Experimental Investigation into Suitable Process Conditions for Plastic Injection Molding of Thin-Sheet Parts

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Abstract

This study performs an experimental investigation into the effects of the process parameters on the surface quality of injection molded thin-sheet thermoplastic components. The investigations focus specifically on the shape, number and position of the mold gates, the injection pressure and the injection rate. It can be seen that the gravity force entering point improved filling of the cavity for the same forming time and injection pressure. Moreover, it shows the same injection pressure and packing time, the taper-shape gate yields a better surface appearance than the sheet-shape gate. The experimental results provide a useful source of reference in suitable the process conditions for the injection molding of thin-sheet plastic components.

Keywords: plastic injection molding, thin sheet, surface quality

1. Introduction

Injection molding has many practical advantages, including high-productivity, good repeatability, close tolerances, geometric flexibility, the potential for full automation, the need for minimal post-injection processing, and so on. As a result, injection forming is one of the most commonly applied methods for manufacturing plastic parts. However, as with all molding methods, the aesthetics of the ejected components are significantly dependent on the process parameters applied. This is particularly true for thin-shell plastic components, in which shrinkage and warpage are a particular concern. As a result, the problem of optimizing the injection molding process parameters has attracted significant attention in the literature.

Yang and Yokoi [1] used a dynamic visualization technique to examine the flow behavior of two core materials (high-viscosity resin GPPS685 and low-viscosity resin GPPS679) in the fork portion of plastic sandwich injection molding. The results showed that for both materials, the processing conditions have almost no effect on the flow pattern of the skin material, but have a significant effect on that of the core material. Chiang [2] proposed a numerical method comprising an orthogonal array, grey relational analysis and fuzzy logic for optimizing the process conditions for thin-sheet injection–molded components. The validity of the proposed method was demonstrated experimentally using a PC / ABS cell phone shell for illustration purposes. Wang et al. [3] constructed a numerical model to analyze the heat transfer during the heating and cooling phases of the rapid heat cycle molding (RHCM) process. The model was then used to optimize the design of an RHCM mold with hot-fluid heating. Altan [4] proposed a method based on the Taguchi experimental design approach and the analysis of variance (ANOVA) technique to optimize the process parameters for plastic injection-molded components in such a way as to minimize the shrinkage of the ejected parts. Kurt et al. [5] performed an experimental investigation into the effects of the cavity pressure and mold surface temperature on the quality of the final product in plastic

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injection molding. Oktem et al. [6] used three-level L_{27} and L_9 Taguchi orthogonal design to determine the process parameters which minimized the warpage and shrinkage of injection-molded thin-shell plastic components for orthose parts. The validity of the optimization results was demonstrated by means of a series of MoldFlow simulations.

Deng et al. [7] presented a hybrid optimization scheme based on a mode-pursuing sampling (MPS) method and a Genetic Algorithm (GA) for minimizing the warpage of injection-molded plastic parts. The proposed approach was demonstrated experimentally by manufacturing a plastic food tray part; with the injection time, mold temperature, melt temperature and packing pressure taken as the principal design variables. Seow and Lam [8] proposed an algorithm for automatically adjusting the thicknesses of the various sections in a mold so as to balance the mold cavity during the filling phase. Song et al. [9] used the Taguchi orthogonal design method and numerical simulations to investigate the effects of the injection rate, injection pressure, melt temperature, metering size and part thickness on the quality of ultra-thin-wall injection-molded plastic parts. Shelesh-Nezhad and Siores [10] presented an artificial intelligence (AI) system based on Rule-Based and Case-Based Reasoning subsystems for determining the optimal process parameters in the plastic injection molding operation. Tsoukalas [11] performed multivariate linear regression (MVLR) and GA analyses to investigate the effects of the slow shot velocity, fast shot set point, gate velocity, pressure rise time, and intensification pressure on the porosity formation in commercial thin-walled die-cast aluminum alloy parts.

