Automatic Design of Cooling Channels for Block Laminated Molds: A Resolution Study

Jianguo Liang, Hiroyuki Narahara, Hiroshi Koresawa, Hiroshi Suzuki

Abstract— This study discusses a method for the automatic design of injection-mold cooling channels using genetic algorithms (GA), the finite element method (FEM), and an evaluation function based on unsteady state heat transfer and linear static deformation. The uniformity of cooling and the deformation effect of the automatically designed cooling channel in the injection mold were examined through case studies based on numerical analysis. The genetic algorithm was applied in the following steps: generation of finite elements of individuals expressing different cooling channel shapes, the definition of the fitness function to evaluate individuals, the genetic operation for individuals, and modification to the automatically generated cooling channel shape. Finally, the automatically generated shape of the cooling channel is discussed and compared with manually designed cooling channels.

Keywords: Cooling channel, Automatic design, Block laminated mold, Rapid prototyping, Laser sintering

I. INTRODUCTION

Highlight a Injection molding is one of the most powerful, highly productive and versatile, rapidly developing methods of polymer processing [1], [2], in the injection molding process, the cooling stage is important because it significantly affects the quality of the 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 in cooling the molten resin so that the product can be ejected without any significant deformation. An efficient cooling system 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 channel or rearrangement of such, such that continuously flowing coolant removes heat from the mold. However, it is difficult 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 and to be more complicated in the future.

Therefore, the mold cooling systems will also become more complicated, and it will become more difficult for 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.

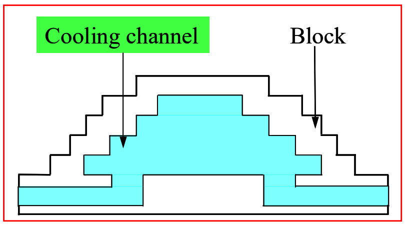


Fig.1 Block lamination mold

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 August 2013.
* Correspondence Author (s)

Jianguo Liang*, Mechanical Information Science and Technology, Kyushu Institute of Technology, Fukuoka, Japan.
Hiroyuki Narahara, Mechanical Information Science and Technology, Kyushu Institute of Technology, Fukuoka, Japan.
Hiroshi Koresawa, Mechanical Information Science and Technology, Kyushu Institute of Technology, Fukuoka, Japan.
Hiroshi Suzuki, Mechanical Information Science and Technology, Kyushu Institute of Technology, Fukuoka, Japan.

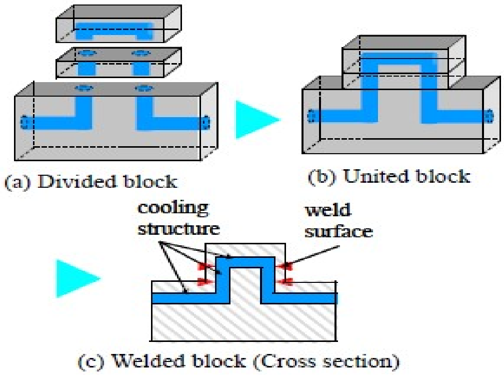


Fig. 2 Lamination process

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]. Also, the authors discuss the results of the automatic design of the cooling channel.

II. METHODOLOGY

A. Cooling channel design

a). General cooling channel design

Cooling of an injection mold is crucial to the performance of the product, influencing both the rate of the process and the resulting quality of the product produced. However, cooling channel design and manufacture have been confined to relatively simple configurations, primarily due to limitations of the manufacturing methods, but also due to the lack of a design methodology appropriate for cooling channels. As a general cooling system in such a mold, a straight-line cooling channel or combination of channels is arranged as shown in Fig. 3. With the demand for increasingly complicated molds, the manufacture of cooling channels will become more and more difficult.

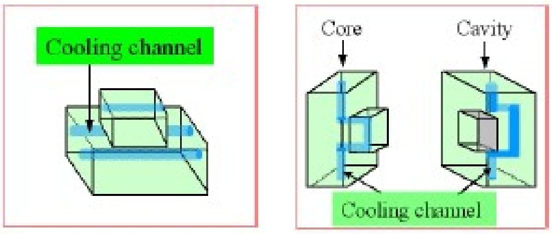


Fig.3 Line channels and their combination

b). Cooling channel design using GA [4]

Table 1 Initial and optimum values for design parameters

	Channel No.	r [mm]	x [mm]	y [mm]	h [W/m²k]	T [deg]
Initial	1	3.01	15.2	15.2	2693.4	8.0
	2	3.01	100.0	17.9	2693.4	8.0
Optimum (76th)	1	3.13	60.0	22.0	3002.1	19.8
	2	3.13	100.0	22.0	3002.1	19.8

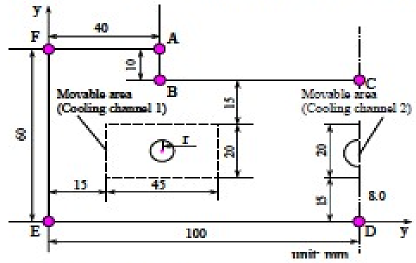


Fig.4 Mold region used for boundary element analysis [4]

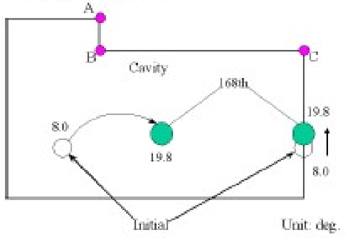


Fig.5 Changes of location and diameters of cooling channels, and temperature of coolant before and after optimization [4]

Some researchers have used GA to optimize the design of cooling channels in the mold [4]. GA has the advantage that it can address a discrete optimization problem such as combining continuous variable design of the cooling channel diameter and discontinuous variable design of the channel position based on the fitness-for-survival theory. Cooling channel design using GA is described as follows:

First, this algorithm generates an initial value for design parameters in the possible field by random methods. Then, the decimal design parameters are translated into binary variables.

