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Gate location design in injection molding of an automobile junction box with integral hinges

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Abstract

Polymers such as polypropylene or polyethylene offer a unique feature of producing an integral or living hinge for automobiles, which can flex over a million times without causing a failure. However, due to increased fluidity resistance at hinges during molding, several defects such as short shot or premature failure can occur with the improper selection of gate locations. In this paper, a design guideline was induced by investigating resin flow patterns depending on several gate positions obtained by numerical analyses of a simple strip with a hinge. The analyses of the simple strip part showed that the resin at the hinge did not flow until the other side of the strip was filled. Once the resin at the hinge did not flow for a long time enough to be solidified, defects such as short shots or hesitation marks formed. For a practical application of the design guideline determined, four gate systems for an automobile junction box were designed. It was found that the properly determined gate location leads to better resin flow and shorter hesitation time. Finally, injection molding tryouts using a mold that was designed by one of the proposed gate systems were conducted. The experiments showed that hinges without defects could be produced by using the designed gate location to assure the induced design guideline to be reasonable.

Keywords: Injection molding; Gate location design; Integral hinge; Junction box; Short shot; Hesitation effect

1. Introduction

Polymers such as polypropylene or polyethylene offer the unique feature of producing an integral or living hinge, which can flex over a million times without failure. With such an extraordinary characteristic, a geometric design of plastic parts, especially assembled parts with covers, can be improved by injecting the whole part as one piece [1,2]. Moreover, the time and cost required in mold making and assembly stages can be reduced remarkably. However, several defects such as short shot or premature hinge failure can occur due to increased fluidity resistance at the hinges. Particularly in the automobile industry, there has been a recent tendency to use resin containing talc or glass fiber in order to increase the strength and stiffness of parts. The additives decrease the fluidity of melted polymer, making it more difficult to fill the hinge area without forming defects. Moreover, as shown in Fig. 1, hinges of large automobile parts are often designed outside of the recommended geometry due to geometrical and functional concerns [3]. Therefore, it is necessary to improve flow balance in the injection molding of parts with hinges before actually making a mold. Currently, the process of trial and errors required at the tryout stage can be reduced through the CAE by simulating resin flow patterns and predicting possible defects that can be avoided by improving flow balance with the proper selection of gate locations [4–6].

In this paper, a design guideline was induced by investigating resin flow patterns obtained by numerical analyses for several different gate positions of a simple strip with a hinge. The analyses of the simple strip part showed that the resin at the hinge did not flow until the other side of the part was filled. Once the resin at the hinge did not flow for a long time enough to be solidified, short shots or hesitation marks formed due to the secondary resin flow over the partly solidified flow front occurred. Therefore, a design

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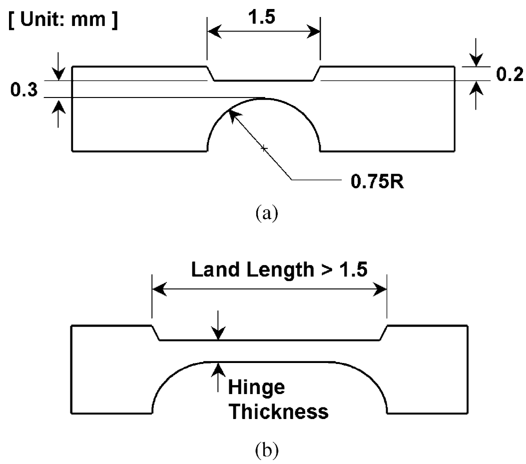

Fig. 1. The integral hinge with (a) the recommended geometry and (b) the increased land length [3].

guideline to properly locate gate positions to minimize flow hesitation at hinge areas will be useful to avoid formation of defects. As a practical application of the guideline determined, four gate systems for an automobile junction box cover were designed. Finally, injection molding tryouts using a mold that was designed by one of the proposed gate systems were conducted using polypropylene that contained 20% talc (LUPOL HI-5205).

