Effects of Process Variables on the Gas Penetrated Part in Gas-Assisted Injection Molding

Seong-Ryeol Han[1], Tae-Won Park[2] and Yeong-Deug Jeong[3,#]

1 Graduate School of Mechanical Engineering, Pukyong National Univ., Busan, South Korea
2 School of Computer Added Mold & Die Engineering, Changwon Polytechnic College, Changwon South Korea
3 School of Mechanical Engineering, Pukyong National Univ., Busan, South Korea
Corresponding Author / E-mail: ydjung@pknu.ac.kr, TEL: +82-51-620-1534, FAX: +82-51-620-15344567

KEYWORDS : Gas-assisted injection molding, Gas penetration, PP, ABS, Taguchi method

Gas-assisted injection molding (GAIM) process reduces the required injection pressure during mold filling stage as well as the shrinkage and warpage of the part and cycle time. Despite of these advantages, this process needs new parameters and makes the application more difficult because gas and melt interact during the injection molding process. Important GAIM factors involved in this process are gas penetration design, locations of gas injection points, shot size, delay time to inject gas as well as common injection molding parameters. In this study, the experiments are conducted to investigate effects of GAIM process variables on the gas penetration for PP (Polypropylene) and ABS (Acrylonitrile Butadiene Styrene) moldings by changing the gas injection point. Taguchi method is used for the design of the experiments. When the gas is injected at a cavity's center, the most effective factor is the shot size. When the gas is injected at a cavity's end, the most effective factor is the melt temperature. The injection speed is also an effective factor in GAIM process.

Manuscript received: June 8, 2005 / Accepted: August 2, 2005

1. Introduction

Plastic parts have been used just for producing small case and bodies or improving aesthetic appearance of products for long time, but recently, they have began to be used for reinforcing structural products by inventing and developing process technologies and new polymers. Therefore, application of plastic materials has been spread in various industries and life. Also, the recognition that plastics can replace metal materials is being rapidly growing.

One of injection molding processes for making a structurally reinforced part is the Gas-Assisted Injection Molding (GAIM). In the GAIM, the mold cavity is partially filled with the polymer melt and then the injection of pressured inert nitrogen gas follows to the core the polymer melt. After the filling is completed, the gas maintains the packing pressure and the part takes up the volumetric shrinkage of the material. The GAIM was originally invented to reduce material consumption and cycle time and to improve surface quality in thick parts.[1,2] The products produced by the GAIM is applied to automobiles, house appliances, furniture, structures and kitchen components. This process prevents warpage and shrinkage of molding. In spite of these advantages, this process introduces new parameters, such as gas pressure, delay time to inject gas, gas injection time, gas holding time and so on, and makes the application more difficult.

In this study, experiments were conducted to investigate the effect of GAIM parameters on gas penetration length in PP (Polypropylene) and ABS (Acrylonitrile Butadiene Styrene) molding parts manufactured with a round shape cavity and an overflow. Gas was injected at the end and middle of the cavity. The end gas injection was studied in many previous papers. Therefore, an additional gas injection point was specially chosen at the middle of the cavity. Taguchi method was used for performing systematic experiments and investigating parameters' influence.

2. Injection molding experiment

Fig. 1 shows the injection molding machine for this experiment (LGH140N) fabricated by LG Machine

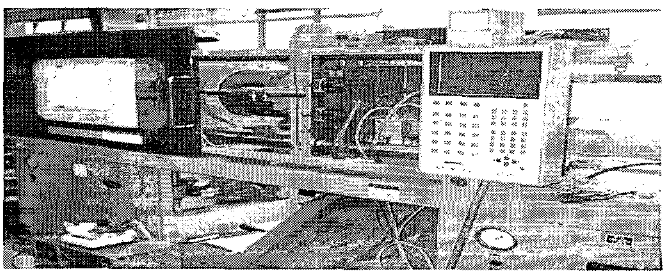

Fig. 1 Injection molding machine

Fig. 2 shows the experimental mold having a size of 200×300×250(mm) and 4 sectional types of cavities such as circular, rectangular, conical and elliptical.

