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Optimal injection molding conditions considering the core shift for a plastic battery case with thin and deep walls †

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Abstract

The objective of this paper is to examine the influence of injection molding parameters on the core shift to obtain the optimal injection molding conditions of a plastic battery case with thin and deep walls using numerical analyses and experiments. Unlike conventional injection molding analysis, the flexible parts of the mold were represented by 3-D tetrahedron meshes to consider the core shift in the numerical analysis. The design of experiments (DOE) was used to estimate the proper molding conditions that minimize the core shift and a dominant parameter. The results of the DOE showed that the dominant parameter is the injection pressure, and the core shift decreases when the injection pressure decreases. In addition, it was shown that the initial mold temperature and the injection time hardly affect the core shift. The results of the experiments showed that products without warpage are manufactured when the injection pressure is nearly 32 MPa. Comparing the results of the analyses with those of the experiments, optimal injection molding conditions were determined. In addition, it was shown that the core shift should be considered to simulate the injection molding process of a plastic battery case with thin and deep walls.

Keywords: Optimal injection molding condition; Core shift; Thin and deep walls; Battery case; Design of experiments

1. Introduction

One of the recent concerns in the automotive industry is the reduction of overall weight to improve fuel efficiency and reduce a vehicle's environmental impact [1-3]. The injection molding process of thinner plastic components allows considerable weight savings on the automotive, a significant reduction in production cost, and a shorter cycle time [1]. Various studies are actively undertaken in an effort to develop the injection molding process of thin-wall plastic parts [1]. High injection pressure and high injection speed are necessary to manufacture plastic parts with thin and deep walls [4]. However, a high injection pressure can give rise to a core shift, which is the spatial deviation of the position of the core during injection molding [5]. Shepard et al. found that the mold design and injection molding conditions strongly affect the core shift of the mold [6]. Leo et al. reported that the deflection of weak plates in the mold causes variations in the thickness of the product and the over-packing of moldings [7]. Bakharev et al. reported that core shift effects in injection molding can be predicted through mold filling simulation coupled with an elastic analysis of the flexible parts of the mold [4].

In this paper, the influence of injection molding parameters on the core shift in the injection molding of a plastic battery case with thin and deep walls is examined to estimate an optimal injection molding condition. The design of experiments is used to estimate a proper molding condition minimizing the core shift, as well as to determine a dominant molding parameter. Several experiments are carried out to obtain an optimal injection pressure. Comparing the results of numerical analyses with those of the experiments, the optimal injection molding condition is acquired. The effects of the core shift on the quality of the product are also discussed.

2. Numerical analysis and experiments

In order to simulate the core shift and injection molding characteristics, a three-dimensional injection molding analysis was performed using the commercial code MPI V6.1. Fig. 1 illustrates the analysis model. The dimensions of the battery case are 164.4 mm (W) × 251.4 mm (L) × 184.0 mm (H). The maximum and minimum thicknesses of the walls are 2.7 mm and 1.8 mm, respectively. The depth of the walls is 168.7 mm. The runner system consists of a conical sprue with an initial

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Table 1. Parameters and their levels for the DOE.

Parameters	Level		
	1	2	3
A : Initial mold temperature (°C)	35.0	40.0	45.0
B : injection time (seconds)	1.6	2.2	2.8
C : Injection pressure (MPa)	40.0	35.0	30.0
D : Holding time (seconds)	2.0	3.2	4.4

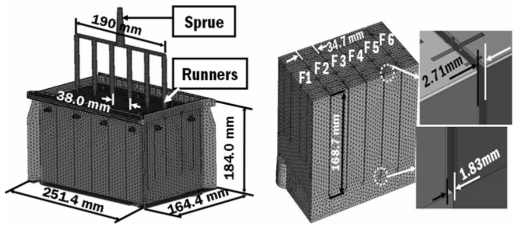


Fig. 1. Design of the runner system and core: (a) Design of the runner system and product, (b) Meshes for the flexible parts of the core.

