Simulation Technologies Supporting Quality Improvement in Injection Molding

YAJIMA, Asuka * SUGATA, Yoshinobu * YOKOMORI, Noriharu *

ABSTRACT

Plastic has excellent electrical insulation properties and is often utilized in various products due to its mechanical properties and characteristics. In order to improve the quality of plastic parts, Fuji Electric has utilized resin flow analysis to elucidate the quality and productivity issues that exist during the early stages of development. Furthermore, we have been reflecting our findings into the design of our products and molds. We have verified ease of assembly in consideration of warping by using the analysis results and a 3D printer, and as a result, we developed parts suitable for automated assembly in a short time. We have also utilized unsteady heat transfer analysis to optimize the temperature control circuit for molds and have significantly reduced the molding cycle. Furthermore, we have been working to estimate the fiber length of fiber-reinforced plastic, and are now able to determine the distribution trends of the fiber length that affects the strength of parts.

1. Introduction

Plastic has excellent electrical insulating properties and many types of plastic have mechanical properties, sliding properties and thinner resistance that makes them applicable to industrial parts. Fuji Electric uses plastic in many of its products including power electronics equipment, food distribution facilities and electronic devices.

In recent years, as the globalization of production bases accelerates, needs have arisen for products that have the same quality all over the world. In order to meet such requirement in plastic parts molding, it is important to establish quality by making every problem that results from product/mold design apparent. This must be done during the early stages of development in which product shapes or mold structures can be designed more freely and modified at lower cost.

Resin flow analysis and other simulation technologies are effective tools not only for predicting improper dimensions or poor external appearance but also for designing products and molds. This should be done in consideration of productivity at stages including verification of the ease of assembly or the optimization of the mold temperature control circuit.

This paper describes our approaches for increasing the quality of injection molded parts by taking advantage of simulation technologies.

2. Simulation Technologies in Injection Molding

In injection molding, plastic material is fed into a mold in the injection process, sent to the dwelling and cooling processes and then removed from the mold. During these processes, the resin, which is the major component of plastic material, changes from a flowing state to a solid as heat is exchanged with the mold, and shrinks after it is released from the mold until the temperature equilibrates. Moreover, the reinforcement fiber in fiber-reinforced plastic material is oriented along the flow of the resin in the mold, which produces anisotropy in shrinkage or strength. Resin flow analysis is a technology for simulating the behavior and state of the resin over this period.

Figure 1 shows the relationship between injection molding processes and resin flow analysis. Resin flow analysis can be used to determine whether molding is possible or not based on filling pressure or the occurrence of unfilled area. It can also be used for predicting various factors of molding quality, such as warp-

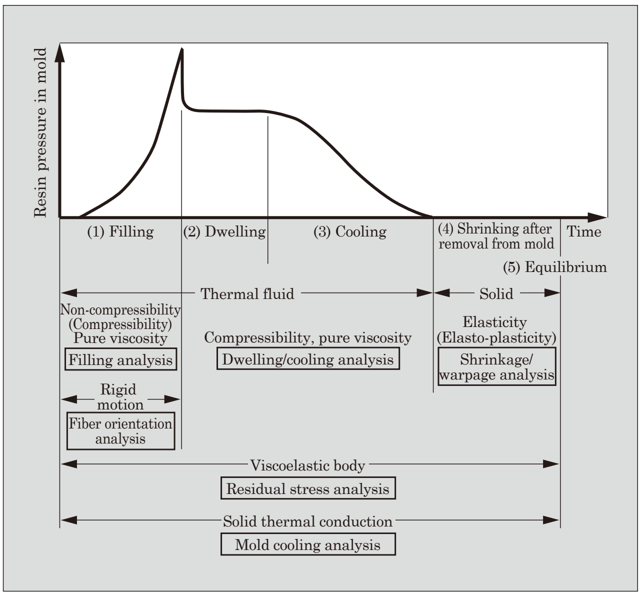

Fig.1 Relationship between injection molding processes and resin flow analysis

* Production & Procurement Group, Fuji Electric Co., Ltd.

age, the deformation of insert parts, or the position of weld[*1]. It is also possible to predict fiber orientation which determines the strength of fiber-reinforced plastic.

Filling pressure can be used not only for calculating a mold clamping force of the injection molding machinery (the force applied to the mold to prevent it from opening), but also together with structural analysis for predicting mechanical stress or deformation of the mold. By checking the strength of mold parts and studying optimum shapes with minimum waste before creating molds, we can ensure more refined mold design and provide more reliable products.