When the melt was injected in the circular cavity and the gas injection applied at ① or ② as shown in Fig. 2, the variation of the gas penetration length was investigated. The gas injection system was made by NARA M&D Co. Ltd.

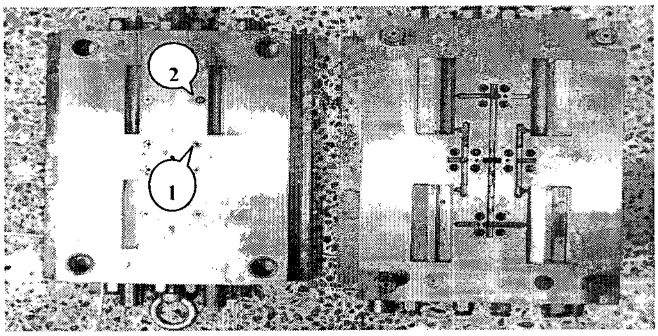

Fig. 2 Experimental mold

Fig. 3 shows molded samples and Fig. 4 is the schematic diagram of the GAIM system. PP (LG chemical M580) and ABS (BASF GP22) were used for this experiment.

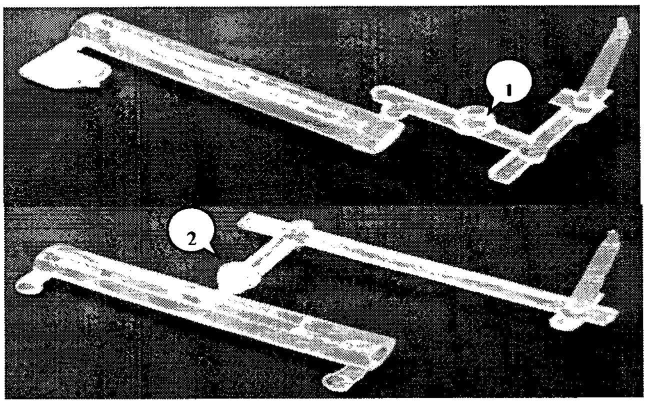

Fig. 3 GAIM samples

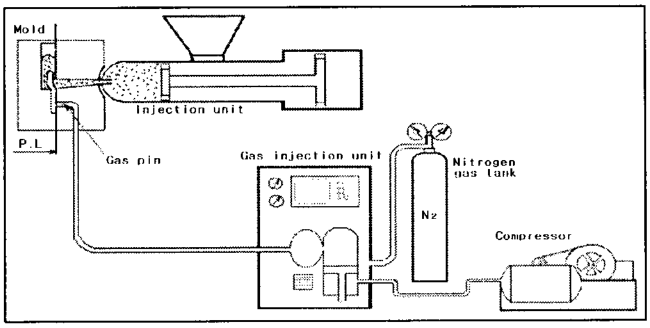

Fig. 4 Schematic diagram of GAIM

3. Design of experiments

3.1 Taguchi method

The Taguchi method was used to analyze effectively the interaction of each parameter and to get the most effective parameter on the gas penetration length. S/N (Signal to Noise) ratio is classified into three types such as 'Nominal-is-best', 'Larger-is-better' and 'Smaller-is-better'. 'Small-is-better' ratio was selected for this study, because increasing the gas penetration means decreasing the weight in molding. Eq. (1) shows definition of the S/N ratio and Eq. (2) shows 'Smaller-is-better'.

$$S/N = \frac{signal\ power}{noise\ power} \tag{1}$$

$$S/N = -10 \log \left[\frac{1}{n} \sum_{i=1}^{n} y_i^2 \right] \tag{2}$$

Here, y_i is a value of the measured gas penetration length and n is the number of experiments. Higher S/N ratio value means robustness to the noise of each factor. The original purpose of the Taguchi method is to find the most effective factor. By the S/N ratio, the noise effect is minimized and the parameters' effect is extracted. In this study, however, after only confirming the influential order of each factor, the interaction effect of factors on the penetration length was not analyzed for simplifying of the experiment.