Griffiths et al. [12] performed finite element analyses to investigate the effects of four process parameters (i.e., the melt temperature, the mold temperature, the injection speed and the part thickness) on the finished quality of micro-injection-molded components. Kamaruddin et al. [13] investigated into the application of Taguchi optimization technique to determine the optimum condition of process parameters used in injection of the plastic tray using PP and LDPE blends as materials to achieve maximum flexure strength. The residual stress accumulated during the post-filling and colling stages will lead to warpage of parts after demolding. Zhou and Li [14] used the finite difference method to solved the deduced stress integral equations for injection moulding post-filling. Shi et al. [15] proposed a sequential optimization design method based on artificial neural network (ANN) surrogate model with parametric sampling evaluation (PSE) strategy.The present study performs an experimental investigation into the effects of the process parameters on the surface appearance of injection molded thin-sheet thermoplastic components. The investigations focus specifically on the shape, position and number of the mold gates, the injection pressure and the injection rate.

2. Experimental Method

The mold and die used Master CAM drawing and design completed at first, moreover that inspected to combined with the Solidwork interference problems. The standard dimensions shown in figure 1.

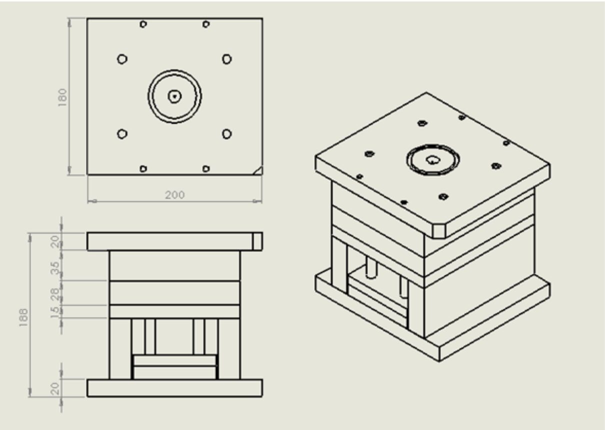


Fig. 1 Standard mold three dimensions diagram

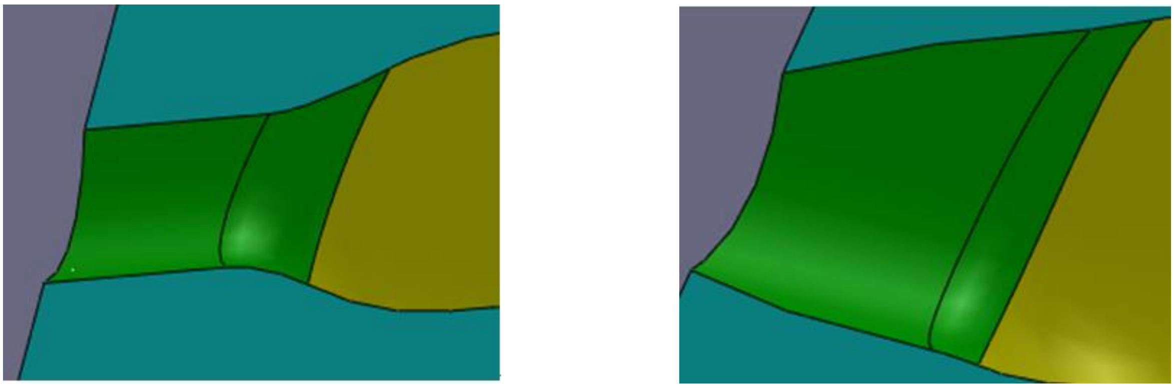
The process parameters considered in the present study can be summarized as follows:

(1) Shape of entry gate: sheet (Fig. 2(a)) or taper (Fig. 2(b)).

(2) Position / number of entry gates: top of cavity / one hole or side of cavity / two holes (Figs. 3(a) and (b)).