2. Resin flow patterns of a strip with a hinge

In order to investigate resin flow patterns depending on gate location, numerical analyses using a commercial CAE code, MOLDFLOW [7], were conducted. As shown in Fig. 2, land length and thickness of the hinge were 5.0 and 0.5 mm, respectively and three gate locations were considered. The gate of Case 1 was positioned at the center of the left region of the hinge, and then, it was moved to the right by 20 mm for Case 2 and 40 mm for Case 3. The material properties, which are extracted from MOLDFLOW material database, are shown in Table 1. The temperature of melted polymer and mold were set to be 220 and 55 °C, respectively. The injection time was set to fill 95 % of the mold in 1.5 s. Once 95% volume of the cavity was filled, change-over to pressure control began so that the injection speed decreased to zero.

Fig. 2. Geometry of a strip part (mm) with a hinge and gate locations used in CAE analyses.

Table 1
Material properties of LUPOL HI-5205

Density (g/cm^3)	0.87732
Specific heat (J/kg °C)	2447
Thermal conductivity (W/m °C)	0.15
Transition temperature (°C)	130

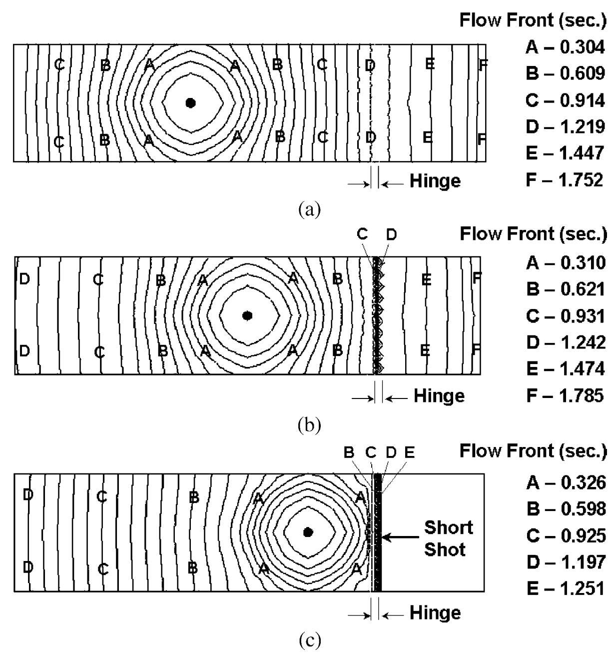

Fig. 3. Predicted flow front for each gate location: (a) Case 1, (b) Case 2 and (c) Case 3.

The flow fronts obtained by numerical analyses are shown in Fig. 3. As shown in Fig. 3(a), the filling of the hinge area of Case 1 was completed successfully. Fig. 3(b), however, shows that one of the flow fronts that had reached the hinge area did not advance until the other side of the part was filled. This phenomenon is called the 'hesitation effect', which occurs due to the different pressure gradient of each flow front. In general, the temperature of the flow front decreases rapidly if melted polymer does not flow into the mold. Fig. 3(c), however, shows that melted polymer that had reached the hinge at about 0.6 s did not flow until the other side of the part filled at 1.2 s. Finally, short shot occurred since the flow front of Case 3 was solidified at the hinge due to long hesitation time.

For each case, the minimum value of the flow front temperature at the hinge was summarized in Table 2. It can be

Table 2
The minimum value of the flow front temperature at the hinge for each case

Cases	Flow front temperature at hinge (°C)	Remarks
1	219.6	–
2	154.6	–
3	130.0	Short shot

seen that the flow front temperature at the hinge of Case 2 decreased to 154.6 °C while that of Case 1 was 219.6 °C. Although the flow front at the hinge of Case 2 became colder during the hesitation, short shot did not occur in these two cases since the minimum value of the flow front temperature was higher than the transition temperature of the resin, which was 130 °C as shown in Table 1.