Second, each individual is evaluated using an evaluation function. Each individual in the population is arranged according to the fitness value. Next, the individuals with the highest values are forced to remain in the next generation as elite individuals. As for the other individuals, crossover or mutation is executed, and offspring are created for the next generation.

Finally, it is judged whether or not the convergence condition can be satisfied. When the convergence condition is satisfied, the calculation can be finished. If not, crossover and mutation are executed again, followed by an evaluation, and the cycle is repeated until the convergence condition is satisfied. Mold region used for boundary element analysis, changes of the location and diameters of cooling channels, and the temperature of the coolant before and after optimization are shown in Fig. 4 and Fig. 5, respectively. The initial and optimum values for design parameters are shown in Table 1. Compared with the algorithmic design, the conventional design procedure based on a manual trial-and-error approach makes the process longer, requires extensive human involvement, and tends to be biased by the designer's preconceptions.

This type of experience-based design approach is not efficient in designing complex products. The optimization of cooling channel design using GA is becoming more and more popular among engineers to deal with complex product specifications.

B. Cooling channel design for a laminated block using GA

a). The concept of GA

GAs are efficient and generally applicable global search procedures based on a stochastic approach which relies upon the Darwinian survival-of-the-fittest principle [8], [9]. GA operates on a population of potential solutions to produce potentially better approximations of the optimal solution through evolution. The population is a set of "chromosomes" and the basic GA operations are selection, crossover and mutation. At each generation, a new set of approximations is created by the process of selecting individuals and breeding them together using crossover and mutation operators which are conceptually borrowed from natural genetics. In theory, this process leads to the evolution of better individuals.
with near-optimum solutions over time. Generally, GA performs well in finding areas of interest even in complex, real-world scenarios. While a GA may never produce the absolute best solution (global optimum), it is mathematically likely to get very close to it using only a fraction of the computational requirements of an exhaustive deterministic search. The advantages of GA include not only the global nature of its search process, but also its indifference to system-specific information.

b). Design methods

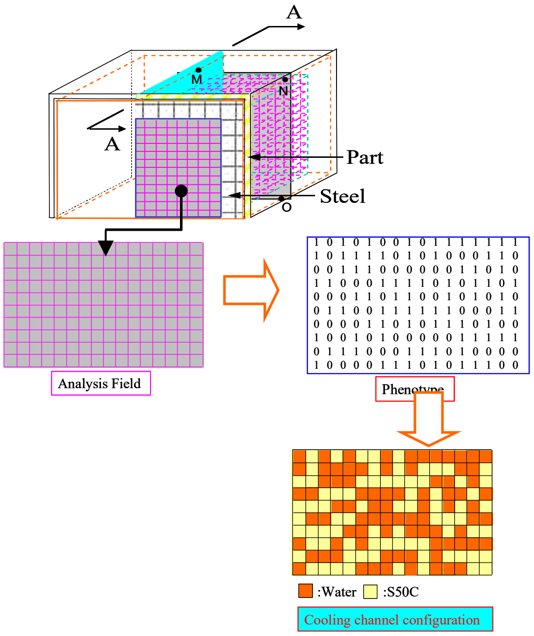


Fig. 6 Definition of analysis field

The definition of the analysis field is shown in Fig. 6. The design field was first converted into a finite mesh, with quadrilateral finite elements corresponding to each design field element. All finite elements corresponding to the cooling element (water) were given a small Young's modulus. Elements corresponding to the material were given a large Young's modulus. Bendse and Kikuchi suggest that if a soft material's Young's modulus is 10^{-2} to 10^{-3} times that of a hard material, the soft material can be regarded as a void or hold [10]. A similar method was used by Jensen [11]. They compared this meshing technique with an adaptive meshing technique where finite elements corresponding to voids are removed from the mesh, and nearly identical optimization and finite-element analysis performance was observed. In our study, void elements (cooling elements) received a Young's modulus 10^{-5} times that of the material element.

c). Genotype and phenotype define

The authors defined the cooling channel shape according to whether the cooling element (water) is present or not in the model fields. When the gene is 1, the cooling element is present, and is shown by a gray rectangle. When it is 0, the cooling element is not present, and is shown by a white rectangle. Then, the phenotype is transformed into a genotype from up to down and from left to right.

d). Genotype and phenotype transfer

Each genotype is represented as a vector of binary numbers, 0 and 1, as shown in Fig. 7. On the other hand, the phenotype of the analysis field is expressed as a matrix constructed by considering the existence or nonexistence of the cooling element. The basic method is depicted in Fig. 7. Firstly, the authors changed the genotype into a phenotype, i.e., changed a one-dimensional model into a two-dimensional model; at the same time, the two-dimensional model was expressed with a finite element code.

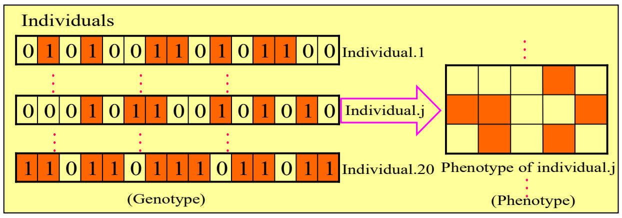


Fig.7 Genotype and phenotype

e). Finite element analysis

For every individual, the authors changed the genotype into a phenotype, and then performed numerical analysis by the finite element method. PATRAN software and the Nastran code are used in our numerical analysis. As the 1st generation, 20 individuals were generated by a random function.

f). Selection, crossover and mutation

GA search operations such as selection, crossover and mutation were applied to obtain a new generation of chromosomes which are presumably better than those of the previous generation. During the selection operation, elite selection operator is used, each individual in the population is arranged according to the fitness value, which is the evaluation function. Several percent of individuals with a high fitness value were chosen as parent individuals for crossover operator, and new individuals were created for the next generation. As for the other individuals, mutation was executed. Regarding crossover, new offspring are created with the characteristics of each parent partially preserved; such individuals are expected to show a higher fitness value than their parents. When new individuals for subsequent generations are created using only crossover, significant improvement in fitness value cannot be expected.

