International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-4 Issue-5, June 2015

Verification Experiment on Cooling and Deformation Effects of Automatically Designed Cooling Channels for Block Laminated Molds

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Abstract— In plastic injection molding process, poor mold cooling conditions will cause the molding defects such as deformation, warpages of the products. An efficient cooling design can significantly reduce the cooling time, and in turn increase the productivity of the injection molding process. On the other hand, severe warpage and thermal residual stress in the product may result from non-uniform cooling. Warpage and sink marks can significantly affect product quality, especially in terms of appearance and precision. In this study, the uniformity of cooling and the deformation effect were observed in the injection mold with the automatically designed cooling channel through a verification experiment. Based on the molding experiment, the cooling and deformation effects were investigated. Results of resin cooling uniformity, temperature distribution of molding parts and deformation of mold were demonstrated.

Keywords: Injection molding process, Cooling channel, Automatic design, Verification experiment, Rapid prototyping, Block laminated molds

I. INTRODUCTION

An injection molding is one of the most powerful, highly productive and versatile, rapidly developing methods of polymer processing [1], [2], in the molding process. The cooling stage is important because it significantly affects the quality of products, as well as their rate of production. It is well known that more than three-fourths of the cycle time in the injection molding process is spent on cooling a molten resin so that a product can be ejected without any significant deformation. An efficient cooling design can significantly reduce the cooling time, and in turn increase the productivity of the injection molding process. On the other hand, severe warpage and thermal residual stress in the product may result from non-uniform cooling. Warpage and sink marks can significantly affect product quality, especially in terms of appearance and precision [3], [4]. Hence, the cooling system is an important and essential part of an injection mold. In most cases, the problem can be solved only by a straight line cooling channels or rearrangements of those, so that continuously flowing coolant removes heat from the mold. However, it is not always easy to create an appropriate temperature field for even cooling in the mold using these cooling methods. Moreover, molded products are expected to have more functions and higher precision, which will become even more complicated in the future. Therefore, the mold cooling systems will also have to become more complicated, according to the complexity of the product to be evenly cooled. Thus, the design of cooling systems for molds is an important research issue [5], [6]. Using a numerical calculation method to estimate the size, layout and shape of the cooling system, a suitable cooling system with uniform cooling can be designed. Conventionally, professional designers rely upon their experience, intuition and a trial-and-error process to design cooling systems manually. However, these designs entail high design costs along with inefficiencies. Some research groups have also reported how to optimize a cooling system optimum by genetic algorithm, but most of these efforts have been focused on obtaining the optimum layout, size, and cooling condition parameters of the cooling channel in the injection mold [4]. However, it is also difficult to create an appropriate temperature field for even cooling in the mold using this method. The authors propose a block laminated mold to solve the above-mentioned problem. A block laminated mold is a mold made by laminated metal blocks as shown in Fig. 1.

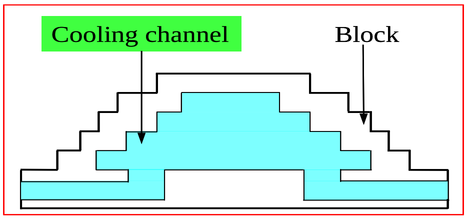

Fig.1 Block lamination mold

Since channels for cooling water can be created arbitrarily inside the mold, a higher production rate and quality of products can be achieved. The production method of block lamination is shown in Fig. 2. First, the core of the mold is divided into several parts, according to the requirements. A cooling channel segment is machined into each part. These parts are integrated into one core block. Finally, the parts are united by welding. In this way, an arbitrarily shaped cooling channel can be made inside the mold.