In general, the most intuitive remedies for removing such short shot are either moving the location of a gate or creating a new one near the unfilled region where short shot occurs during the tryout stage. In the molding case of parts with a uniform thickness, these kinds of modifications could be effective since larger injection pressure could be delivered. If the part had large variation of thickness and short shot occurred in the thin region, however, it would be more difficult to fill such areas due to the increased hesitation time. Therefore, a guideline for determining gate location design for a part with hinges can be induced by investigating the previous simulation results of the strip part such that gate locations should be determined to minimize flow hesitation at the hinges. Therefore, it is recommended that gates be located properly so that every flow front reaches the corners of the part and hinges simultaneously.

3. Application: automobile junction box cover

3.1. Analysis conditions

Fig. 4 shows the geometry of the automobile junction box cover, which has hinges at the lower sides (H1, H2 and H3) and the right side (H4). The land length and thickness of the hinges were 4.0 and 0.4 mm, respectively. On the other hand, the basic thickness of the part was 3.0 mm, which was much larger than that of the hinge. The part shown in Fig. 4 is an upper side cover that will be assembled to a lower side cover by H1, H2 and H3. With the advantages of using hinges, the assembling job will be easier and the reparability of the part can increase. Before applying the hinge component to the part, it was very difficult to open the junction box cover because it was assembled with very tight and stiff cantilever snaps. Meanwhile, H4 acts as a joint for the door 'A' shown in Fig. 4, which is a cover for a bundle of wires, requiring easy opening and closing.

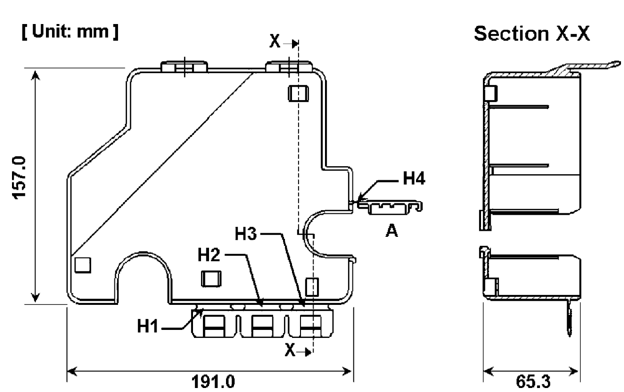

Fig. 4. Geometry of an automobile junction box.

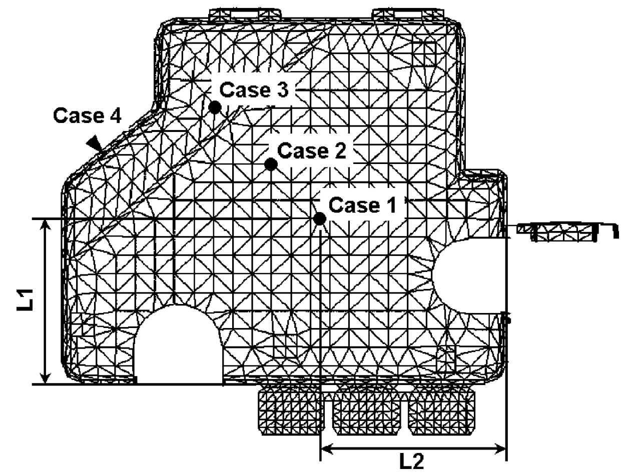

Fig. 5. Analysis model and gate locations.

As mentioned previously, it is desirable that every flow front reaches the hinge areas simultaneously in order to minimize hesitations but it is not easy to intuitively select the best location for the gate. Therefore, in this study, a gate location was initially selected by an injection mold designer who has 15 years experience and then other three gate locations were also selected according to the recommended design guidelines.

Fig. 5 shows four gate locations, called here Case 1, 2, 3 and 4. It was Case 1 that the mold designer proposed and the reason of selection was that melted polymer would fill every corner of the part simultaneously and sufficient injection pressure could be transmitted to the hinge areas with the selected gate location. Of course, it is most important to fill every boundary or extremity at about the same time [8–10]. In this case, however, it was predicted that hesitations at hinges H1 and H4 would be severe since the flow front would reach the hinges before filling all corners of the part with basic thickness of 3.0 mm. Therefore, the gate positions of Case 2, 3 and 4 were selected additionally to reduce hesitations at hinges since it was predicted that the melted polymer would reach the hinge areas after the left and upper sides of the part was filled.