Thus, a random part of the genotype undergoes mutation using probability laws; this process is essential to the automatic design of the cooling channel. In this study, the two-point crossover rate was 0.5, and the mutation rate was 0.1.

g). The convergence condition

Generally, the GA generation process continues until a convergence condition is satisfied. In our study, the convergence conditions were considered to be satisfied when the fitness of the best individual and all individuals do not change through 20 generations. At that point, the calculation was considered finished.

h). The flow of automatic design

In the present study, the authors automatically searched for the cooling channel shape by the genetic algorithm method, and a flow chart of the automatic design is shown in Fig. 8.

First, a population consisting of 20 individuals expressing a cooling channel was set up and defined as the 1st generation (process a). Then, shape modification occurred (process b). The following two processes were conducted for individuals (process c): calculation of the temperature distribution of product surface and pressure deformation of the mold surface, and calculation of the fitness value using a fitness function. After process b was complete, automatic design for cooling channel was performed based on whether the convergence condition had been met (process d). The convergence condition is met when no fitness value could be observed regarding individuals with their maximum values over the succeeding generation.

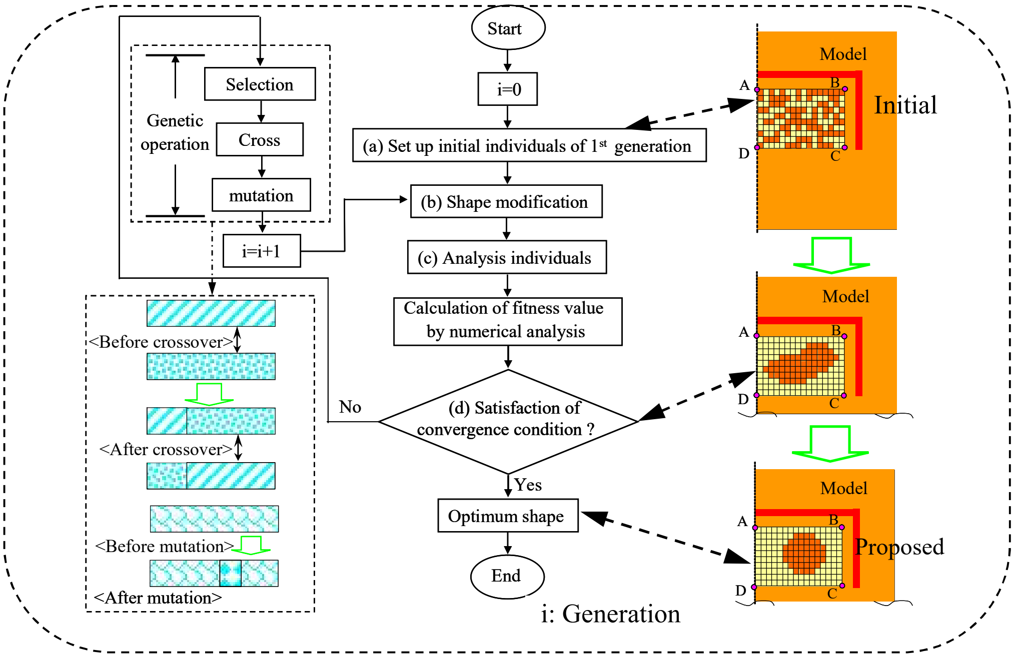


Fig. 8 Flow chart of automatic design

When the convergence condition is not fulfilled, genetic operation is executed for all individuals. This process consists of four operations: preservation of elite individuals with high fitness values, selection of individuals with low fitness values, crossover between two individuals, and mutation. With each operation, new individuals are created as offspring for the succeeding generation. Then, process b is conducted again, and the above-mentioned series of processes is repeated until the convergence condition is fulfilled.

C. Evaluation Function

a). Temperature evaluation function

First, several items used for the evaluation are considered as follows.

Evaluation surface: the surface used for the evaluation of cooling uniformity in a three-dimensional model. The evaluation surface has contact with the mold cavity (see Fig.9 **(b)).**

Evaluation Point: an arbitrary point on the evaluation surface used for the calculation of the temperature error on this point. Temperature error: the temperature difference between the evaluation point and the average value of the evaluation surface. Using these concepts, toward the design goal of minimizing the combination of the product surface temperature distribution and the cooling time, the objective function is defined as follows:

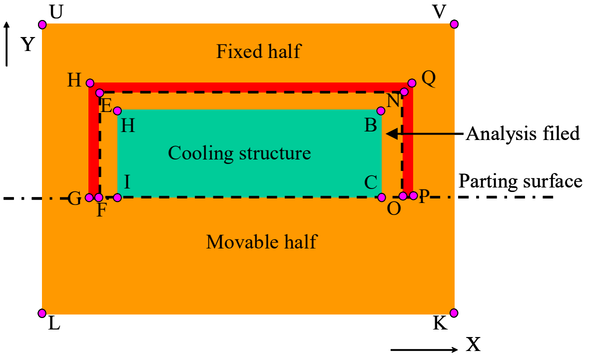


Fig.9 (a) Analysis model

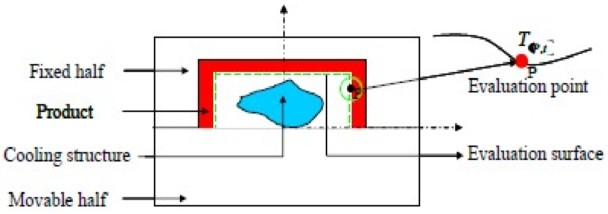


Fig. 9 (b) Evaluation of temperature

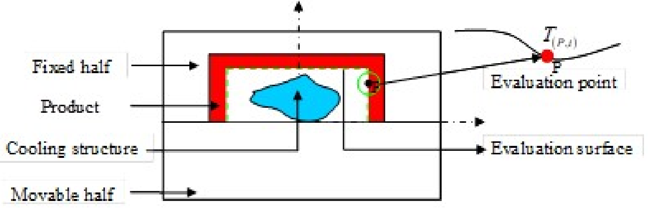


Fig. 9 Temperature evaluation model

The average temperature of all points and the temperature error of evaluation point P at moment on the evaluation surface were calculated. They are defined by Equations (3) and (4).

$$P = (x(q,r), y(q,r)) \tag{1}$$

$$(P \in \Omega, 0 \le q \le 1, 0 \le r \le 1)$$

$$S = \iint_{\Omega} dqdr \tag{2}$$

$$T_{ave}(t) = \frac{1}{S}\iint_{\Omega} T(P(q,r),t)dqdr \tag{3}$$

$$\Delta T(P,t) = T(P,t) - T_{ave}(t) \tag{4}$$

where $\Delta T(P,t)$ is the temperature of the evaluation point P at this moment, and $T_{ave}(t)$ denotes the average temperature of the all points on the evaluation surface.

Next, Equation (5) was used to calculate the dispersion of temperature distribution on the evaluation surface in the whole cooling process.

$$f_{t_c}(P) = \frac{1}{t_c}\int_0^{t_c} \Delta T^2(P,t)dt \tag{5}$$

Finally, for all points in the whole cooling process, small values and even distribution of $F_s(i, j)$ are expected. This can be calculated by Equation (6).

$$F_s(i, j) = \frac{1}{S}\iint_{\Omega} f_{t_c}(P)dqdr$$

$$(i \in generation, \ j \in individual) \tag{6}$$

Equation (6) gives a total description of mold cooling, which considers both the spatial factors and the temporal factors in the whole cooling process. The value can describe the cooling uniformity. A small value means a good temperature distribution on the surface of the evaluated product.

b). Deformation evaluation function

The molten resin is injected at a high flow rate into the cavity. Immediately after the filling, high hold pressures are set during the packing phase to generate a post-filling phase, which compensates for the shrinkage of the polymer due to its cooling. The polymer pressure in the mold cavity often reaches several tons. Such pressure levels lead to cavity deformation due to mold and machine compliance. Consequently, injection molding will cause variations in the cavity dimension. During the deformation evaluation, several items were considered as follows.

Evaluation surface: the surface used for the evaluation of deformation change in a three-dimensional model. The evaluation surface is in direct contact with the product (see Fig.10 (b)).

Evaluation Point: an arbitrary point on the evaluation surface used for the calculation of deformation error.

Deformation error: the displacement difference between an evaluation point and the average value of the evaluation surface.

Using these concepts toward the design goal of minimizing the deformation of the mold, the objective function is defined as follows:

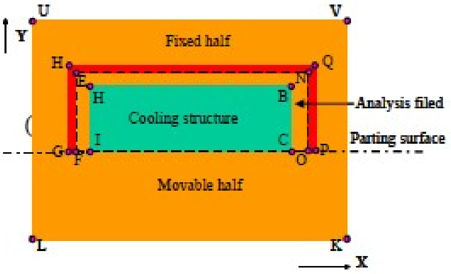


Fig.10 (a) Analysis model

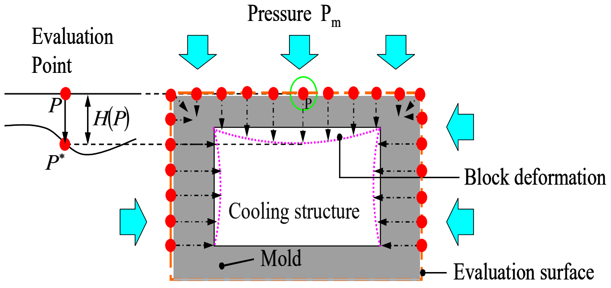


Fig.10 (b) Evaluation of deformation

Fig.10 Deformation evaluation model

First, the average deformation of all points and the deformation error of evaluation point P were calculated. They are defined by Equations (7) and (8).

$$H_{ave} = \frac{1}{S}\iint_{\Omega} H(P(q,r))dqdr \tag{7}$$

$$\Delta H(P) = H(P) - H_{ave} \tag{8}$$

where $H(P)$ is the deformation of the evaluation point P at movement direction, and H_{ave} denotes the average deformation.

Next, for all points on the whole evaluation surface, small values are expected. They can be calculated by Equation (9).

$$N_s(i,j)=\frac{1}{S}\iint_{\Omega}\Delta H^2(P)dqdr \quad (i\in generation\ ,\ j\in individual\ ) \tag{9}$$

Equation (9) gives a total account of mold deformation, and can therefore describe the uniformity of deformation. A small value indicates an even deformation on the evaluated mold surface.

c). Automatic design

To minimize the objective function and optimize the design, temperature and deformation analyses are essential requirements. Temperature analysis and the corresponding deformation analysis are described in sections 2.3.1 and 2.3.2, respectively. Toward this design goal of minimizing the combination of both the uniformity of the product surface temperature distribution and the mold surface deformation related to pressure, the normalized objective function is chosen as:

$$\begin{aligned}E_m(i)&=\underset{j}{Min}\left\{\alpha\frac{F_s(i,j)}{F_s(1,1)}+(1-\alpha)\frac{N_s(i,j)}{N_s(1,1)}\right\}\\E_A(i)&=\frac{1}{m}\sum_{j=1}^{m}\left\{\alpha\frac{F_s(i,j)}{F_s(1,1)}+(1-\alpha)\frac{N_s(i,j)}{N_s(1,1)}\right\}\\&(i\in n,\ j\in m)\end{aligned} \tag{10}$$

Where $E_m(i)$ is the smallest value of all individuals for generation, and $E_A(i)$ is average value of all individuals for i generation. n is the generation, and m is the individual. $F_s(1,1)$ is the reference value for the product surface temperature distribution, which is the first individual of $F_s(i,j)$ in the temperature evaluation.