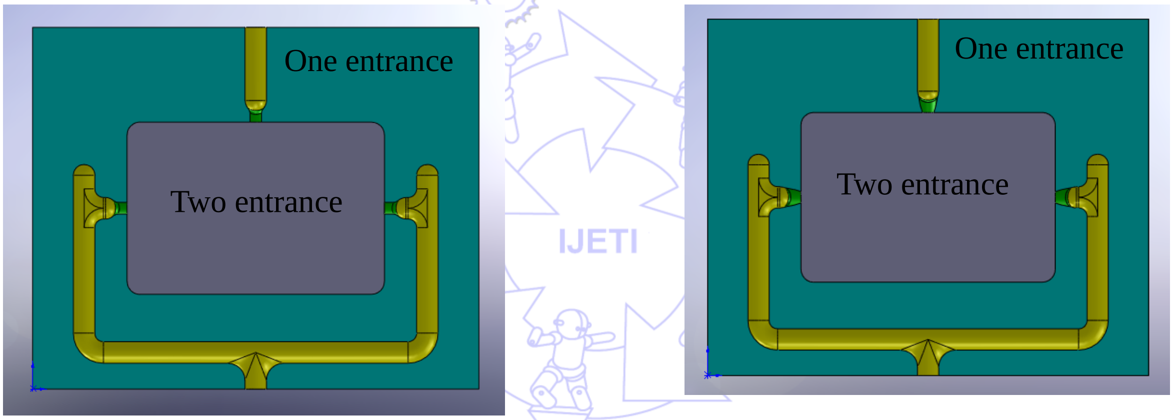
(3) Injection pressure: 30 ~ 90 kg/cm^2.

(4) Injection rate: 30 ~ 100 cm/sec.



(a) Sheet-shape gate (b) Aper-shape gate

Fig. 2 Shape of entry gate



(a) Sheet-shape gates (b) Taper-shape gates

Fig. 3 Position / number of entry gates

This study uses a PVC material. Note that the packing time is equal to 25 seconds in every case. Moreover, the melt temperature and mold surface temperature are 70°C and 40°C, respectively.

The injection-molding experiments were performed using a CTF120 plastic injection-molding machine with the standard mold and die shown. The resin was used in the experiments. The core was fabricated of steel SKD61 and was machined using an electrical discharge machining (EDM) technique. The principal dimensions of the mold/ die are shown in Fig. 4. As shown in Fig. 5, the core comprised two sides (side A and side B). Each side incorporated two flow routes, namely an upper flow route, in which the melt entered the cavity from a centrally-placed upper gate, and a lower flow route, in which the melt entered the mold from beneath the cavity and was then injected into the cavity by means of two horizontal gates positioned on either side of the cavity at the horizontal centerline. Side A was patterned with sheet-shape gates, while Side B was patterned with taper-shape gates. Figure 6 (a) presents a photograph showing the finished core. Figure 6(b) shows a photograph of the lower mold and die.

