A STUDY ON GATE LOCATION OPTIMIZATION FOR PLASTIC INJECTION MOLDING TO IMPROVE PRODUCT QUALITY

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ABSTRACT

Gate location is the position where melt plastic flow was directly injected into the mold cavity for the product formation purpose. The gate location has strong effects on the filling flow and product quality because it is related to the filling flow orientation of the melting material flow in the mold cavity. Defects can be appeared on the product due to selecting the gate location such as: weld lines, wrapage, and shrinkage. Therefore, gate location is one of the most criteria to control the quality of the injected product. This paper demonstrates a numerical simulation experiment method to find an optimal gate location for the plastic injection molding to reduce defects and enhance the product quality. The defects on the product were analysed and minimized by using a numerical simulation tool. With the computerized simulation method, the optimal gate location is selected, the product defects are easy to detect and control, and the plastic product quality is enhanced.

NGHIÊN CỨU TỐI ƯU HÓA VỊ TRÍ CỔNG PHUN CHO KHUÔN ÉP NHỰA ĐỂ NÂNG CAO CHẤT LƯỢNG SẢN PHẨM

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TỪ KHÓA

Cổng phun
Sản phẩm nhựa
Khuôn ép nhựa
Tối ưu hóa
Mô phỏng số

TÓM TẮT

Cổng phun là vị trí dòng nhựa nóng chảy được phun trực tiếp vào lòng khuôn để tạo hình sản phẩm. Vị trí cổng phun có ảnh hưởng lớn đến khả năng điền đầy vật liệu trong lòng khuôn và chất lượng sản phẩm vì có liên quan việc đến định hướng dòng chảy trong lòng khuôn. Các khuyết tật không mong muốn có thể tạo ra trong quá trình ép phun liên quan đến việc lựa chọn vị trí cổng phun như: đường hàn, cong vênh, và hiện tượng co ngót. Do đó vị trí cổng phun là một trong những tiêu chí quan trọng nhất để điều khiển chất lượng của sản phẩm ép phun. Bài báo trình bày một phương pháp mô phỏng số hóa để tìm ra vị trí cổng phun tối ưu trong thiết kế khuôn ép nhựa để làm giảm các khuyết tật và nâng cao chất lượng sản phẩm trong quá trình ép phun các sản phẩm nhựa. Các khuyết tật trên sản phẩm nhựa được phân tích và giảm thiểu thông qua việc sử dụng công cụ mô phỏng số có sự trợ giúp của máy tính. Thông qua phương pháp này, vị trí cổng phun tối ưu được lựa chọn, các khuyết tật trên sản phẩm dễ dàng được phát hiện và kiểm soát, chất lượng sản phẩm ép phun được cải thiện.

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1. Introduction

Plastic products are generally produced by an injection molding process. In the production, the melting plastic material is injected into the mold cavity to form the required parts. There are many injection molding parameters affected on the quality of plastics product such as machine control parameters, gate location, runner and cavity structures, and cooling structure. The gate location is one of the most important factors because it directly affects the molten plastic flow into the cavity. That influences the quality of plastic product, such as the appearance or disappearance of the weld lines, shrinkage, and warpage in the product. Therefore, it is necessary to use proper gate type and gate location in the design of the injection mold. The optimal gate location is the position located gate with reducing or losing of the weld lines, shrinkage, and warpage in the final part. There are many researches on the gate location to find a best location in the mold design process such as using an optimal method of the design constraint control with an integrated tool of the computer aided design (CAD) and computer aided engineering (CAE) software to select the optimal gate location to satisfy requirement of the fill pattern and warpage [1], using a integrated method of simulated annealing and hill climbing to get the optimal gate location [2], using an automatical predict method to find the optimal gate location [3], using a genetic algorithm to find the optimal gate location in the liquid composite molding process to get the minimization of the filling pressere to achieve advantage of the uniform filling pattern [4], using a multi-objective evolutionary algorithm to optimize the gate location in liquid composite molding to minimize the filling time and prevent the resin lost [5], a solution of using modified hill-climbing algorithm to predict the optimal gate location for complicated parts [6], using a genetic algorithm to optimize gate location to minimize fill time and dry spot formation in the resin transfer molding process [7], using a branch and bound search method to find the optimal injection gate location to minimize the dry spot size and fill time [8], using an empirical search method to optimize gate location in injection molding [9] .