$N_s(1,1)$ is the reference value for the mold surface deformation, which is the first individual of $N_s(i,j)$ in the deformation evaluation. There is a different rule for the temperature and deformation evaluations, so the authors have to take a reference evaluation to normalized objective function. The weighting parameter α is set to 0.5, and all of the design conditions are equally considered.

III. NUMERICAL EXPERIMENT

A. Analysis model and assumptions

Fig. 13 shows a 3-D model and the cross section of a 2-D analysis mold in the present research. Because the model is symmetrical, this analysis takes the right side as the analysis object. The product in this model is the shape of a box with 2-mm walls. There are some differences between the simulation and the practical mold process. (a) There is a 1~2 degree temperature difference between the coolant at the inlet and outlet. This temperature is usually controlled in the practical mold process. (b) The temperature of resin changes during the filling process. (c) There is a complicated contact state between the mold and the resin. (d) There is heat transfer between mold and air. In order to simplify the process of analysis, there are several assumptions in this simulation:

(1) The cooling water temperature is assumed to be constant.
(2) The temperature of injected resin at the filling stage is assumed to be uniform.
(3) The molten resin and cavity wall are assumed to have ideal thermal contact.
(4) The packing pressure or holding pressure does not influence the solidification of the resin.

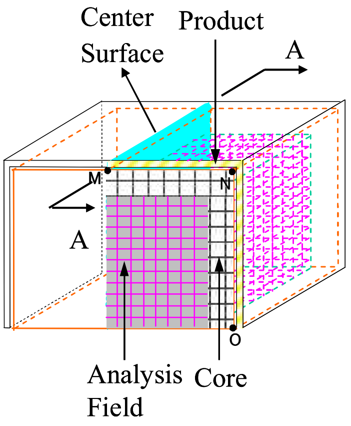


Fig.11 (a) 3-D Model

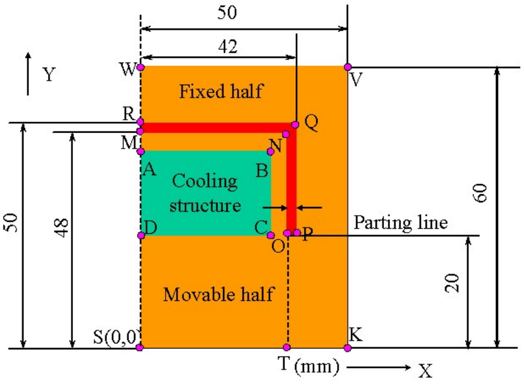


Fig.11 (b) 2-D model

Fig.11 Analysis model

B. Analysis methods and materials

The rectangular field ABCD was divided into 16 × 10 elements. Thereby, a genotype of which the length is 160 can be achieved. There are 20 individuals for each generation in our study. The boundary conditions of the numerical analysis model that was used to calculate the temperature distribution of the product and the pressure deformation of mold are shown in Fig. 11. Because the product and mold are symmetrical to the line WS, line WS can be considered an insulated surface in terms of the heat equilibrium. Water, SKD11 and PS are the cooling material, mold material and resin material in this study, respectively. Molding conditions and properties used in the numeral analysis are shown in Table 2.

Table 2 Molding conditions and properties

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Resin (PS)	Thermal conductivity （W/m・K） Specific heat （J/kg・K） Density （Kg/m³） Filling temperature （℃）	0.15 1340 893 240
Mold (SKD11)	Thermal conductivity （W/m・K） Specific heat （J/kg・K） Density （Kg/m³） Temperature （℃）	29.3 460 7850 40
Coolant (Water)	Thermal conductivity （W/m・K） Specific heat （J/kg・K） Density （Kg/m³） Temperature （℃）	0.6 4180 1000 25
Core Block (SKD11)	Injection Pressure (MPa) Elastic Modulus Density （Kg/m³） Poisson Ratio	5.8 2.1E+011 7800 0.3

IV. RESULT ANALYSIS

The analysis model is shown in Fig. 13. A 2-D unsteady numerical analysis has been made to perform the evaluation and find the temperature distribution on the product surface. The cooling time was set to 20 seconds. The inner surface MNO of the product was chosen as the evaluation range of the product cooling and mold deformation. Analysis software used in the present study is NASTRAN 2005. There were 20 individuals in each generation in our numerical experiments, and the optimization lasted 100 generations. The authors had 10 different calculations with different initial conditions. The resulting initial shape channel is shown in Fig. 12. The optimization cooling channel shape is shown in Fig. 13. The fitness transition of each analysis step is shown in Fig. 16. After the 73rd generation, no change in the fitness of the best individual and all individuals were seen. After that, through the 20 generations, since no change in fitness for individual with the least fitness was seen, the treatment was halted at the 100th generation. It took 60 hours to finish the calculation, and the smallest value was 0.8908. Automatic generation produce from initial shape is shown in Fig. 15.