Manuscript published on 30 June 2015.
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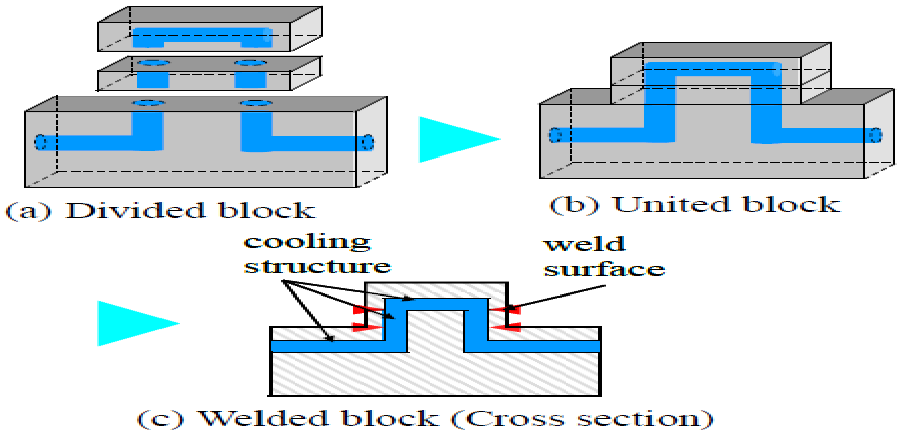

Fig. 2 Lamination process

Considering these parameters and the design issues mentioned above, the authors propose an automatic method for designing injection mold cooling systems utilizing a simple Genetic Algorithm (GA) and the finite element method. Firstly, the authors propose a method about how to design the shape of block laminated mold, and how to make some cases are realized in which the finite element model is not suitable for the geometry of the mold since those types of mold are difficult to be manufactured. Then, a procedure of optimizing the shape of cooling channel is demonstrated by considering temperature and deformation of Mold, and also demonstrated some design cases based on proposed method in the study. By using the evaluation and automatic design method, the uniformity of cooling and the deformation effects of the designed cooling channel in a block laminated mold are examined through case studies based on numerical analysis [7]. The authors have discussed the automatic design method of the cooling channel for block laminated molds in the paper which has been published in the international journal of engineering and advanced technology [8]. In this paper, the authors will discuss the verification experiment on cooling and deformation effects of automatically designed cooling channels for block laminated molds

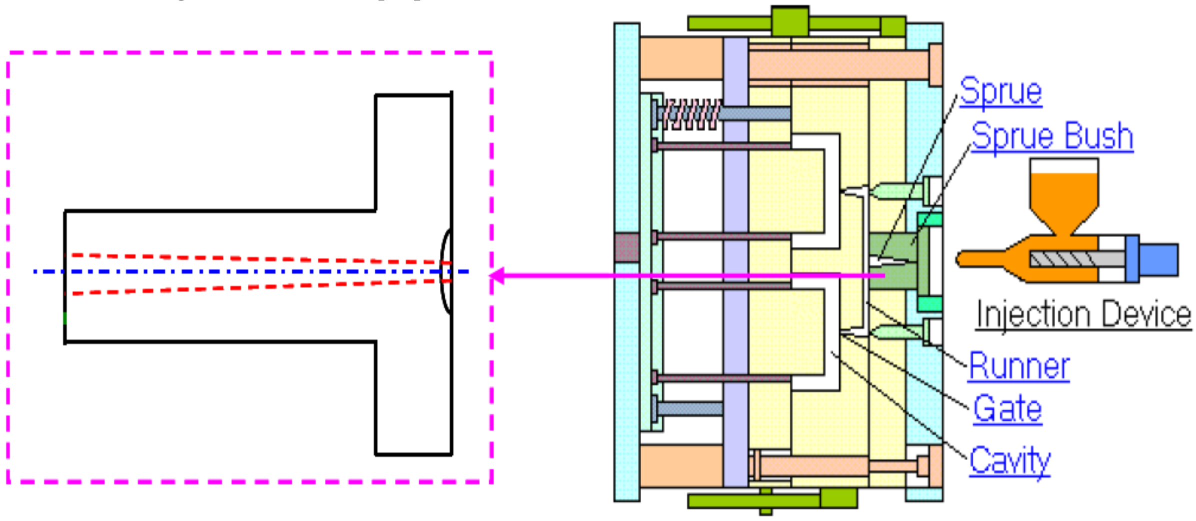

Fig.3 Mold Basic construction with sprue bush

II. Molding Experiment

A. Sprue bush

The molten plastic injected from an injector nozzle will go through a bush (sprue bush), a runner, and a gate and fill up a cavity. As the temperature of molten plastic is lowered while going through a bush and runner, the viscosity will rise. Therefore, the viscosity is lowered by shear heat generated when going through the gate to fill the cavity. As a sprue bush is the part that has first contact with the melted plastic, bad design of a sprue bush can make not only a defective plastic product, but also a broken sprue and a broken runner. Therefore, the study of sprue bush design is important. A basic mold construction with a sprue bush is shown in Fig.3.

