한국기계가공학회지, 제21권, 제7호, pp. 84∼90(2022.07) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 21, No. 7, pp. 84∼90(2022.07) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2022.21.07.084

Optimization of Gate and Process Design Factors for Injection Molding of Automotive Door Cover Housing

Man-Jun Yu*, Jong-Cheon Park**,#

*Department of Mechanical Engineering, Graduate School, KIT,
**Department of Mechanical Engineering, KIT

자동차 도어용 커버 하우징의 사출성형을 위한 게이트 및 공정 설계인자의 최적화

유만준*, 박종천,#**

*금오공과대학교 대학원 기계공학과, **금오공과대학교 기계공학과

(Received 21 April 2022; received in revised form 09 June 2022; accepted 12 June 2022)

ABSTRACT

The purpose of the cover housing component of a car door is to protect the terminals of the plug housing that connects the electric control unit on the door side to the car body. Therefore, for a smooth assembly with the plug housing and to prevent contaminants from penetrating into the gaps that occur after assembly, the warpage of the cover housing should be minimized. In this study, to minimize the warpage of the cover housing, optimization was performed for design factors related to the mold and processes based on the injection molding simulation. These design factors include gate location, gate diameter, injection time, resin temperature, mold temperature, and packing pressure. To optimize the design factors, Taguchi's approach to the design of experiments was adopted. The optimal combination of the design factors and levels that minimize warpage was predicted through L_{18}-orthogonal array experiments and main effects analysis. Moreover, the warpage under the optimal design was estimated by the additive model, and it was confirmed through the simulation experiment that the estimated result was quite consistent with the experimental result. Additionally, it was found that the warpage under the optimal design was significantly improved compared to both the warpage under the initial design and the best warpage among the orthogonal array experimental results, which numerically decreased by 36.9% and 23.4%, respectively.

Keywords : Injection Molding Simulation(사출성형 시뮬레이션), Door Cover Housing(도어용 커버 하우징), Orthogonal Arrays(직교배열), Warpage(휨), Optimization(최적화)

1. Introduction

Warpage[1,2] is one of the most common quality defects in injection molded products. In general, when the design factors related to parts, mold cavities, cooling channels, and process conditions are improperly designed, residual stresses may be unevenly distributed inside the parts after molding, eventually resulting in warpage. If the molded product has significant warpage, its appearance may be

---

Corresponding Author : cadpark@kumoh.ac.kr
Tel: +82-54-478-7297, Fax: +82-54-478-7319

degraded, and in particular, the ability to assemble with other components may be lost.

Therefore, minimizing the warpage of injection-molded products is desirable. This requires an optimal design of the parameters that affect the warpage. Until recently, injection molding simulations have been widely used to predict and quantify warpage in injection-molded products and optimize the relevant design factors for minimal warpage[3-8].

The cover housing for an automotive door is a cover-shaped part assembled into a connector that connects the electric control device installed on the door side to the vehicle body. The cover housing protects the connector from external impact and prevents foreign substances from entering the gap after assembly and contaminating the connector terminal. This study aims to minimize the warpage of automotive door cover housing to prevent functional problems due to excessive warpage during and after assembly with connectors.

To this end, an integrated injection molding simulation and statistical optimization approach was utilized to perform an optimal design for injection molding factors relevant to warpage. These design factors include gate position, gate diameter, and several important process conditions. To optimize the design factors, an experimental design method based on Taguchi's orthogonal array[9,10] was applied.

Finally, this study determines the optimal design for the feed system and process conditions through the optimization procedure and compares the optimal design with the two selected design alternatives for warpage. The results confirm that warpage is significantly improved in the optimal design.

2. Cover Housing Model and Warpage

Fig. 1 shows the shape of the cover housing for an automotive door, an injection-molded part to be considered in this study. The dimensions of this part are a length, width, height, and thickness of 72.5 mm, 19 mm, 25 mm, and 1.5 mm, respectively. The resin used for the simulation was PBT-GF10 supplied by Albis Plastic.

The molding goal for this part is to minimize the warpage caused by the inward deformation of both parallel walls of the part after injection molding. An increase in the warping deformation between the two sidewalls of the cover housing can cause two problems; first, it can make assembly cumbersome because the two curved walls must be pried apart to mate with the connector. Second, the gaps between the assembled walls allow foreign matter to penetrate the interior of the assembly. The warpage was measured as the maximum displacement in the inward direction observed at the finite element nodes on the two sidewalls after injection molding, as shown in Fig. 2.