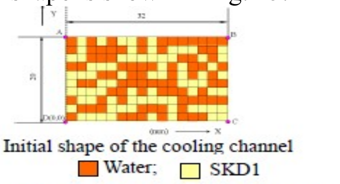


Fig. 12 Initial shape of the cooling channel

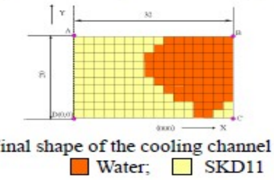


Fig. 13 Final shape of the cooling channel

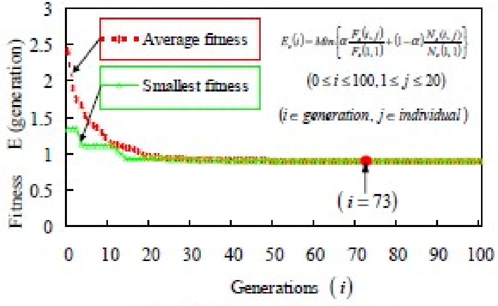


Fig.14 Fitness transition

$$Average : E_A(i)=\frac{1}{20}\sum_{j=1}^{20}\left\{\alpha\frac{F_s(i,j)}{F_s(1,1)}+(1-\alpha)\frac{N_s(i,j)}{N_s(1,1)}\right\}$$

$$Smallest : E_s(i)=Min\left\{\alpha\frac{F_s(i,j)}{F_s(1,1)}+(1-\alpha)\frac{N_s(i,j)}{N_s(1,1)}\right\}$$

$$(1\le j\le 20)$$

$$(i\in generation,\ j\in individual)$$

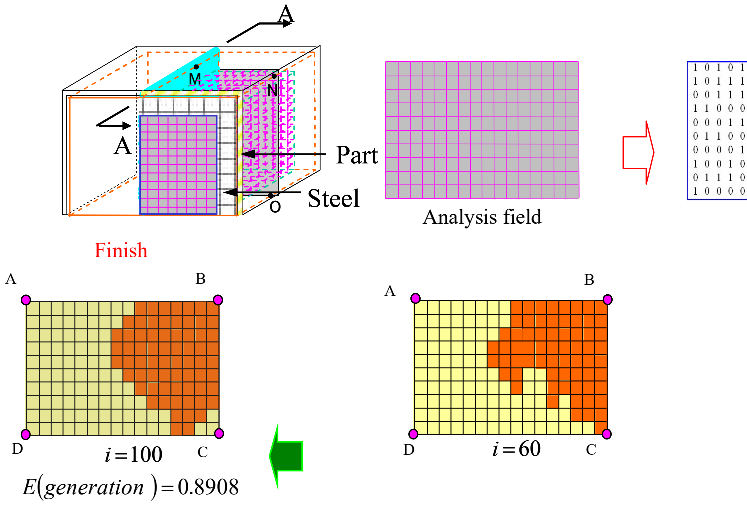


Fig.15 Automatic generation process of c

The authors compared cooling channels with and without design optimization in temperature and deformation so as to verify the effectiveness of proposed method. Two cooling channels without optimization, case_1 and case_2, are shown in Fig. 16.

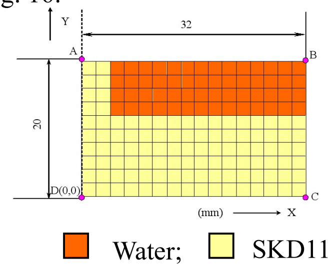


Fig. 16 (a) Case_1

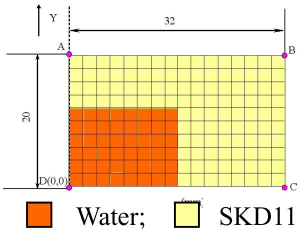
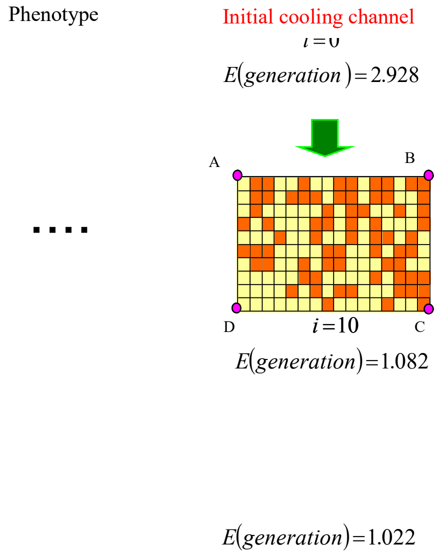


Fig. 16 (b) Case_2

Fig. 16 Cooling channel shapes of case_1 and case_2

The authors compared the temperature distribution on the evaluation curve in the cases of the initial cooling channel and the optimized cooling channel. Fig. 17 and Fig. 18 show the temperature distribution on the product surface MNO, taken at the time of 0, 1.5, 4.5, 7.5, 10.5 and 20 seconds after the beginning of the cooling. The vertical ordinate in the graph is the temperature; the horizontal ordinate is the expanding length of mold surface around the evaluated curve MNO.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)



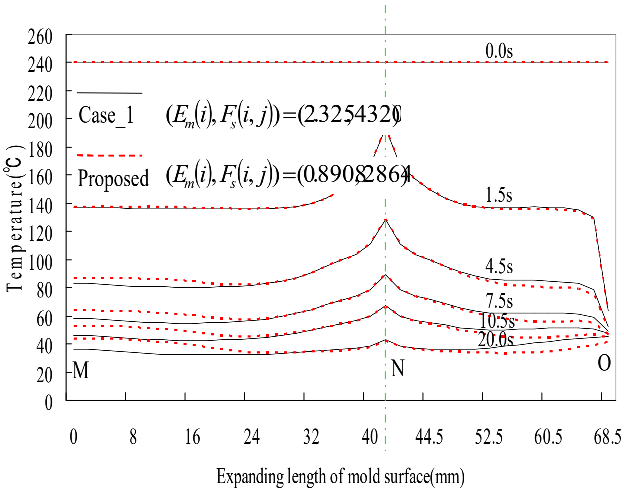


Fig. 17 Temperature distribution on product surface of case_1 and final

In the graph, the solid curves stand for the cooling channel without design optimization. The dashed interval curves stand for the optimized cooling channel.