Table 3 shows the location and type of the gate and the available structure of the mold for each case. Because it was required to cut-off the gate automatically, three plate molds

Table 3
The location and type of gate and the available mold structure for each case

Cases	L1 (mm)	L2 (mm)	Gate type	Mold structure
1	63.8	77.5	Pin point	Three plate
2	91.1	97.6	Pin point	Three plate
3	115.6	121.1	Pin point	Three plate
4	95.5	167.6	Tunnel	Two plate

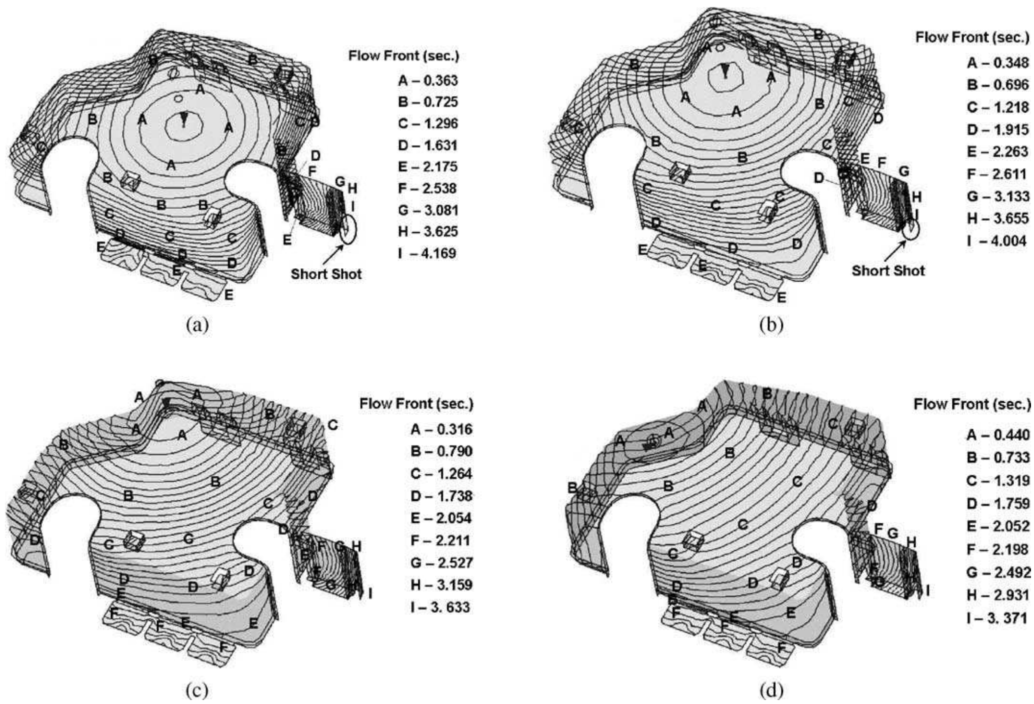

Fig. 6. Predicted flow front for each gate location: (a) Case 1, (b) Case 2, (c) Case 3 and (d) Case 4.

with a pin point gate were used for Case 1, 2 and 3, while two plate mold with a tunnel gate was applied to Case 4 [11]. LUPOL HI-5205 was used for numerical analysis, which was the same resin used for the strip part. The melting and mold temperature were set to be 220 and 55 °C, respectively and the injection time was 2.1 s for 95% filling.

3.2. Analysis results and discussion

The predicted flow front for each case was shown in Fig. 6. As shown in this figure, short shot occurred in Case 1 and 2 while filling was completed successfully in Case 3 and 4. Fig. 6(a) shows the flow front of Case 1 reached H4 at about 1 s and then, H1, H2 and H3 were filled within 1.6–1.8 s. However, severe flow hesitations occurred at H1 and H4 since the flow fronts at the hinge regions did not advance until the filling of the left and upper sides of the part was completed. As shown in Table 4, flow front temperatures at H1 and H4 reduced to 130 °C, which was the transition temperature of the resin and short shot occurred at the corner of the door connected to H4. In addition, the premature hinge failure of H1 was predicted since severe hesitation marks were formed at the hinge due to secondary resin flow over the solidified flow front. As a result, the mold designer's selection without considering the possible hesitation effect may lead to fatal defects.