3.2 Gas injection factors and orthogonal array

Mold temperature, melt temperature, injection speed, shot size, gas pressure, gas injection time, gas delay time and gas holding time were selected as the factors that affect on the penetration length. Preliminary experiments were conducted seven times to get reasonable levels for the factors. Table 1 shows the factors and levels used in this experiment. The melt temperature was chosen in an range of the region of ±10℃ from the recommended temperature given by the polymer manufacture.

Table 1 Factors and levels used in the experiment

Factors		Levels		
		1	2	3
A. Mold temperature (℃)		50	60	70
B. Melt temp. (℃)	PP	190	200	210
	ABS	240	250	260
C. Injection speed (%)		50	60	70
D. Shot size (mm)		8	9	10
E. Gas pressure (kg/㎠)		10	15	20
F. Gas injection time (sec)		1	1.5	2.0
G. Gas delay time (sec)		0.5	1.0	1.5
H. Gas holding time (sec)		1	1.5	2.0

$L_{27}(3^8)$ orthogonal array was used for planning the experiments. The 27 trials of the experiment were performed and the injection was repeated 3 times for each trial. The original plan was to measure the penetration length. However, the plan was changed to measure the parts weight because there were really small bubble groups in the parts which were made by mixing the melt and the gas. Therefore, the penetration length was indirectly revealed by measuring the weight of parts. The penetration length increase means that the parts weight decreased. The data were analyzed with MINITAB. Fig. 5 shows a flowchart of this study.

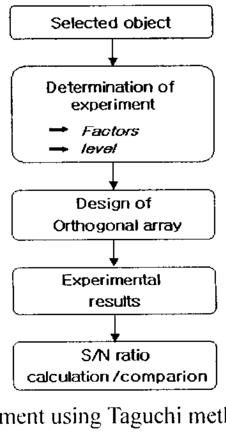

Fig. 5 Design of experiment using Taguchi method

4. Result and discussion

4.1 Penetration in PP moldings

4.1.1 Gas injection at the middle of cavity

Fig. 6 shows the degree of the effect of the factors on the penetration when the gas was injected at the middle of the cavity. The influential order was D, C, B and A in the PP moldings. However, the factors that were related to the gas such as E, F, G and H, did not influence on the penetration.

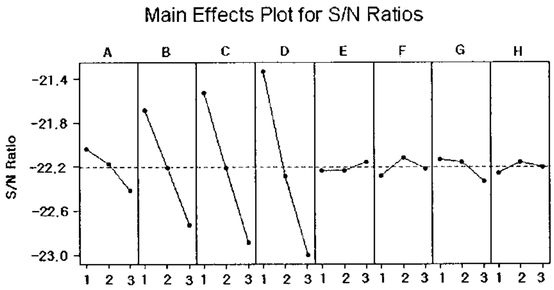

Fig. 6 Effects of factors on the molding weight

Fig. 7 shows a relation between the molding weight and injection speed for each shot size. The molding weight increased as the injection speed and the shot size of the melt increased. It means that more melt is injected in the cavity by increasing the injection speed. Therefore, to ensure that a small part has a big penetration the injection speed and the shot size should be reduced.

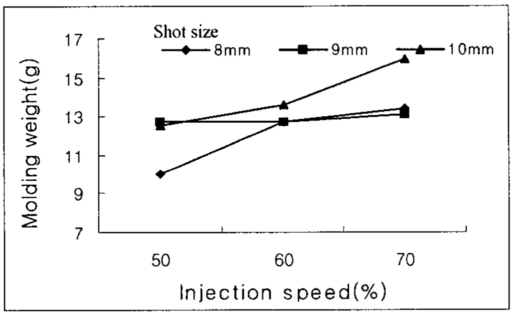

Fig. 7 Molding weight versus injection speed

4.1.2 Gas injection at the end of cavity

Fig. 8 shows the degree of the effect of the factors on the penetration when the gas was injected at the end of cavity. The influential order was B, C, G and D. The gas delay time was an effective factor in this case. It differs from the result of the injection at the middle. From the result, it appears that the degree of solidification of the melt injected in the cavity affects the penetration.