B. Product model and experiment mold

In order to compare the cooling effects and deformations of the method, proposed optimization cooling channels and optimization cooling channels in sprue bushes are discussed. A molding experiment is carried out using a designed sprue bush model. The results of the investigation on the effects of different cooling channels, and the sprue surface temperature and deformation are reported. Product Model, experiment mold, proposed optimization cooling channel, optimization cooling channel, practical mold and sprue product are shown in Fig.4, Fig.5, Fig.6, Fig.7, Fig.8 and Fig.9, respectively. Molding Conditions are shown in Table 1.

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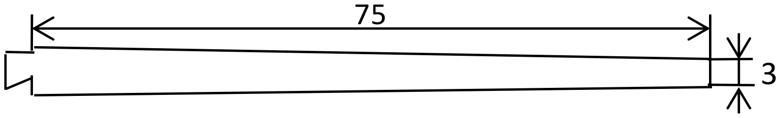

Fig.4 Product model Unit [mm]

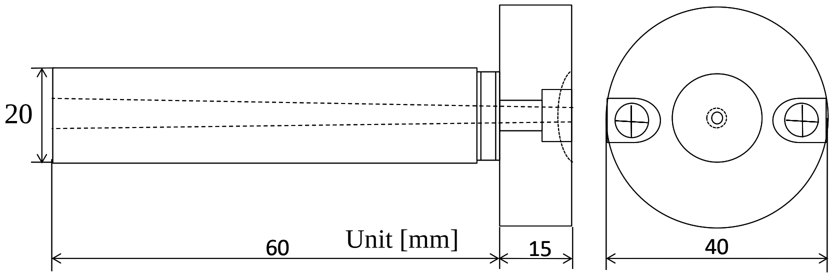

Fig.5 Experiment model

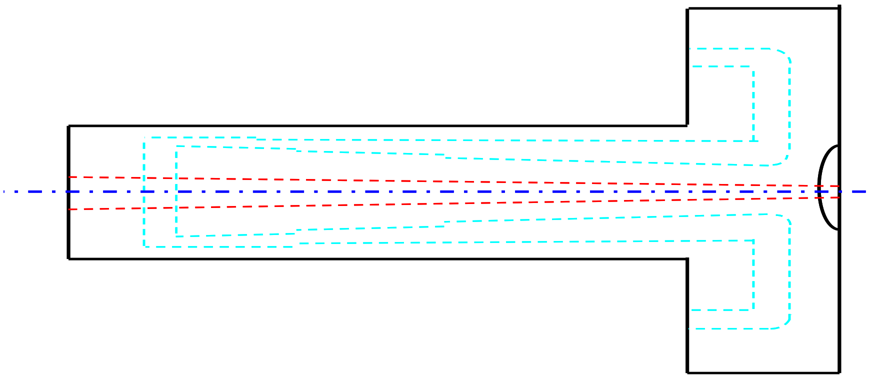

Fig.6 Proposed optimization cooling channel

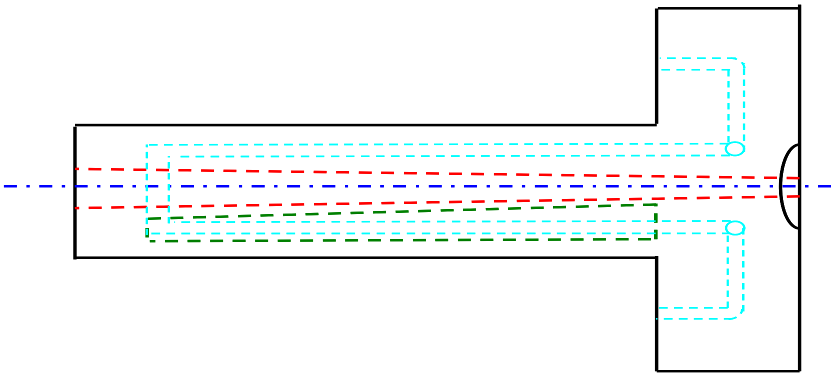