Table 4
The minimum values of the flow front temperature at the hinges

Case	Flow front temperature at hinge (°C)			
	H1	H2	H3	H4
1	130.0	189.3	206.1	130.0
2	217.7	215.8	219.8	130.0
3	216.6	214.2	219.8	192.5
4	209.8	212.2	219.2	199.8

As shown in Fig. 6(b) and Table 4, although H1, H2 and H3 were filled successfully with the reduced hesitations, it was predicted that short shot would occur at H4, where the flow front became colder than the transition temperature. Because H4 was laid vertically, flow front reached the top of the hinge earlier than bottom one so that severe hesitation occurred at the top of H4.

Comparing the flow pattern of Case 3 with those of the previous ones, it can be seen that flow front reached the hinges after the left and upper sides of the part was filled. If there were unfilled regions at the left and upper sides, flow front would not advance through the hinge area since the flow resistance at hinges was larger than that of regions with the basic thickness. Cooling of the flow front of Case 3 was reduced remarkably in comparison to Case 1 and Case 2, as shown in Table 4. Therefore, it was predicted that all hinges were filled successfully in this case.

As shown in Fig. 6(d), no possible defects were predicted in Case 4 as well. The flow front, which reached H1 and H4 at about 1.9 s, did not show severe hesitations since the left and upper side of the part had already been filled. Case 4 had the largest value for the flow front temperature at H4 among all four cases, as shown in Table 4.

In this study, flow patterns and occurrence of defects that varied with the different four gate locations were investigated by numerical analyses. As a result, it could be seen that the proper selection of gate locations can avoid defects such as short shot or hesitation marks by minimizing hesitations at the hinges. Of course, resin flow can be affected by several process conditions such as the melting temperature, mold temperature, injection speed and so on [12]. In general, hesitations at hinges can be reduced by increasing the injection speed and melting temperature due to better fluidity of melted polymer. However, it would be safer to select proper gate locations with moderate process conditions at the mold design stage because there are limitation to the machine capacities and variation of the operator's skill.

3.3. Injection molding tryout

In this study, injection molding tryouts were conducted using a mold designed by one of the proposed gate systems. Although both Case 3 and 4 were available, Case 4 was selected since the two plate mold structure could be applied. Compared with the three plate mold, the two plate mold requires a shorter ejecting stroke and a lower mold making cost.

As shown in Fig. 7, a mold with two cavities was designed based on the gate location of Case 4. The size of the mold was 800 mm × 530 mm × 475 mm and a tunnel gate was installed on the upper and left side of the part as indicated as 'A' shown in Fig. 7(a). An injection molding machine with a clamping force of 300 t was used at tryouts. Table 5 shows the finally determined process conditions, which were obtained by trial and errors based on the initial values obtained from the numerical analysis of the previous section. The injection speed and melting temperature of the tryouts were not modified significantly from those of the numerical analysis and hinges without forming defects could be produced successfully with 50 °C of the mold temperature, which had been set-up as 55 °C in the numerical analysis.

Fig. 8(a) shows the hinges H1, H2 and H3 obtained by injection molding tryouts. As shown in this figure, the hinges were produced successfully with the selected gate positions. Although relatively deep weld lines were observed at the region indicated as 'A' shown in Fig. 8(a), there was

Table 5
Process conditions for tryouts

	Filling stage				
	1	2	3	4	
Injection pressure (%)[a]	60	65	55	–	
	Packing stage				
	1	2	3		
	38	35	30		
Injection speed (%)[b]	60	65	60	55	
	NH	H1	H2	H3	H4
Cylinder temperature (°C)	210	220	185	175	165
	Fixed core	Moving core			
Mold temperature (°C)	50	50			

[a] The maximum injection pressure of the machine used: 1670 kg/cm^2.
[b] The maximum injection speed of the machine used: 375 cm^3/s.