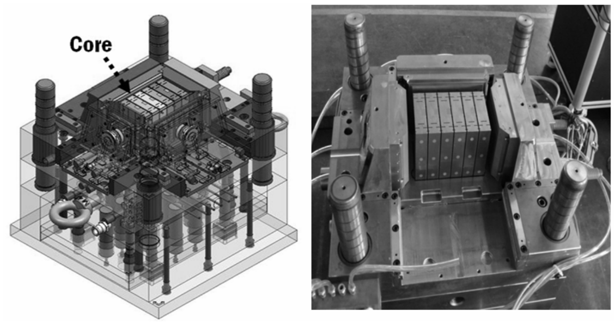


Fig. 2. Mold for the manufacture of the plastic battery case: (a) Design of the mold, (b) Manufactured mold.

diameter of 8 mm and a final diameter of 15 mm, circular runners with diameters of 8 mm, and pin-point gates with diameters of 2 mm. In order to consider the core shift phenomenon in the numerical analysis, the flexible parts of the mold and the flow part were represented by 376,674 EA of tetrahedron meshes and 61,098 EA of shell meshes, respectively. The injection material was a polypropylene resin. The melting temperature of PP was set at 230 °C.

The design of experiments (DOE) was used to quantitatively examine the influence of injection molding parameters on the core shift. Table 1 shows the injection molding parameters and their levels for the L_9 (3^4) orthogonal array. The signal-to-noise (S/N) ratio with the-smaller-the-better characteristics was calculated to estimate the proper condition for minimizing the core shift. The contribution ratio of each parameter is estimated using Analysis of Variance (ANOVA) to obtain the dominant parameter affecting the core shift.

Several experiments were performed using an injection molding machine with 600 tons of clamping force. Fig. 2 shows the design of the mold, as well as the manufactured

Table 2. Orthogonal array and results of the numerical analyses.

# of Exp	A	B	C	D	Deformation of flexible parts (mm)					
					F1	F2	F3	F4	F5	F6
1	1	1	1	1	0.16	0.11	0.07	0.14	0.08	0.23
2	1	2	2	2	0.18	0.09	0.07	0.14	0.08	0.23
3	1	3	3	3	0.13	0.09	0.05	0.11	0.08	0.16
4	2	1	2	3	0.14	0.10	0.07	0.13	0.08	0.18
5	2	2	3	1	0.12	0.09	0.05	0.11	0.08	0.16
6	2	3	1	2	0.14	0.10	0.07	0.14	0.08	0.21
7	3	1	3	2	0.11	0.09	0.05	0.10	0.08	0.15
8	3	2	1	3	0.17	0.10	0.07	0.14	0.08	0.23
9	3	3	2	1	0.15	0.10	0.07	0.15	0.08	0.22

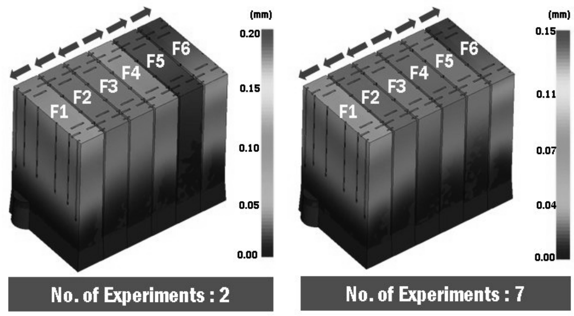


Fig. 3. Results of the numerical analysis (Core shift).

mold, for the experiments. The dimensions of the mold are 750 mm (W) × 700 mm (L) × 870 mm (H). The dominant parameter was varied within ± 10 % of the proposed condition by the DOE to determine the optimal condition. In order to examine the influence of core shift on the simulation of the injection molding process, the results of the experiments are compared to those of the numerical analyses.

