperature. From the viewpoint of prevention of sinks, molding at high mold temperature is disadvantageous because the temperature difference of the resin between the condition before resin filling and the condition after the cooling becomes larger, and the shrinkage after molding becomes large resulting in generation of sinks. The temperature rise of the cavity must be maintained within a minimum required range to prevent molding defects when applying H&C molding method. With all those factors considered, it is required to heat up the cavity surface temperature as evenly as possible and the cavity surface temperatures throughout all the cavity surface areas should be raised to the crystallization temperature almost at the same time without making any thermal spot on the cavity surface that exceed the temperature that the molding defects are generated.

Heating Method in Heat and Cool Molding

In H&C molding, heating and cooling of the mold are repeatedly applied. Therefore, one of the key issues to reduce the total molding cycle time is to carry out the heating and cooling processes efficiently. Especially, the time needed for heating is the main cause of elongation of the molding cycle time. It is because the resin filling process cannot be processed unless the mold becomes fully heated to a predetermined temperature. Consequently, methods to complete mold heating in a shorter time have been investigated. In the case of H&D molding for LCD panels, heating time of 20 seconds from 30°C to 120°C has been achieved by applying a steam heating system. In that system, the molding cycle time is 70 seconds [6].

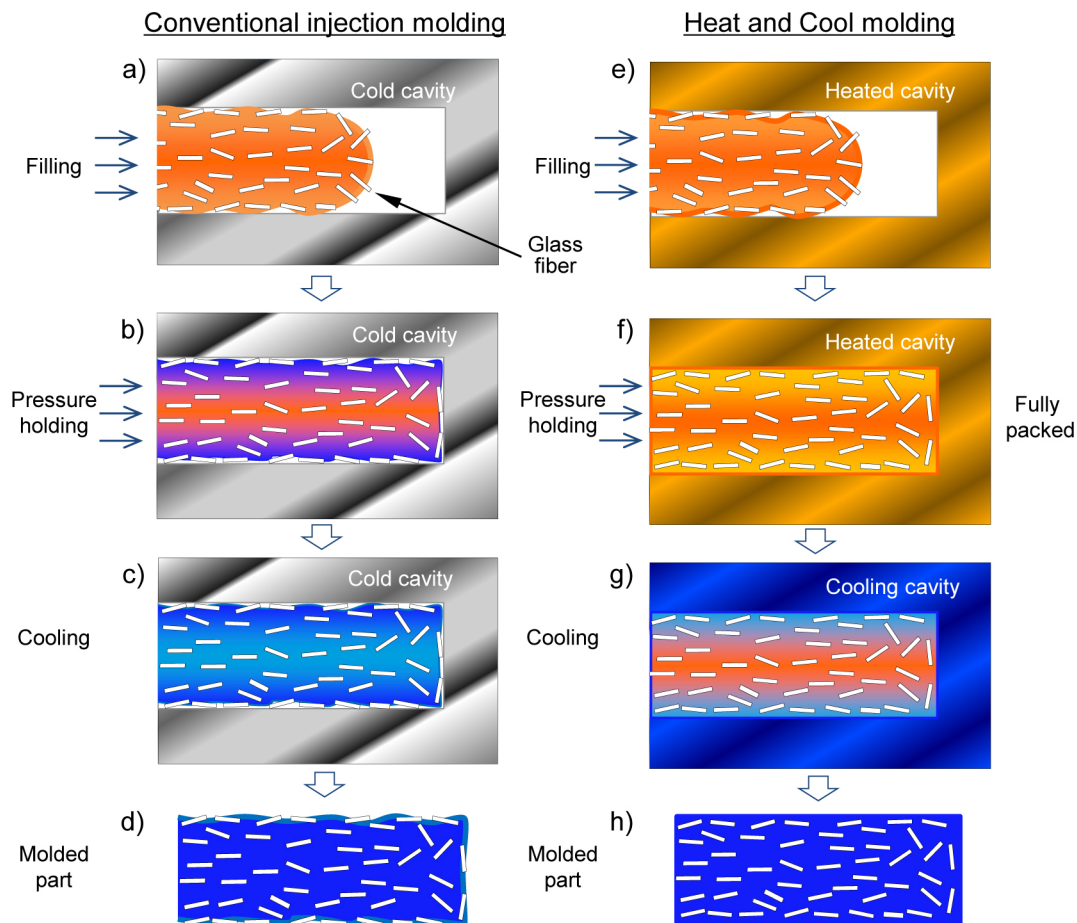


Figure 8. Comparison of suppression effects against exposure of glass fibers on surface of glass fiber reinforced resin molded by conventional or H&C method

In this process, the target temperature for heating is 120°C. This is because the mold temperature of 120°C is high enough to get a sufficiently good appearance in the case of using ABS or PC/ABS that are generally used for outer frames of LCD panels. To get this target temperature, a steam heating system with a simplified boiler that provides steam of 180°C or a heating system employing pressurized hot water is generally used. However, in the case of molding the materials with a high melting point, such as engineering plastics or super engineering plastics that are frequently chosen as raw materials for motorcycle exterior parts, or in the case that reduction of a molding cycle time is required to achieve a high manufacturing cycle rate, far more high target temperature and a very rapid heating system is required. Accordingly, developments of temperature control systems that satisfy those requirements are currently underway. Various methods are proposed, such as a method that utilizes electric heater or electromagnetic induction for heating, or a method that employs steam or oil stream that are flown through the pipes closely located along the cavity surface to control the temperature [4].

Cooling Method in Heat and Cool Molding

In addition to heating process, cooling process of a mold is also a critical cause of molding cycle time elongation. In H&C molding, basically, the efficiency of cooling is not good because the temperature of the mold just before the beginning of additional pressurizing and the temperature of the cooling process after full packing of the resin are higher than those in conventional injection molding methods. As a

consequence, the mold must be cooled down immediately after the full packing of the resin to reduce the cooling time. In H&C systems, steam for heating and water for cooling are switched to flow alternately through the same temperature control piping located adjacent to the cavity surfaces and, as a result, the cooling rate can be increased. In contrast, in the system employing a heater or oil for heating, the heat conveying apparatus should be located close to the cavity surfaces and, as a result, the piping for cooling water can be built only somewhere away from the cavity surfaces making the cooling efficiency generally low. Therefore, many countermeasures to enhance the cooling speed of a mold are also proposed [4, 5].

Temperature Control of Metal Mold and Molding Cycle Time

As heating and cooling of a mold are frequently repeated in H&C molding, the better thermal efficiency can be obtained if only the adjacent regions to the cavity surfaces are put under control of temperature, and shorter molding cycle time can be achievable. Accordingly, the piping that functions as a heat source should preferably be located as close as possible to the cavity surfaces. Moreover, in H&C molding system, the temperature differences that appear on the cavity surface are highly susceptible to the arrangement of temperature control piping. For this reason, the pipes should be arranged with fixed distance away from the cavity surface and the spacing between the pipes should also be kept the same. Meanwhile, motorcycle exterior parts are often structured by curved surfaces having three-dimensional contours, and a method that allows the