The fiber orientation, position of weld and warpage predicted in resin flow analysis can be incorporated into an analysis model for structural analysis to predict the strength of molded products. In recent years, it has become possible to analyze not only fiber orientation but also fiber damage in the flowing resin including those in the molding machinery cylinder. This is then used to predict the fiber length distribution in molded products. Consequently, it has become possible to predict the strength with higher accuracy and reflect it in the design of products and molds.

Mold temperature is a factor that greatly affects productivity as well as the ease and quality of molding. Conventional mold cooling analysis was steady analysis assuming that the average value was constant while the temperature fluctuated in the molding cycle. By using unsteady mold cooling analysis, we can now see the chronological change in the temperature of various sections of the mold from the start of molding to when the mold temperature stabilizes, and check for hot spots after the temperature stabilizes.

3. Resin Flow Analysis

3.1 Warpage analysis utilization

Warpage in molded products caused by resin shrinkage not only reduces the functionality of parts but also affects the fit with other parts and the feasibility of automated assembly.

We have already utilized the result of warpage analysis for studying fitting state (see Fig. 2). The ease of assembly has been checked with prototypes created by cutting or with a 3D printer based on the drawing dimensions; however, the influence of warpage was mainly verified with products molded with prototyped molds. In recent years, we have been using a 3D printer to print out a deformed shape obtained in the warpage analysis and using it to check the ease of assembly (see Fig. 3). Such an approach makes it possible to optimize parts shapes or mold structures to determine dimensions applicable to automated assembly in the design stage. This results in less mold modifications and a shorter development period.

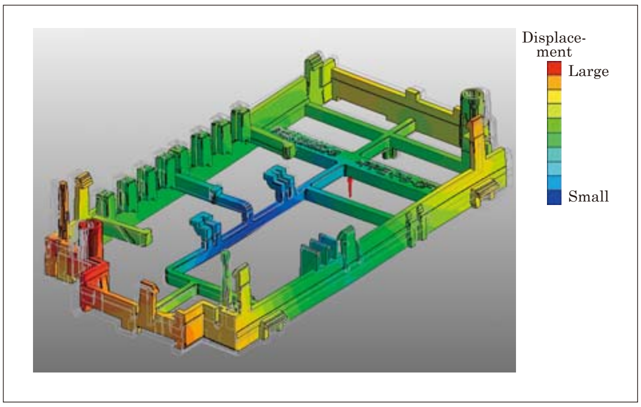

Fig.2 Example of warpage analysis of power electronics equipment part

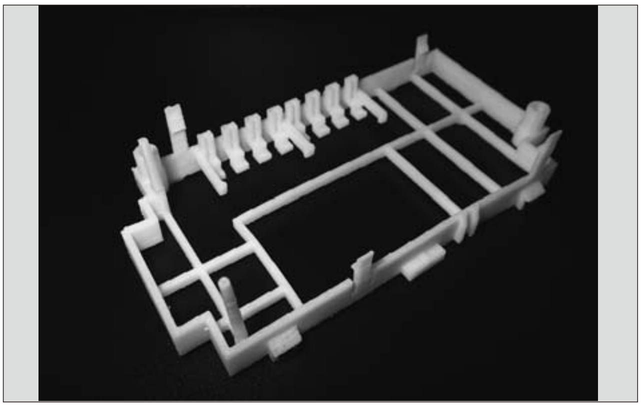

Fig.3 Example of 3D printer printout of power electronics equipment part

3.2 Weld avoidance

Not only does a weld have a poor external appearance, but also it is known that weld regions have extremely low strength that might cause fractures especially in the case of fiber-reinforced plastics.