Fig.7 Optimization cooling channel

Table 1 Molding Conditions

Laser Type	CO_2 Laser
Laser Maximum Power [W]	500
Maximum Rotation of Axis [rpm]	50,000
Maximum Product Dimension [mm]	250 × 250 × 185

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Fig.8 Practical mold

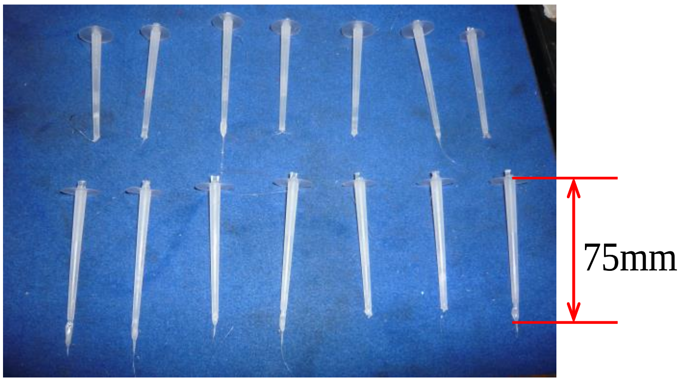

Fig.9 Sprue products

Fig.10 Experiment overview

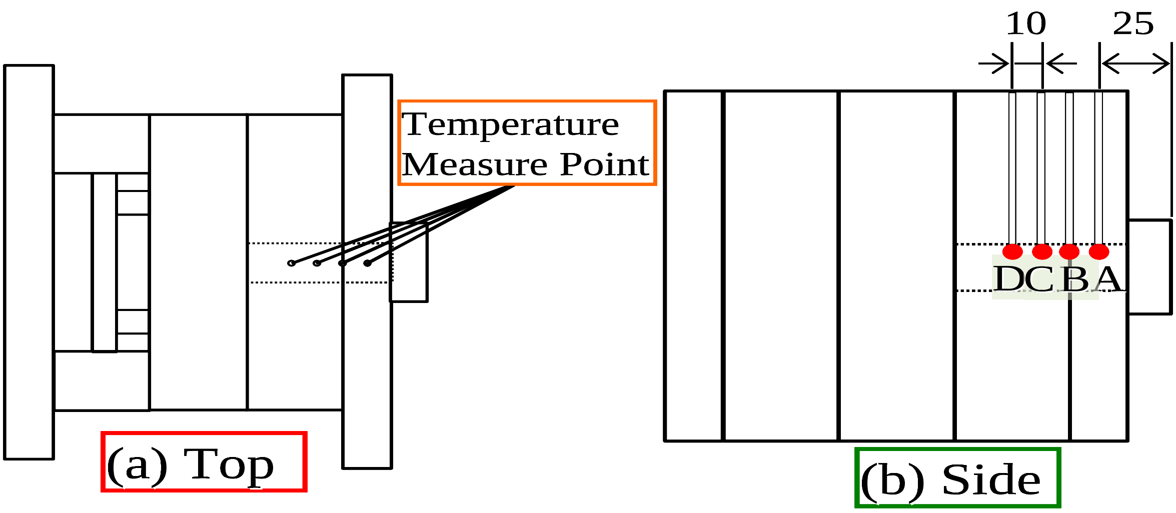

Fig.11 Temperature measurement points

C. Equipment and molding conditions

The molding machine used in this experiment is a 75-ton hydraulic molding machine (NIGATA, NN75SH7000), which is shown in Fig.10. The overall cycle time is controlled at 30 seconds, cooling time takes 15 seconds. The temperature of the injection cylinder is 190℃. The cooling water is maintained at 25℃, and the mold temperature in a steady run is 40℃, the whole experiment is conducted in a room temperature environment of 20℃-24℃. LABVIEW is used for measuring the temperature of points A, B, C and D in the experiment mold.