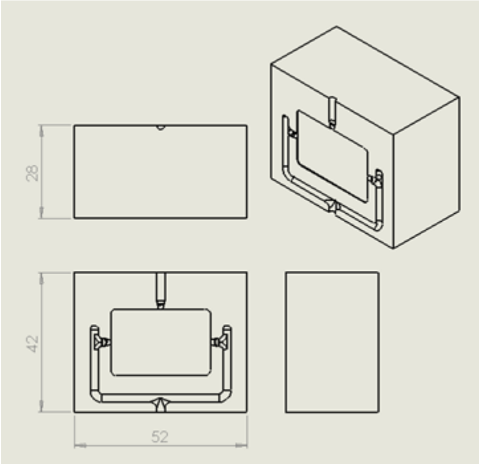


Fig. 4 Main dimensions of mold and die

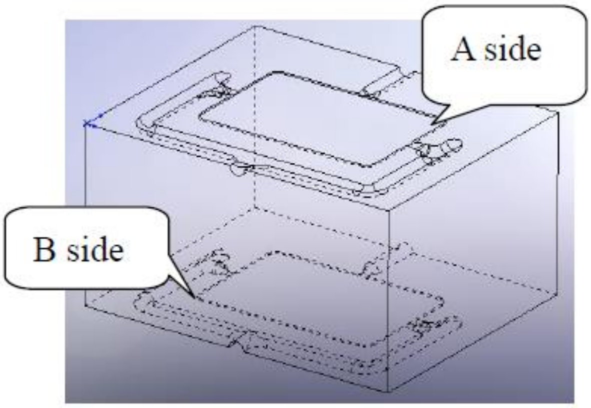
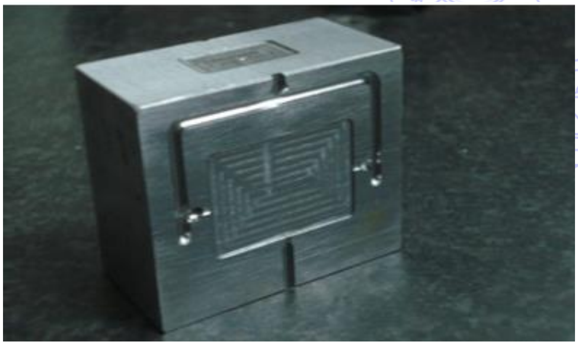


Fig. 5 Side A and Side B of die



(a) Core of mold and die

(b) lower mold and die

Fig. 6 Photograph of core /lower of mold and die

Table 1 Summary of plastic injection-molding parameters

Case	Pressure (kg/cm^2)	Velocity (cm/sec)	Position of injection mold (mm)
First stage	First stage pressure	First stage velocity	23
Second stage	Second stage pressure	Second stage velocity	10
Maintain pressure time (sec)	25	25	1.7

Table 2 Process parameters for single sheet-shape gate flow route

Numbers	First stage pressure	Second stage pressure	First stage velocity	Second stage velocity	Annotations
A-1-1	30	30	30	30	
A-1-2	35	35	35	35	
A-1-3	40	40	40	40	
A-1-4	45	45	45	45	
A-1-5	50	50	50	50	
A-1-6	55	55	55	55	
A-1-7	60	60	60	60	Fully forming, comparison entrance point numbers of sample
A-1-8	35	35	30	30	Beginning check-out pressure
A-1-9	40	40	30	30	
A-1-10	50	50	30	30	
A-1-11	60	60	30	30	
A-1-12	70	70	30	30	
A-1-13	80	80	30	30	
A-1-14	30	30	40	40	Beginning check-out velocity
A-1-15	30	30	50	50	
A-1-16	30	30	60	60	
A-1-17	30	30	70	70	
A-1-18	30	30	80	80	
A-1-19	30	30	90	90	

Table 1 summarizes the plastic injection forming parameters considered in the present study. Tables 2 and 3 indicate the detailed process parameters for the flow routes comprising the single and double sheet-shape gates, respectively. Similarly, Tables 4 and 5 indicate the detailed process parameters for the flow routes comprising the single and double taper-sheet gates, respectively.

Table 3 Process parameters for double sheet-shape gate flow route

Numbers	First stage pressure	Second stage pressure	First stage velocity	Second stage velocity	Annotations
A-2-1	30	30	30	30	
A-2-2	40	40	40	40	Comparison entrance point style of sample
A-2-3	50	50	50	50	Fully forming, comparison entrance point numbers and gravity effect of sample
A-2-4	40	40	30	30	Beginning check-out pressure
A-2-5	50	50	30	30	
A-2-6	60	60	30	30	
A-2-7	70	70	30	30	
A-2-8	80	80	30	30	
A-2-9	30	30	40	40	Beginning check-out velocity
A-2-10	30	30	50	50	
A-2-11	30	30	60	60	
A-2-12	30	30	70	70	
A-2-13	30	30	80	80	
A-2-14	30	30	90	90	Comparison gravity effect of sample
A-2-15	30	30	100	100	