Many of the plastic parts that Fuji Electric handles are product housings and mechanical parts that require good mechanical properties. Due to their

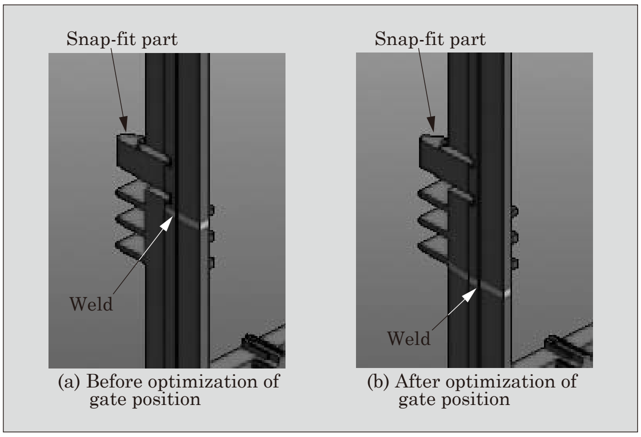

Fig.4 Example of prediction of weld positions

*1: Weld refers to a thin line-shaped molding failure generated at the section where the flows of molten resin meet.

complex shapes and openings, weld is inevitable. We therefore use filling analysis to predict the positions where welds will be generated. We then avoid placing welds in high-stress sections by optimizing gate positions and product shapes in consideration of molding possibility (filling pressure, occurrence of unfilled area), fiber orientation and the amount of warpage.

Figure 4 shows an example of predicting weld positions. In the power electronics equipment part shown above, optimizing the gate position allows us to avoid placing welds at the base of the snap-fit part to which high stress is applied.

3.3 Mold corrosion prevention

In injection molding, the air in the mold before plastic material is fed in and the decomposition gas generated from the plastic material flowing into the mold may cause various molding failures such as short shots (incomplete filling) or burn marks (scorch on the product surface). Fire-resistant plastic materials, in particular, generate corrosive gases which must be discharged efficiently from the mold. This is because they may be heated to a high temperature by adiabatic compression at the final filling area in the mold and cause mold corrosion that degrades productivity and quality.

Filling analysis enables us to predict the position of final filling or trapped air (gas trapped by resin), and we use it for optimizing gate and the gas vent (opening for discharging the gas from the mold) position and product shapes.

Figure 5 shows an example of filling analysis for the housing of a low-voltage circuit breaker. This is an example of optimizing a product shape to prevent mold corrosion. The images show that, before the optimization, resin filling was completed faster on the gas vent side and inhibited the discharge of the gas. After the optimization, the resin is filled more slowly on the gas vent side so that the gas can be discharged more easily.

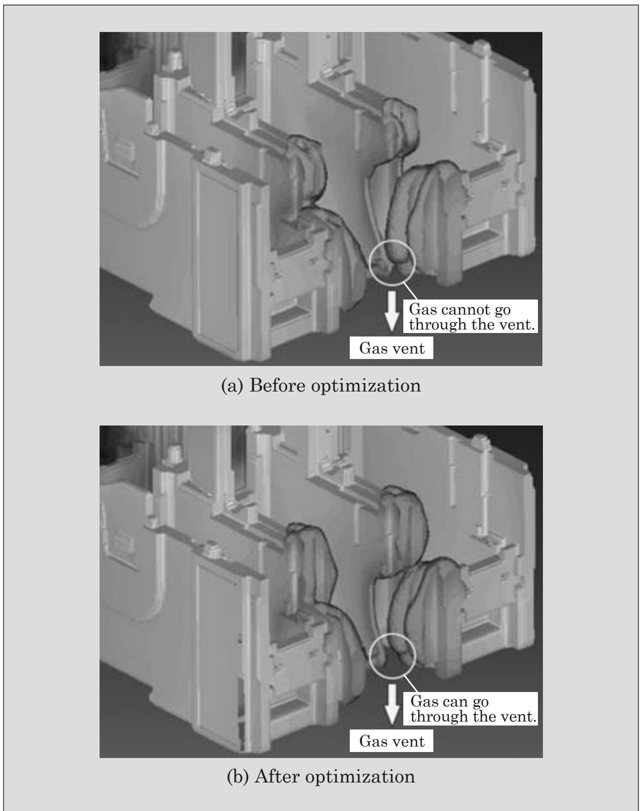

Fig.5 Example of filling analysis for housing of low-voltage circuit breaker (filling ratio: 90%)

4. New Approaches for Increasing Quality

4.1 Optimization of the temperature control circuit of the mold for high-speed molding

In injection molding, the cooling time takes up most of the molding cycle. The larger the size of molded products, the higher the ratio tends to be. Consequently, one possible measure for improving productivity is to lower the mold temperature and shorten the time for cooling injection molded parts. It must be noted that lowering the mold temperature may cause insufficient filling or transfer failure.