D. Temperature and deformation measuring

Temperature of the resin surface is the most direct parameter for describing the cooling effect. It is difficult to understand the temperature vibrations on a resin surface over the whole cooling process via experiment. This research tests the temperature of the sprue bush, where a 1mm distance far from the resin surface is measured. The temperature of points A, B, C and D are shown in Fig.11.

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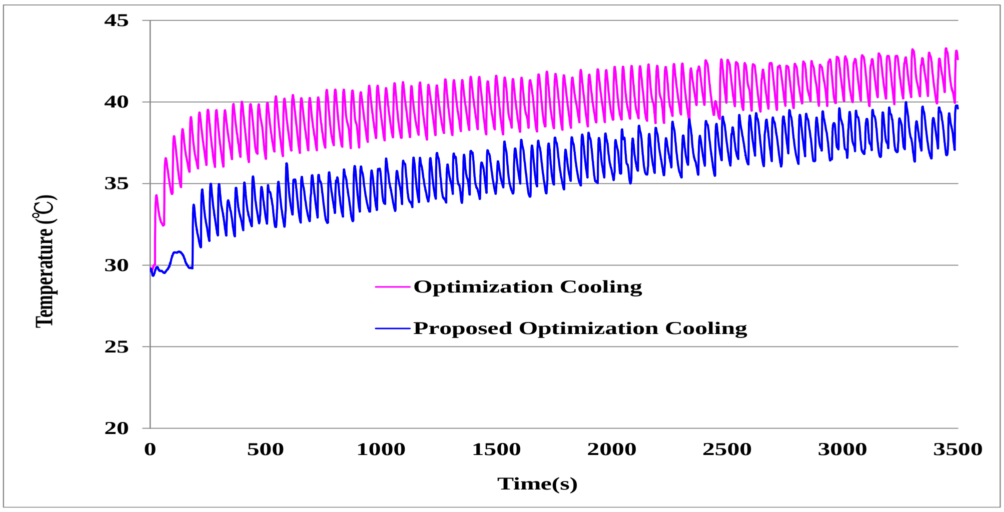


Fig.12 Temperature dispersion of the sprue bush with proposed optimization Cooling channel and optimization cooling channel

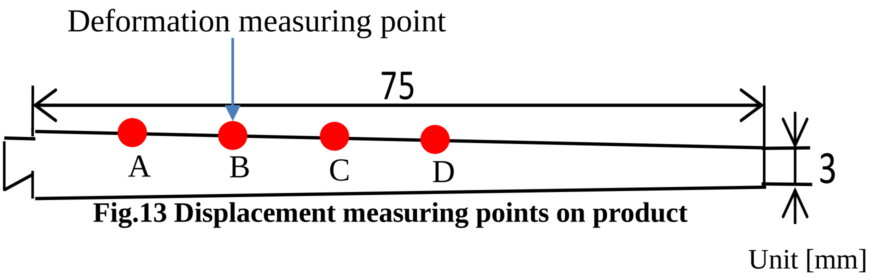
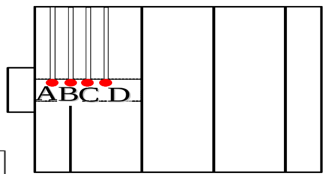


Fig.13 Displacement measuring points on product

Authors compared the temperature and deformation distribution of the sprue bush with the proposed optimization cooling channel and an optimization cooling channel. Fig.12 shows the temperature distribution after cooling start. The vertical ordinate in the graph is the temperature change; the horizontal ordinate is the time from the beginning of cooling. According to this result, there is a lower temperature distribution of the proposed optimization cooling channel in the sprue bush compared with an optimization cooling channel. A three dimensional coordinate measuring machine is used as a tool for measuring the deformation of a product.