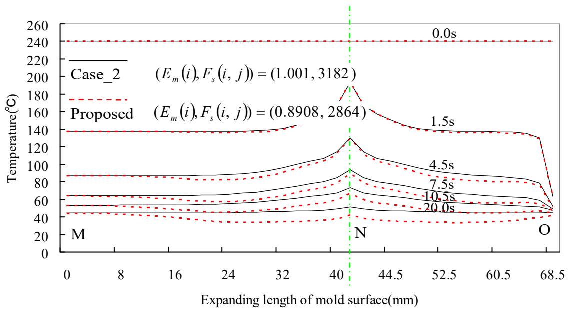


Fig. 18 Temperature distribution on product surface of case_2 and final

The temperature of the corner point N decreased to 43.27℃ (see Fig. 17) at 20 seconds after the beginning of the cooling in case_1. The temperature of the corner point N decreased to 42.66℃ when cooling finished for the optimized cooling channel. There was a 0.61℃ difference between case_1 and the optimized cooling channel sample at corner point N. The temperature of the corner point N decreased to 51.75℃ (see Fig. 18) at 20 seconds after the beginning of the cooling in case_2. There was a 9.09℃ difference between case_2 and the optimized cooling channel sample at corner point N. From these results, the optimized cooling channel lowers the product surface temperature compared with that of case_1 and case_2 as the cooling time increases.

The thermal deformation is one of the major problems that affect a product's quality in plastic injection molding. Once product deformation is controlled to the lowest level, production should benefit high quality products with a minimum material wastage. The product can be ejected without any significant deformation when the temperature reaches the solidifying point (glass transition temperature), the state of resin is becoming a solid. In this study, the object temperature is that the highest temperature inside the resin area decreases to 105℃, which the resin can complete its solidification under the assigned molding conditions. The temperature of the corner point N decreased to 58.26℃ (see Fig. 19) at 20 seconds after the beginning of the cooling for the optimized cooling channel. From these results, the optimized cooling channel can meet the object temperature which has been set up.

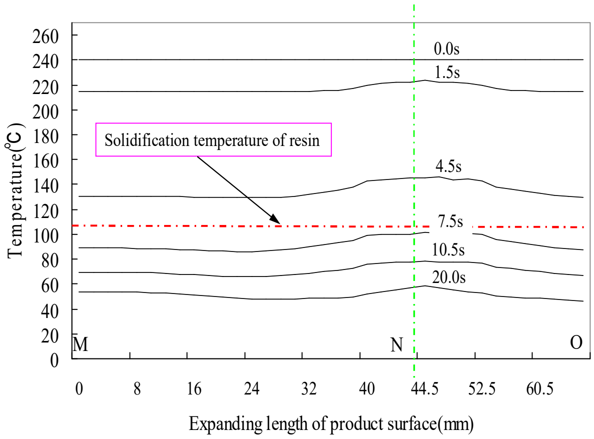


Fig. 19 The highest Temperature distribution on product inner

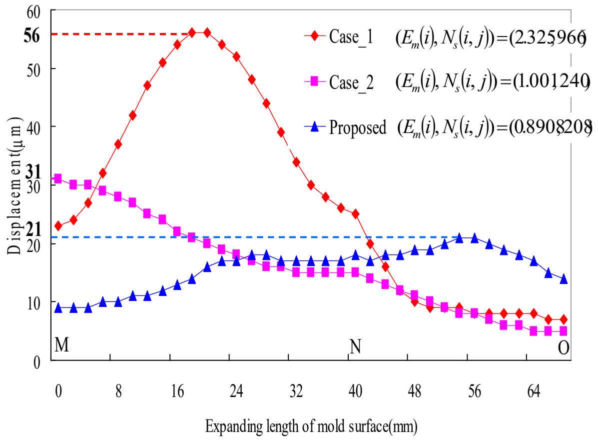


Fig. 20 Comparison of the deformation in cases_1 and 2 and the sample from the proposed optimization method

The authors compared the deformation distribution on the evaluation curve for the proposed cooling channel and cases_1 and 2. Fig. 20 shows the deformation distribution on the mold surface MNO. The vertical ordinate in the graph is the deformation; the horizontal ordinate is the expanding length of mold surface around the evaluated curve MNO. According to this result, the maximum mold surface deformation with the optimized cooling channel is 21*u*m whereas the maximum mold surface deformation of the case_1 is 56*u*m, and that of case_2 is 31*u*m. The proposed optimization of the cooling channel can decrease the deformation of the mold surface.

The authors compared the temperature distribution over cavity surface in the cases of the pipe cooling channel and the optimized cooling channel. Fig. 23 shows the temperature distribution on the cavity surface ABC. From these results, the optimized cooling channel lowers the cavity surface temperature compared with that of pipe cooling channel. On other hand, as shown in Fig. 24, which spend 10 seconds for cavity surface temperature of pipe cooling channel to reach 28.3℃, and only 6 seconds for cavity surface temperature of the optimized cooling channel to reach 27℃. It can be understand that optimized cooling channel not only can make cavity surface temperature cooling uniformity, but also short quite cycle time compare with pipe cooling channel.