To solve this problem, Fuji Electric has established a high-speed molding technology that proactively controls mold temperature during a molding cycle. By this technology, greatly shortens the molding cycle time while ensuring high quality. Figure 6 shows the mold temperature profile obtained with the high-speed molding technology. Specifically, a heater is placed near the contact surface between the mold and plastic material. It heats the mold quickly after the molded product of the previous shot is removed and until the next injection starts. After the filling is complete, the temperature is controlled to help the material be cooled with cooling water.

This technology cannot be achieved without a temperature control circuit that can heat and cool the mold quickly and uniformly. We use resin flow analysis to predict the resin temperature distribution, determine the sections that should be heated or cooled proactively, and reflect the result in the design of the mold for high-speed molding. Since we need to proactively cool the mold parts which heat up easily, we achieved a

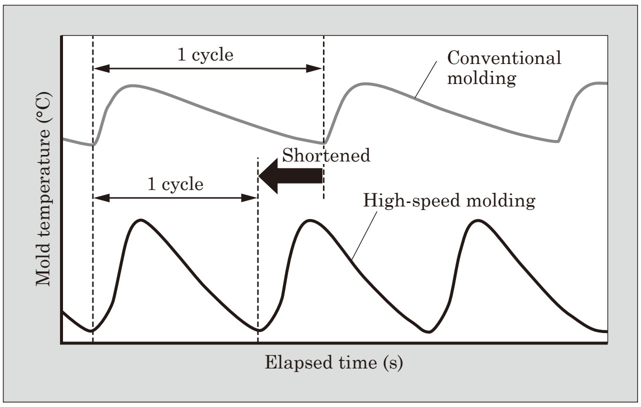

Fig.6 Mold temperature profile

cooling effect and uniform temperature of the mold by using a 3D printer to form a 3D cooling water channel inside, which is shown in Fig. 7.

We optimized the layout of the heater by checking the temperature rise rate and temperature distribution of the heated surface through unsteady heat transfer analysis. We considered a heater installation method to increase thermal efficiency and installed heaters onto moving parts with small and complex structures. Figure 8 shows a comparison between the analysis value and measured value of the temperature distribution of the mold. Figure 9 shows a comparison between the analysis value and measured value of the heater current dependence of the mold temperature rise rate. The measured values of the temperature distribution and temperature rise rate of the mold well match with the analysis result.