The flatness of the product surface is used for evaluating the product deformation. Fig.13 shows the temperature measuring points on the product surface. Near the injection nozzle of the molding product, there is a runner, so the place is not used as a measuring area. In order to evaluate the thickness of the surfaces, the top wall surface along the 4 temperature measuring points are measured. Fig.14 shows the deformation distribution of the evaluated points A, B, C, D. The vertical ordinate in the graph is the deformation;



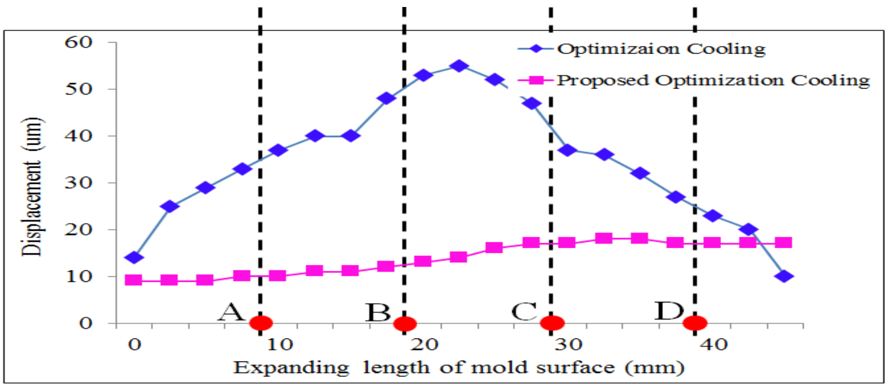


Fig.14 Displacement of sprue bush with proposed optimization cooling channel and optimization cooling channel

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The horizontal ordinate is the expanding length of mold surface around the evaluated points A, B, C, D. According to this result, the maximum mold surface deformation with the optimized cooling channel is 17□m, whereas the maximum mold surface deformation of the cooling channel is 55□m. The proposed optimization of the cooling channel can decrease the deformation of the mold surface.

The experiment verified the utility of the proposed cooling channel design method based on resin cooling uniformity and deformation reduction of the mold. This can decrease temperature distribution of the product and improve the cooling effect. Also, it can reduce deformation of the mold. The proposed optimization cooling channel gained a more effective result. Experimental data shows the best result when the proposed optimization cooling channel inside the sprue bush is applied. The authors should provide more experimental results to show the effectiveness of the proposed method; this will be future work in this research.

III. Discussion

By numerically evaluating the surface temperature of the product and the deformation of the mold, the authors proposed an automatic design method for the cooling system of a block laminated mold utilizing a simple Genetic Algorithm (GA) and a finite element method. The obtained cooling channel shape would not likely have been designed similarly through trial and error. The proposed optimization of the cooling channel can further decrease product surface temperature compared with the optimization of the cooling channel. The proposed optimization of the cooling channel also considerably decreased the mold surface deformation compared with the optimization of the cooling channel. In order to further verify the effectiveness of this method, there are some steps that need to be taken in future work. One is that the mesh number of FEM elements is small in this study; a larger mesh number of FEM elements should be used to improve the precision of the mold cooling channel. Another is that the authors should manufacture a practical mold, and compare the result of the simulation with the result of the product under conventional design methods to investigate the cooling effect.

IV. Conclusion

In this study, by using the evaluation and automatic design method, the cooling and mold deformation effects of the cooling channel in the injection mold were examined based on a verification experiment. According to the experiment verification, the authors can draw a few conclusions.

- Optimization of the cooling channel can reduce the heat concentration near the inner surface of the product and improve cooling uniformity. Optimization of the cooling channel can also decrease the deformation of the mold surface. The appropriately established binary GA operations could be applied to a cooling channel optimization problem.
- The experiment verified the utility of the proposed cooling channel design method based on resin cooling uniformity and deformation reduction. This can decrease the temperature dispersion of the product and improve the cooling effect. In addition, deformation reduction of molds is also verified. The proposed optimization cooling channel gained a more effective result. Experimental data shows the best result when the proposed optimization cooling channel is applied inside the sprue bush.

Acknowledgement

This work is partly supported by KAKENHI (21560128).

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