3. Results and discussion

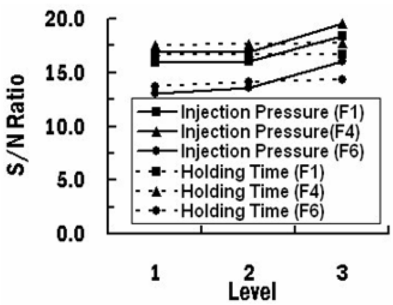
3.1 Results of injection molding analysis and DOE

Fig. 3 and Table 2 show the results of the injection molding analysis. The flexible parts of the core were deformed in identical directions regardless of the combination of injection molding conditions, as shown in Fig. 3. Fig. 3 and Table 2 show that the deformations of the F1, F5, and F6 parts of the core were greater than 0.1 mm and flexible parts of the core deformed symmetrically. In addition, it was noted that the shifts of the F2 and F3 parts are negligible in comparison with those of other parts. From the results of the injection molding analysis, the S/N and contribution ratios were calculated for the F1, F5, and F6 parts of the core with relatively large core shifts.

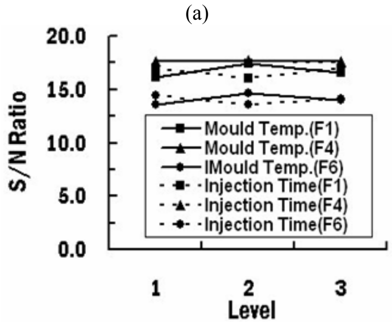
Fig. 4 and Table 3 show the results of the DOE. In Fig. 4, it can be seen that the S/N ratios of the injection pressure, the holding time, the injection time, and the initial mold temperature are maximized when their values are 30 MPa, 1.6 seconds, 4.4 seconds, and 40 °C, respectively. The S/N ratio of the in

Table 3. Pure contribution ratios of each injection molding parameter for different flexible parts.

Flexible Parts	Contribution ratio (%)		
	Injection time	Injection Pressure	Holding time
F1	4.1	56.5	15.8
F4	0.0	99.2	0.2
F6	3.3	73.3	6.3
Mean	2.5	76.3	7.4



(a)



(b)

Fig. 4. Variation of signal-to-noise ratios according to the levels of injection molding parameters: (a) S/N ratios of injection pressure and holding time, (b) S/N ratios of initial mold temperature and injection time.

jection pressure also increases remarkably when the injection pressure decreases, as shown in Fig. 4.

Table 3 shows that the mean value of the contribution ratio of the injection pressure is nearly 76.3 % and that the contribution ratio of the injection pressure is markedly higher than that of the other parameters. From these results, it was noted that the dominant parameter, which mainly affects the core shift, is the injection pressure. The variation in S/N ratio and the contribution ratio for the injection time and the initial mold temperature are negligible, as shown in Fig. 4 and Table 3. From these results, it was noted that the injection time and the initial mold temperature hardly affect the core shift.

3.2 Results of the experiments

Using the results of the DOE, the experimental conditions of injection time, holding time, and initial mold temperature were set at 1.6 seconds, 4.4 seconds, and 40 °C, respectively. The injection pressure was varied in the range of 27-32 MPa.