Table 4 Process parameters for single taper-shape gate flow route

Numbers	First stage pressure	Second stage pressure	First stage velocity	Second stage velocity	Annotations
B-1-1	30	30	30	30	
B-1-2	40	40	40	40	
B-1-3	50	50	50	50	
B-1-4	60	60	60	60	Fully forming
B-1-5	40	40	30	30	Beginning check-out pressure
B-1-6	50	50	30	30	
B-1-7	60	60	30	30	
B-1-8	70	70	30	30	
B-1-9	80	80	30	30	
B-1-10	30	30	40	40	Beginning check-out velocity
B-1-11	30	30	50	50	
B-1-12	30	30	60	60	
B-1-13	30	30	70	70	
B-1-14	30	30	80	80	
B-1-15	30	30	90	90	
B-1-16	30	30	100	100	

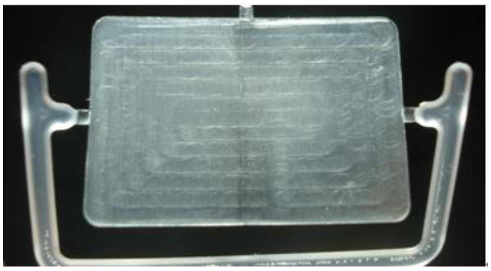
Table 5 Process parameters for double taper-shape gate flow route

Numbers	First stage pressure	Second stage pressure	First stage velocity	Second stage velocity	Annotations
B-2-1	30	30	30	30	
B-2-2	40	40	40	40	Comparison entrance point style of sample
B-2-3	50	50	50	50	Fully forming, comparison gravity effect of sample
B-2-4	40	40	30	30	Beginning check-out pressure
B-2-5	50	50	30	30	
B-2-6	60	60	30	30	
B-2-7	70	70	30	30	
B-2-8	80	80	30	30	
B-2-9	90	90	30	30	
B-2-10	30	30	40	40	Beginning check-out velocity
B-2-11	30	30	50	50	
B-2-12	30	30	60	60	
B-2-13	30	30	70	70	
B-2-14	30	30	80	80	
B-2-15	30	30	90	90	Comparison gravity effect of sample
B-2-16	30	30	100	100	

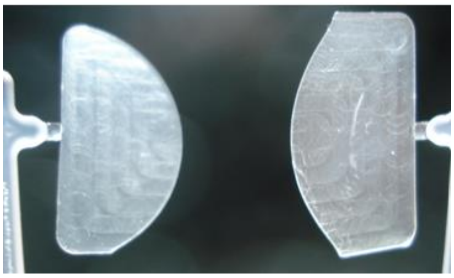
3. Analysis of Experimental Data

In the present study, the optimal process conditions were identified via a simple qualitative comparison of the thin-sheet components formed using the parameter settings shown in Tables 2 ~ 5. Figures 6(a) ~ 6(c) show the thin-sheet components formed using parameter settings A-1-7, A-2-3 and A-2-2, respectively. Figure 6(d) shows the thin-sheet component formed using parameter settings B-2-2. It can be seen the filling is optimal forming and surface roughness for Figure 6(b) and (d). Finally, Fig. 7(a)~(d) show the thin-sheet components formed using parameter settings A-2-14, B-2-15, A-2-3 and B-2-3, respectively. I can be seen that Fig. 7(c) and (d) have optimal filling results for thin-sheet forming.