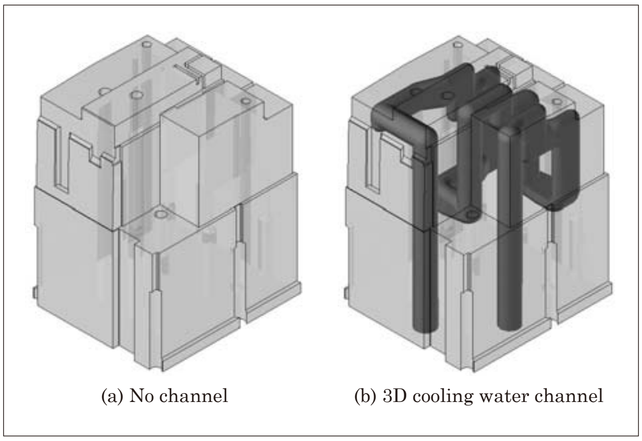

Fig.7 3D cooling water channel in mold part

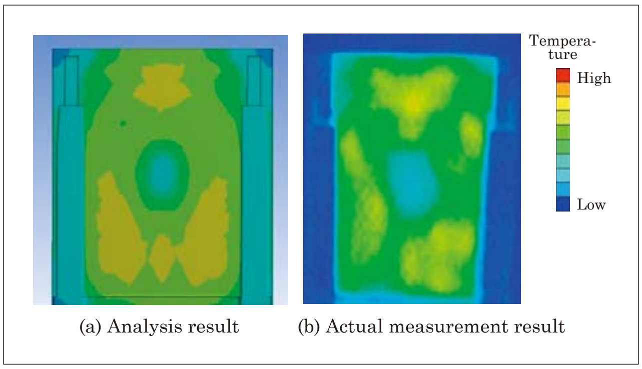

Fig.8 Comparison of temperature distribution in mold

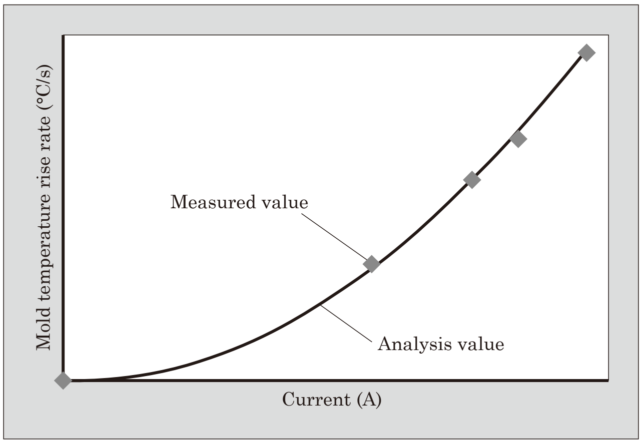

Fig.9 Comparison between analysis value and measured value of mold temperature rise rate

4.2 Prediction of glass fiber length

The strength of fiber-reinforced plastic depends on the length and orientation of the reinforcement fiber contained in the molded products. The fiber is damaged while flowing and this makes it shorter and causes it to have a lower strength. A longer reinforcement fiber is damaged more easily. Consequently, in the application of long fiber glass-reinforced plastic offering a strength equivalent to metal, it is important to establish technology to predict the glass fiber length contained in the molded products and reflect the result in the design of products and molds.

We have revealed so far that the area of modeling and consideration of the damage inside the molding machinery cylinder (incorporation of the injection screw shape into analysis conditions) will affect the result of analysis of glass fiber length. Furthermore, we have been studying analysis parameters including the possibility of glass fiber damage or the degree to which a compression force that results from resin flow contributes to fiber damage.

Figure 10 is a result of analyzing glass fiber length in a shape simulating a mechanical part for which high strength is required. Figure 11 is a comparison of the changes in the glass fiber length of the same part during a molding process with an actually molded part. The glass fiber becomes shorter as the molding progresses. The glass fiber length matches well with the measured value from when the resin was inside the cylinder until the point immediately after it passed through the gate.

We will improve the accuracy of the analysis after the resin passes through the gate by optimizing the element breakdown, glass fiber physical properties and fiber length distribution parameters. We will then apply the result to the design of long fiber glass-rein-

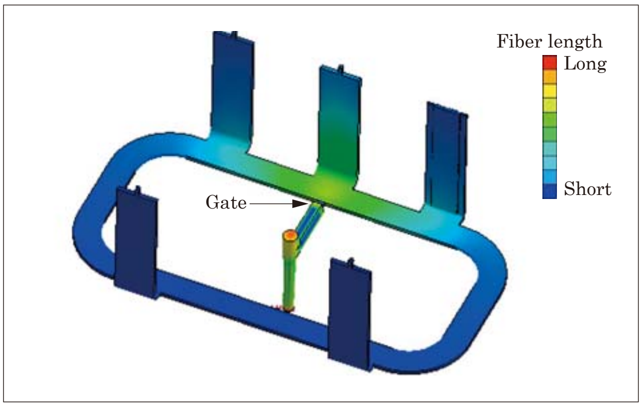

Fig.10 Analysis result of glass fiber length

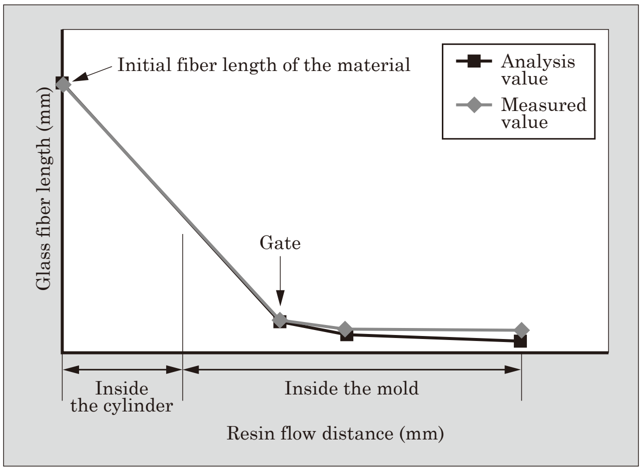

Fig.11 Change in glass fiber length during molding process

forced plastic molded products and their molds.

5. Postscript

This paper has described our approaches for increasing the quality of injection molded parts by taking advantage of simulation technologies.

We will continue working to achieve further sophistication and higher accuracy of analysis technologies so that we can provide products of higher quality to our customers.