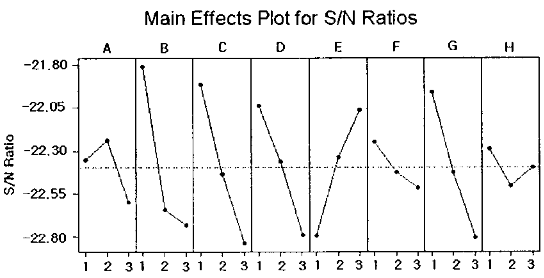

Fig. 8 Effects of factors on the molding weight

Fig. 9 shows a relation between the molding weight and the injection speed for each melt temperature. The molding weight decreased as the injection speed and the melt temperature increased. When the gas was injected at the end of cavity, the penetration was smaller than at the middle of the cavity. This phenomenon was caused by the amount of the melt that should be pushed into the overflow. In the case of having a gas point at the end of cavity, amount of the melt that should be pushed into the overflow was more than at the middle of the cavity.

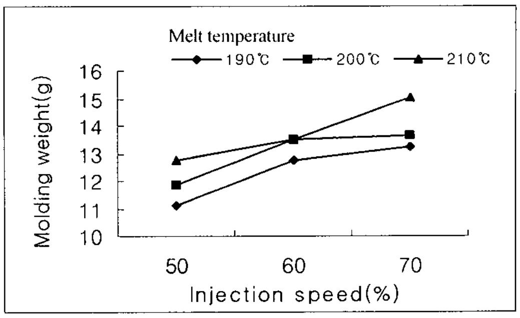

Fig. 9 Molding weight versus injection speed

4.2 Penetration in ABS moldings

4.2.1 Gas injection at the middle of cavity

Fig. 10 shows the degree of the effect of the factors on the penetration when the gas was injected at the middle of the cavity. The influential order was D, B, C and A in the ABS molding.

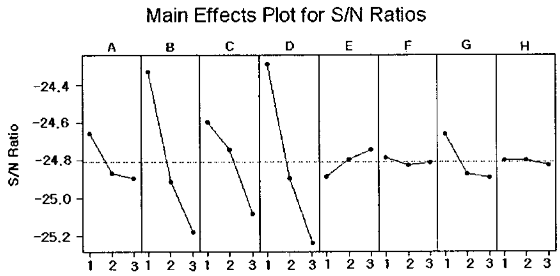

Fig. 10 Effects of factors on the molding weight

Fig. 11 shows a relation between the molding weight and the melt temperature for each shot size. The molding weight increased as the melt temperature and shot size increased. The weight of the ABS molding was similar to that one of the PP molding.

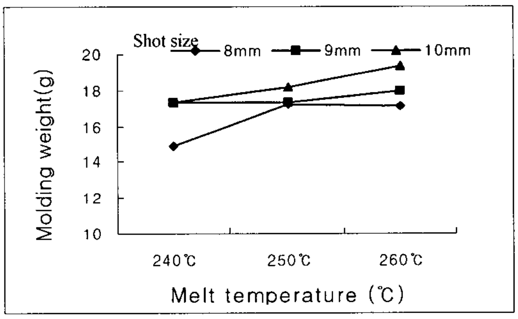

Fig. 11 Molding weight versus melt temperature

4.2.2 Gas injection at the end of cavity

Fig. 12 shows the degree of the effect of the factors on the penetration when the gas was injected at the end of the cavity. The influential order was B, D, C and A.