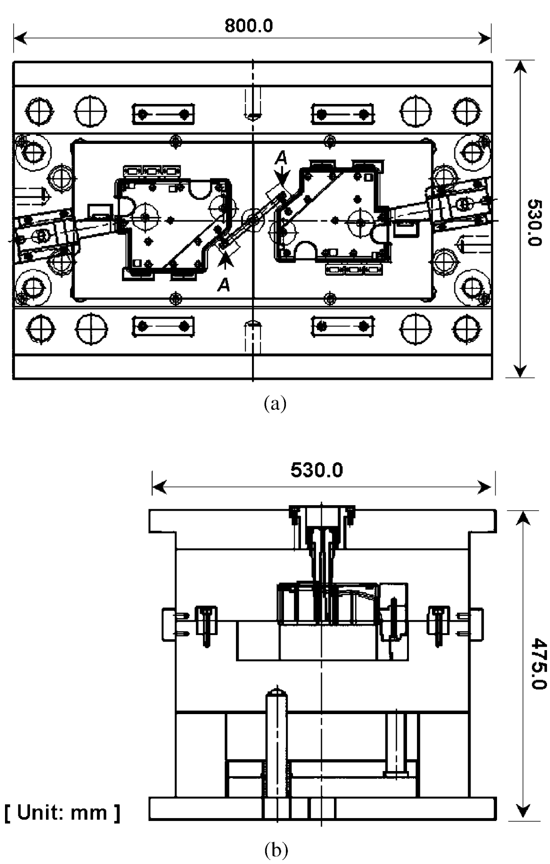

Fig. 7. The simplified geometry of the two-cavity mold designed by case 4: (a) top and (b) side view.

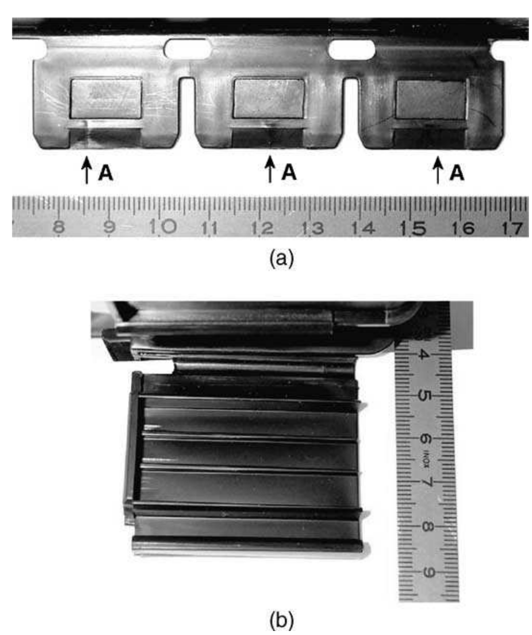

Fig. 8. Hinges obtained by injection molding tryouts: (a) H1, H2 and H3 and (b) H4.

Fig. 9. An automobile junction box cover obtained.

no significant problem since this region would be inserted into assembling holes of a lower junction box cover. As shown in Fig. 8(b), H4 was injection molded successfully as well.

Fig. 9 shows the junction box cover obtained by injection molding tryouts. As shown in this figure, hinges without defects could be produced by using the proposed gate location. Thus, it can be ascertained that the induced design guideline was reasonable.

4. Conclusions

In this paper, investigations were conducted into resin flow patterns depending on several gate positions obtained by numerical analyses of a simple strip. As a result, it was revealed that gate positions should be located properly to minimize flow hesitation at hinge area in order to avoid the formation of defects. As a practical application of the guideline determined, four gate systems for an automobile junction box were investigated. It was found that the properly determined gate location leads to a better resin flow and shorter hesitation time. Finally, injection molding tryouts using a mold which was designed by one of the proposed gate systems were conducted. The experiments showed that parts without defects could be obtained and the induced design guideline was reasonable.

Acknowledgements

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