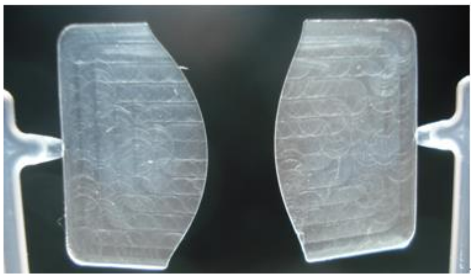
(a) A-1-7



(b) A-2-3

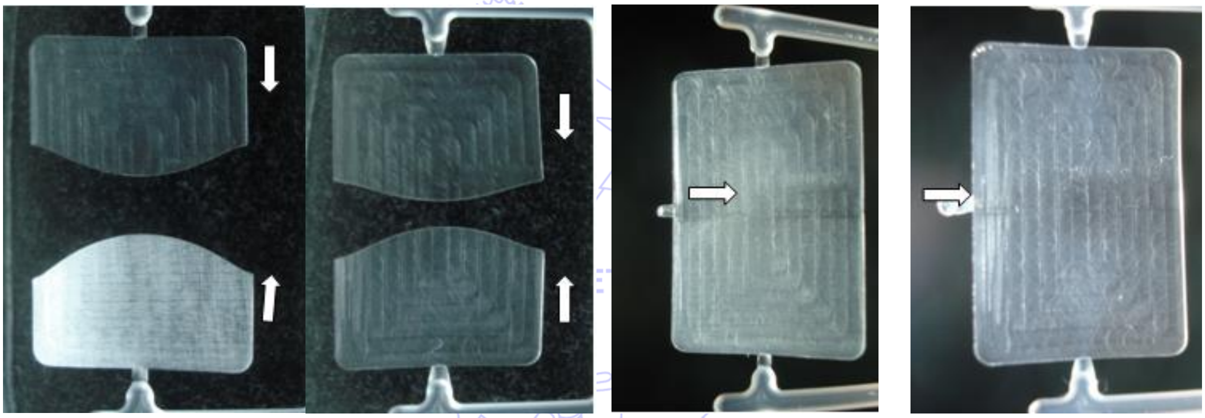


(c) A-2-2



(d) B-2-2

Fig. 6 Photograph of thin-sheet plastic component (I)



(a) A-2-14 (b) B-2-15 (c) A-2-3 (d) B-2-3

Fig. 7 Photographs of thin-sheet plastic components (II)

An observation of Figs. 6 ~ 7 supports the following conclusions:

(1) Number of gates: a comparison of Fig. 6(a) (A-1-7, single sheet-shape gate) and Fig. 6(b) (A-2-3, two sheet-shape gates) show that an improved aesthetic appearance is obtained using two gates given the same injection pressure and packing time.

(2) Shape of gates: a comparison of Fig. 6(c) (A-2-2, two sheet-shape gates) and Fig. 6(d) (B-2-2, two taper-shape gates) show that the taper-shape entering point yields an improved surface finish appearance given the same injection pressure and packing time.

(3) Position of gates: a comparison of Fig. 7 (A-2-14 and B-2-15) shows that the gravity force entering point improved filling of the cavity for the same forming time and injection pressure. From the number A-2-3 and number B-2-3 samples, the welding line is in the lower position of the sample, so that the gravity force influences thin-sheet plastic injection forming.

4. Confirmation of Simulation Analysis

In this paper, alternative simulation and experiment for under the mold cavity configuration diagram shown in Figure 8. The figure has 8 group cavity shape and configuration position. This paper used number to indicate the shape of each cavity. The first letter indicates the gate form, “A” represents semicircular gate, “B” represents taper gate, “C” represents rectangular gate. Moreover, the second letter indicates the runner profile, “a” represents is semicircular runner, “b” represents trapezoidal runner. Finally, the third number indicates gate number. Figure 9 shows to complete the processing die cavity. Fig. 10 shows filling ratio and Fig. 11 shows warpage phenomenon. Finally, Fig. 12 shows plastic injection flow velocity diagram. Because the mold design has symmetrical position and flownet slip smoothly, it can be seen that the simulation results are sound for plastic injection forming of thin-sheet parts. The simulative and experimental results provide a useful source of reference for industry.