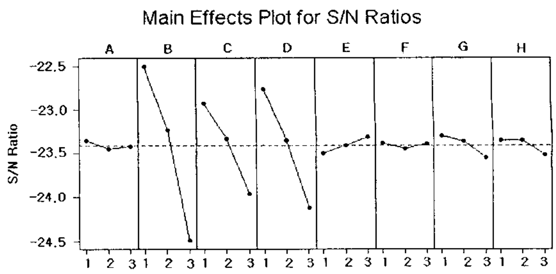

Fig. 12 Effects of factors on the molding weight

Fig. 13 shows a relation between the molding weight and the shot size for each melt temperature. Increasing the melt temperature induced lowering of viscosity and increasing fluidity. Therefore, the molding weight increased as the shot size and the melt temperature increased.

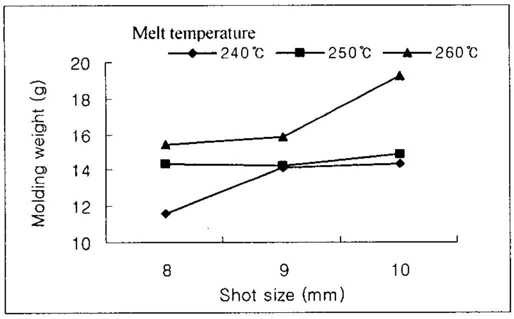

Fig. 13 Molding weight versus shot size

4.3 Comparison of factors for each polymer

By analyzing the results of each experiment, the effective factors are summarized in table 2. The shot size and the melt temperature are the effective factors on the penetration for all polymers.

Table 2 Rank of effective factors for each experiment

Rank		1	2	3
PP	Center	D	C	B
	End	B	C	G
ABS	Center	D	B	C
	End	B	D	C

When the gas was injected at the center of the cavity, the shot size was the most effective factor. When the gas was injected at the end of the cavity, the melt temperature was the most effective factor.

The shot size, the melt temperature, and the injection speed are factors that directly affected on the amount of the melt filled in a cavity. The injection speed was specially considered as a controllable factor for lowering viscosity caused by friction between the melt and mold wall. By increasing the injection speed, the friction increased and viscosity decreased. Therefore, the injection speed directly affected on the molding weight.

In the PP polymer, different from the ABS, the gas delay time was the third effective factor. This result was considered that the proper melt temperature of the PP polymer is lower by about 50℃ than that of the ABS. It means that the creation of a solidification layer in the PP melt is easier than that in the ABS.

5. Conclusions

In this paper, the effective factors on penetration were investigated during the GAIM process. The obtained conclusions are as follows:

(1) When small PP and ABS moldings were injected by the GAIM process, the most effective factors were the shot size and the melt temperature in the injection at the center and at the end of the cavity, respectively and the most effective factor was the melt temperature at the end of cavity.
(2) Increased injection speed caused lowering of viscosity due to friction between the melt and the mold wall. As a result, the amount of the melt filled in the cavity increased.
(3) When the gas was injected at the end of the cavity in the PP molding, the gas delay time was a dominant effective factor.

ACKNOWLEDGEMENT

This work was partially supported by the NURI Project in 2005.

REFERENCES

1. Shah, S., "Gas assisted injection molding: a technology overview," J. Injection Molding Technol. Vol.1, No.2, pp. 96-100, 1997.
2. Barton, K. S. and Turng, L. S., "General design guidelines for gas-assisted injection molding using a CAE tool," ANTEC Technical Paper, pp. 421-425, 1994.
3. Lee, S. H. and Son, J., "Optimization of nano machining parameters using acoustic emission and the Taguchi method," Journal of the KSPE, Vol. 21, No. 3, pp. 163-170, 2004.
4. Kwak, J. S. and Ha, M. K., "Optimization of Grinding Conditions and Prediction of Surface Roughness Using Taguchi Experimental Design," Journal of the KSPE, Vol. 21, No. 7, pp. 37-45, 2004.
5. Beaumont, J. P., Young, J. H., "Mold Filling Imbalances in Geometrically Balanced Runner System," Journal of Injection Molding Technology, Vol. 1, No. 3, pp. 133-143, 1997.
6. Je, D. G. and Jeong, Y. D., "Filling Imbalance in 3 Plate Type Injection Molds with Multi-Cavity," Journal of the KSPE, Vol. 21, No. 6, pp. 117-121, 2004.