Fig. 5 shows the results of the injection molding experi-

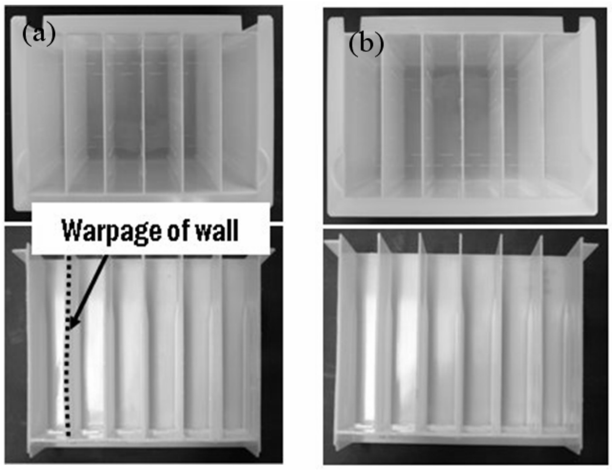
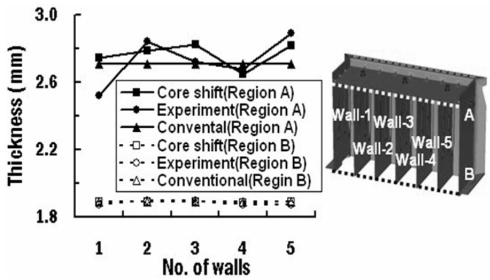
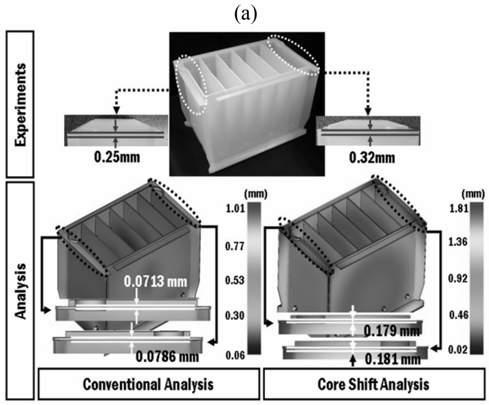


Fig. 5. Molded product for different injection pressures: (a) Injection pressure = 30 MPa (Condition proposed by the DOE), (b) Injection pressure = 32 MPa (Optimal condition).



(a)



(b)

Fig. 6. Comparison of the results of numerical analyses and those of the experiments: (a) Thickness distribution of channels, (b) Post-deformation of the molded product.

ments. The shortshot did not occur in all experimental conditions, as shown in Fig. 5. However, the warpages of the walls of the molded product occurred when the injection pressure was lower than 30 MPa, as shown in Fig. 5(a). This results from the insufficient holding pressure. The warpages of the product walls do not occur when the injection pressure is 32 MPa, as shown in Fig. 5(b). From these results, the optimal injection molding conditions of the tested plastic battery case with thin and deep walls were determined as an injection pressure of 32 MPa, an injection time of 1.6 seconds, a holding time of 4.4 seconds, and an initial mold temperature of 40 ^oC.

The results of the experiments were compared to those of the numerical analyses, as shown in Fig. 6. Fig. 6(a) shows that the difference in wall thickness between the analyses and the experiments is reduced from -0.15 mm ~ 0.18 mm to -0.09 mm ~ 0.07 mm when the core shift is considered in the numerical analysis. In addition, it was noted that the thickness variation of the walls is properly predicted by the core shift analysis. Fig. 6(b) shows that the core shift appreciably affects the post-deformation pattern of the molded product, and the numerical analysis accounting for the core shift can predict the post-deformation of the product within 0.15 mm of computational accuracy. The results of the numerical analyses show that the injection pressure is reduced from 50.2 MPa to 32.0 MPa when the core shift is considered. This is due to increased cavity volume induced by the elastic deformation of the core. Based on the above results, it is noted that injection molding analysis accounting for the core shift can properly simulate the injection molding process of the battery case with thin and deep walls.

4. Conclusions

The influence of injection molding parameters on the core shift in the molding of a plastic battery case with thin and deep walls was investigated using numerical analysis and the experiment. The elastic deformation of the core was considered to reflect core shift effects on the numerical analysis. Through numerical analysis and DOE, it was shown that the injection pressure is the dominant process parameter affecting core shift and that the core shift decreases when the injection pressure decreases. In addition, it was noted that the injection time, the holding time, and the initial mold temperature hardly affect core shift. It was demonstrated through experiments that the molded product without warpages can be manufactured at an injection pressure of approximately 32 MPa. Comparing the results of the numerical analyses with those of the experiments, the optimal injection molding conditions were obtained. In addition, it was shown that the core shift should be considered to accurately simulate the injection molding process of a plastic battery case with thin and deep walls.

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