There are researches on the influence of gate location and injection molding parameters on the injection molding process such as using a 3D method to demonstrate the effect of gate location on the cooling of plastics material in injection molding [10], finding efficient frontier of process parameters to apply for injection molding of a digital camera[11], using a genetic algorithm method to minimize the defect of weld line in injection molding product [12], developing a neutral network for surface defect prediction of polypropylene product by injection molding [13], using an analysis of short shot possibility in the plastic injection molding [14], introducing a new gate system geometry in injection molding to reduce the defects of plastic parts [15].

This paper demonstrates a numerical simulation method to find an optimal gate location for the plastic injection moulding to reduce defects and enhance the product quality. The defects on the product were analyzed and minimized by using a numerical simulation tool. By using the computerized simulation method, an optimal gate location is selected, the product defects are easy to detect and control, and the plastic product quality is enhanced.

2. Governing equations and simulation preparation

Governing equations

The melt plastic flow is deliberated incompressible during flow into the mold cavity. In comparison with viscous force, gravitation and inertia are neglected in the calculation process [16]. So that, governing equation including: the momentum equations, the continuity equation, and the energy equation.

The momentum equations as below:

$$\frac{\partial}{\partial x}\left(2\eta\frac{\partial u}{\partial x}\right)+\frac{\partial}{\partial y}\left[\eta\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right]+\frac{\partial}{\partial z}\left[\eta\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]-\frac{\partial(P)}{\partial x}=0$$

$$\frac{\partial}{\partial x}\left[\eta\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)\right]+\frac{\partial}{\partial y}\left(2\eta\frac{\partial v}{\partial y}\right)+\frac{\partial}{\partial z}\left[\eta\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)\right]-\frac{\partial(P)}{\partial y}=0$$

$$\frac{\partial}{\partial x}\left[\eta\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)\right]+\frac{\partial}{\partial y}\left[\eta\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)\right]+\frac{\partial}{\partial z}\left(2\eta\frac{\partial w}{\partial z}\right)-\frac{\partial(P)}{\partial z}=0 \quad (1)$$

Where: x, y, and z are the three-dimension coordinates; u, v, and w are velocity components corresponding to x, y, and z directions, respectively.

The continuity equation as below:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (2)$$

The energy equation as below:

$$\rho C_p\frac{\partial T}{\partial t}=\rho C_p\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}\right)+\frac{\partial}{\partial x}\left(K\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(K\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(K\frac{\partial T}{\partial z}\right)+\eta\dot{\gamma}^2 \quad (3)$$

Where: Pis the pressure; Tis the temperature; ρ is the density, $\dot{\gamma}$ is shear rate, and η is the viscosity.

Simulation preparation

Figure 1 shows the design of the model with the overall dimensions in the millimetre unit. The model has a thickness of 3.2mm. The model design process was done with the help of Solidworks software. The model material is high density polyethylene (HDPE) with the properties of tensile modulus, drying temperature, drying time, melting temperature, specific gravity, vicat point, shrinkage, and processing temperature as shown in Table 1 [17]. The analysis processes were done in Moldflow software (a computer-aided engineering software). Figure 2 shows the computer-aided engineering model used for the simulation of filling process. The model constructs of the 3D mesh model with the element type of tetrahedra elements. The analyses were conducted by using the melt temperature of 235°C, and the mold temperature of 35°C.

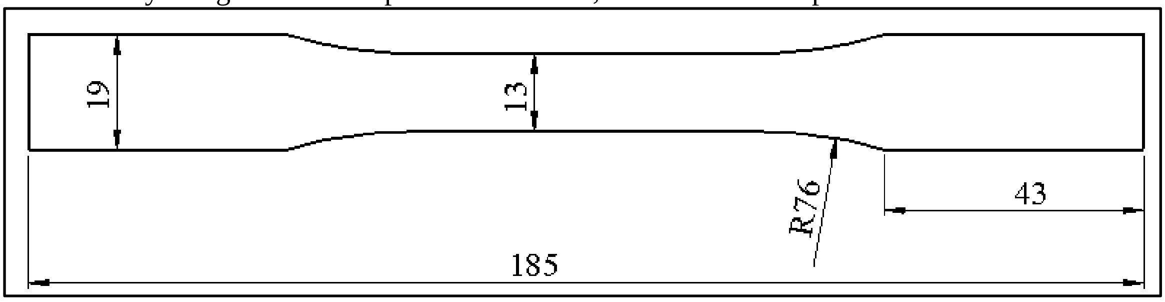

Figure 1. *The model with overall dimensions for the test.*

Table 1. *The material properties of high density polyethylene*

Properties	**Value (Unit)**
Specific gravity	0.94 (g/cm^3)
Drying temperature	65.6 (°C)
Drying time	3 (h)
Tensile modulus	0.2 (Mpsi)
Melting temperature	125-135 (°C)
Vicat point	107.2 (°C)
Shrinkage	1.1-1.4 (%)
Process temperature	204.4-279.4 (°C)