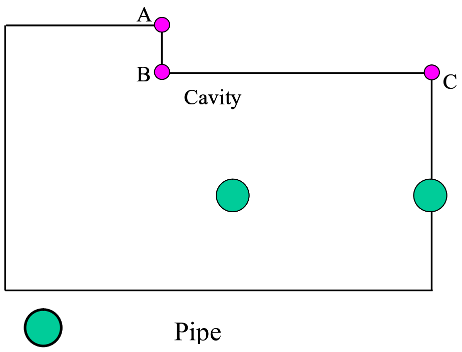


Fig. 21 Pipe shape of cooling channel

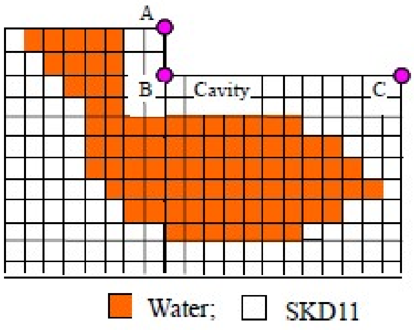


Fig. 22 Final shape of cooling channel

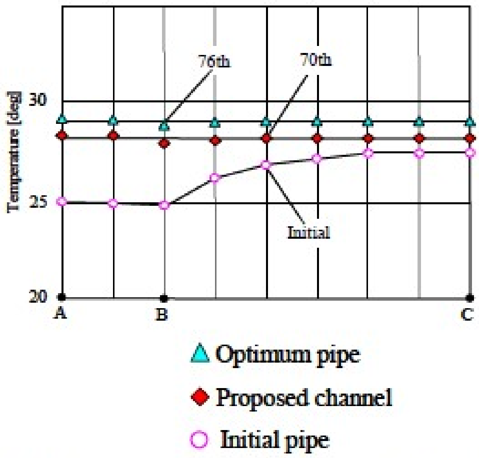


Fig. 23 Temperature distribution over cavity surface of pipe and final

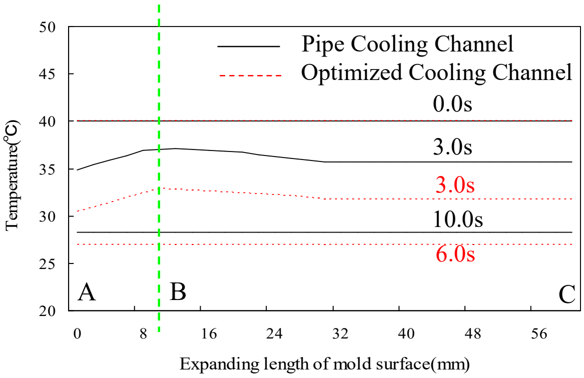


Fig. 24 Temperature distribution on product surface of pipe cooling channel and optimized cooling channel

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. Although it may not enough when the authors optimized an arbitrary shape cooling channel of 3 demission models by proposed optimization method. It should be received an optimization result based on the convergence condition by subdivided the meshes of model as soon as ensure the number of genes. Calculation time will be longer with the number increase of genes, which is our research in the future.

VI. CONCLUSION

In this study, an optimization approach for the cooling channel shape in a block laminated mold was performed. The evaluation function was proposed based on unsteady state heat transfer and linear static deformation. A genetic algorithm was used as the optimization method. By using the evaluation and automatic design method, the cooling and mold deformation effect of the cooling channel in the injection mold was examined through case studies based on numerical analysis. According to the numerical results, 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.

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.

ACKNOWLEDGEMENT

This work is partly supported by KAKENHI (21560128).

REFERENCES

[1] Park, S. J., and Kwon, T. H. (1998). Thermal and Design Sensitivity Analyses for Cooling system of Injection Mold, Part 1: Thermal Analysis, Journal of Manufacturing Science and Engineering, 120, 5, 287-295.

[2] Sachs, E., Wylonis, E., Allen, S., Cima, M., and Guo, H. (2000). Production of Injection Molding Tooling with Conformal Cooling Channels Using the Three Dimensional Printing Process, Polymer Engineering and Science, 40, 5, 1232-1247.

[3] Koresawa, H., Sakashita, M., and Suzuki, H. (2001). Automatic design for parting line on injection mold. ANTEC, 937-941.

[4] Matsumoto, T., Tanaka, M., and Yamamura, A. (2000). Optimization of cooling channels of injection mold using GA and BEM, Journal of the Japan Society of Mechanical Engineers (A), 66, 641, 14-19.

[5] YAO, D. (2002). Development of Rapid Heating and Cooling Systems for Injection Molding Applications, polymer engineering and science, 42, 12 , 2471-2481.

[6] Matsumori, T., and Yamazaki, K. (2008). A study on Optimal Layout Design of Cooling Channel for Plastic Injection Molding Die, Journal of the Japan Society of Mechanical Engineers (C), 74, 3, 239-246.

[7] Yoneyama, T., Kagawa, H., Ito, T., Iwane, A., Kuramoto, Y., Nishimoto, K., and Yan, C. (2001). Effective Cooling and Accuracy Improvement in Injection Molding Using a Metal Mold with Cooling Channels Composed by Laser Sintering (1st Report): Fabrication of a Mold with Cooling Channel and Verification of a Basic Effect, Journal of the Japan Society for Precision Engineers, 67, 12, 1991-1995.

[8] Takafuji, A., Tamura, K., and Yokoyama, A. (2003). Optimum Design Method for Injection Molding Die by Genetic Algorithm, Seikei-Kakou, 15, 5, 357-362.

[9] GALANTE, M. (1996). Genetic Algorithms as an Approach to Optimize Real-world Trusses, International Journal for Numerical Methods in Engineering, 39, 361-382.

[10] Chen, T. Y., and Chen, C. J. (1997). Improvements of Simple Genetic Algorithm in Structural Design, International Journal for Numerical Methods in Engineering, 40, 1323-1334.

[11] Jensen, E., Topological Structural Design Using Genetic Algorithms, Doctor of Philosophy Thesis, Purdue University, November.