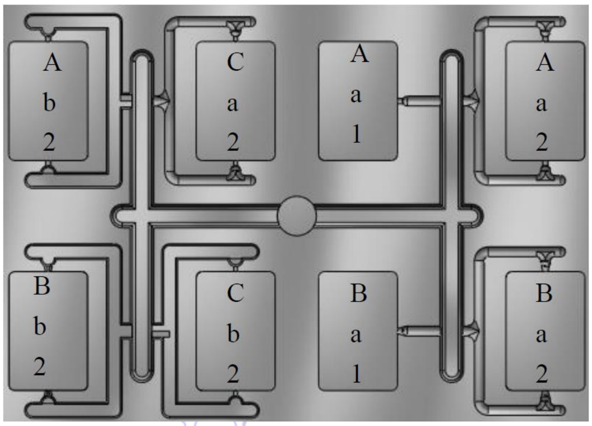


Fig. 8 The die cavity configuration


Fig. 9 Complete the processing die cavity

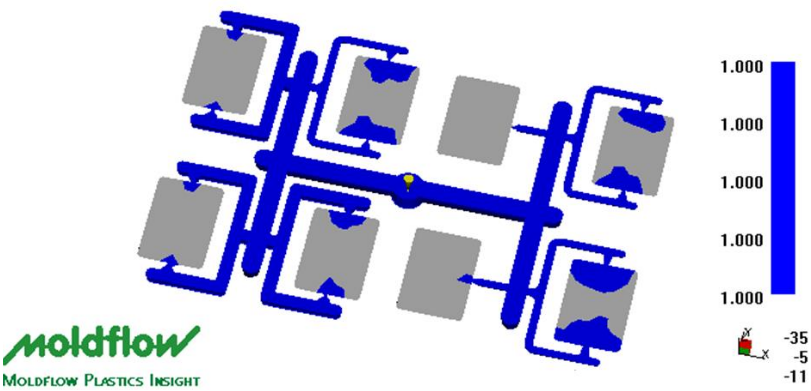


Fig. 10 Schematic of filling ratio

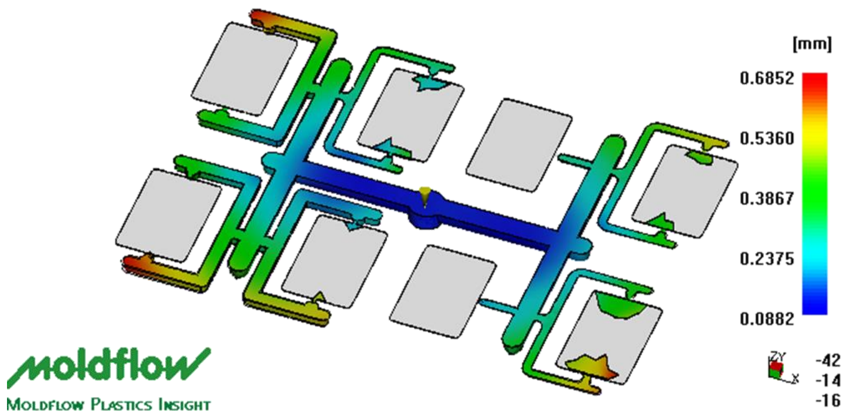


Fig. 11 Schematic of warpage phenomenon

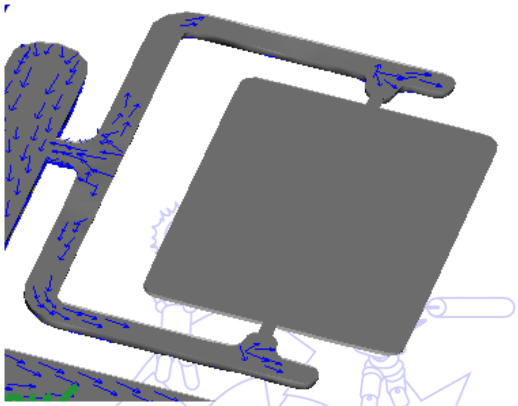


Fig. 12 Plastic injection flow velocity diagram

5. Conclusions

This study has performed an experimental investigation into the effects of the injection-molding process parameters on the surface appearance of thin-film components. The investigations have considered five specific parameters, namely the shape, number and position of the mold gates, the injection pressure and the injection rate. The major findings can be summarized as follows:

(1) Given the same injection pressure and packing time, the use of two sheet-shape gates located on either side of the cavity at the horizontal centerline yields, a better aesthetic appearance of the ejected component than that obtained using a single sheet-shape gate.

(2) Given the same injection pressure and packing time, the taper-shape gate yields a better surface appearance than the sheet-shape gate.

(3) The gravity force entering point improved filling of the cavity for the same forming time and injection pressure.

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