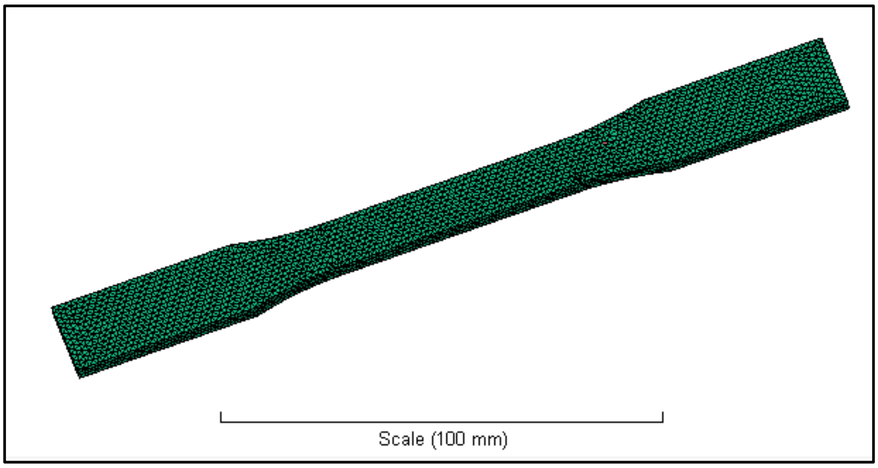

Figure 2.*The three dimensional mesh model*

3. Results and discussion

To get the optimal gate location on the molding part, the study based on simulation was conducted with different positions on the part. To reduce effect of the gate location error on the big surfaces of the model, locations were planned at the small sides with the small faces of the model. To show the best affect of gate location in the comparison, the gates are the same shape, dimensions, and using one gate for each study case. The simulation processes were done in the conditions of fill-pack-warp in the study. Figure 3 shows the filling process of the different cases in the test. Figure 3(a) shows the case 1 of analysis with the gate location at Gate 1. Figure 3(b) shows the filling result of the case 2 with the gate location at position Gate 2. Figure 3(c) shows the filling consequence of the case 3 with the gate location at position Gate 3. Figure 3(d) shows the filling result of the case 4 with the gate location at position Gate 4. The analysis results show that the fill times are 1.962s, 1.506s, 1.732, and 1.966 correspondings to the gate locations of case 1, case 2, case 3, and case 4, respectively. Table 2 shows the results of the analysis processes with the pressure, wrapage, volume shrinkage, and longest weld line of the case 1, case 2, case 3, and case 4, respectively. The minimal wrapage is 2.224mm in the gate location of the case 4. The minimal volume shrinkage is 21.72% in the gate location of case 4. The minimal weld line is 15.7mm in the gate location of case 4. The maximal wrapage is 2.252mm the gate location of the case 1. The maximal volume shrinkage is 21.78% in the gate location of case 2. The maximal weld line is 18.8mm in the gate location of case 1. The minimal fill time is 1.506s in the gate location of the case 2. The maximal fill time is 1.966s in the gate location of the case 4. The minimal pressure is 8.103MPa in the gate location of the case 2. The minimal pressure is 8.103MPa in the gate location of the case 4. The fill time and pressure are resonable in the four case. The product quality belongs to the case 4 with the minimum values of volume shrinkage, wrapage, and weld line. The products with high values of the shrinkage, wrapage, and weld line will appear more defects than the products with lower shrinkage, wrapage, and weld line. The analysis sesults reveal that the optimal gate location was found at the position of the case 4 in the study. The optimal gate location is the location that it is easy to feed the melting plastic material into the mold cavity than other cases. The optimal gate location also approciate with theory of fluid flow in the mold cavity [16].

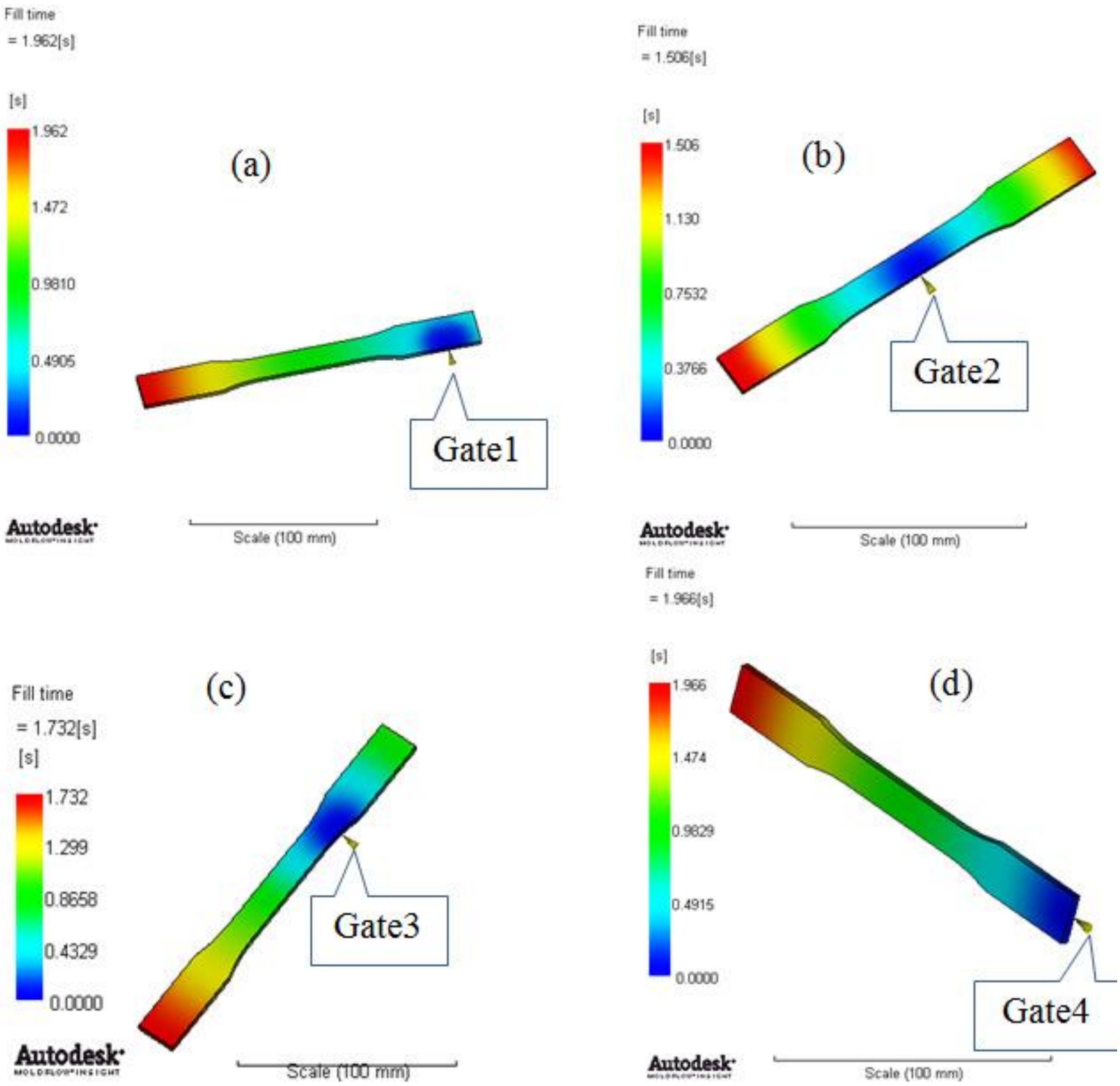

Figure 3. *The filling process of the analysis cases in the test*

Table 2. *The results of the analysis process*

Study case	Fill time (s)	Pressure (MPa)	Total warpage (mm)	Volume shrinkage (%)	Weld line (mm)
Case 1	1.962	13.37	2.252	21.83	18.8
Case 2	1.506	8.103	2.392	21.87	16.3
Case 3	1.732	10.08	2.240	21.75	16.2
Case 4	1.966	14.79	2.224	21.72	15.7

4. Conclusion

The numerical simulation method was successfully applied in this study to solve the problem of optimization of the gate location. The analysis processes were conducted at the special position on the part. The material is high density polyethylene used in the study. The product quality will be improved as the factors of wrapage, shrinkage, and weld line are reduced to the minimum in the molding process. The optimal gate location is easy to flow by melting plastic material. The result is appropriate to the theory of fluid flow. This method can be used to optimize the gate located in the mold design to improve the product quality in the research and practical application.

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