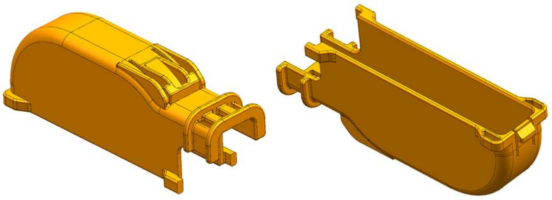


Fig. 1 Geometric shape of automotive door cover housing

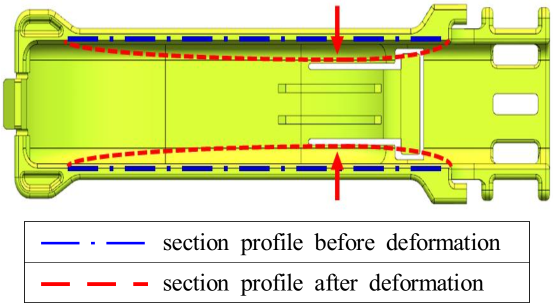
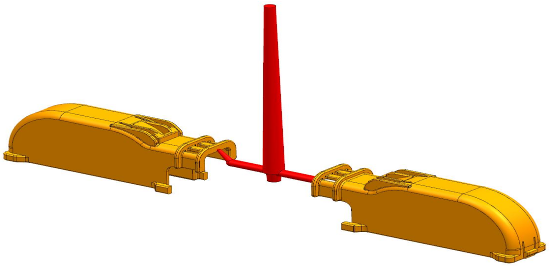
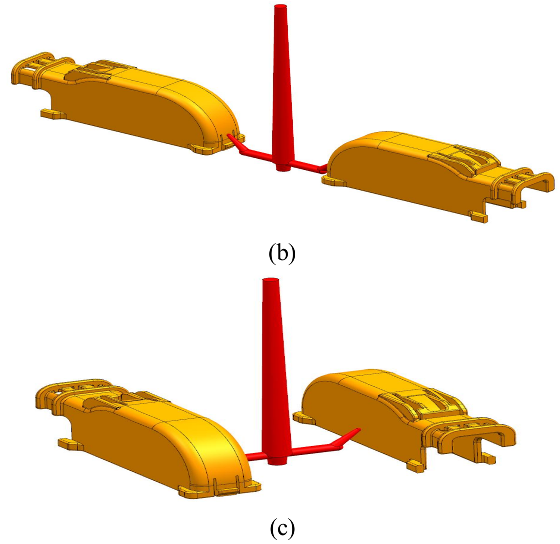


Fig. 2 Warpage measurement



(a)



(b)

(c)

Fig. 3 Three alternative designs of feed system: (a) type-1, (b) type-2, and (c) type-3

3. Optimization of Gate and Process Design Factors by Orthogonal Array-Based Design of Experiments

3.1 Design factors and levels

Based on empirical judgment, the gate location was selected as the design factor that could have the greatest influence on the warpage of the cover housing. In this study, we considered three resin feed systems, as shown in Fig. 3, that can be applied to a two-plate mold system to determine the optimal gate position.

Table 1 Design factors and their levels

Design factor			Level		
Symbol	Description	Unit	1	2	3
A	Gate position	-	type-1	type-2	type-3
B	Gate diameter	mm	0.8	1.0	1.2
C	Fill time	sec	0.8	1.0	1.2
D	Melt temperature	℃	250	260	270
E	Mold temperature	℃	40	60	80
F	Packing pressure	%	60	80	100

For the injection molding simulations, finite element models were generated for each of the three feed system alternatives, as shown in Fig. 3. In total, 55,056 triangular elements and 27,516 nodes were created in a dual-domain[11] type for multi-cavity products. To create a finite-element model of the cover housing, the mesh size was set to 1.0 mm. This was determined by considering both the reliability of the warpage prediction and computation time from warpage simulation results for mesh sizes of 0.5 mm to 2.5 mm. For the feed system composed of gates, runners, and sprue, 39–41 one-dimensional beam-type elements were constructed.

In addition to the gate location, the gate diameter is included as a design factor. Injection time, resin temperature, mold temperature, and packing pressure were considered as design factors for process conditions. Table 1 presents the six design factors selected for the orthogonal array experiment and the three-level design values for each factor. On the other hand, the initial design conditions for the design factors were given as a combination of the second-level values of each design factor.

3.2 Orthogonal array experiment and optimal factors combination

The Taguchi's $L_{18}(2^1 \times 3^7)$-orthogonal array[9,10] was chosen to estimate the optimal design conditions for the six three-level design factors presented in Table 1 with the minimum number of experiments. In the L_{18}

Table 2 $L_{18}(2^1X3^7)$ orthogonal array and warpage simulation results

Run	1	2	3	4	5	6	7	8	Warpage (mm)
	-	A	B	C	D	E	F	-	
1	1	1	1	1	1	1	1	1	1.0264
2	1	1	2	2	2	2	2	2	0.9030
3	1	1	3	3	3	3	3	3	0.8609
4	1	2	1	1	2	2	3	3	0.8754
5	1	2	2	2	3	3	1	1	1.1795

6	1	2	3	3	1	1	2	2	0.8792
7	1	3	1	2	1	3	2	3	1.2836
8	1	3	2	3	2	1	3	1	0.9452
9	1	3	3	1	3	2	1	2	1.5084
10	2	1	1	3	3	2	2	1	0.8912
11	2	1	2	1	1	3	3	2	0.8194
12	2	1	3	2	2	1	1	3	1.0056
13	2	2	1	2	3	1	3	2	0.8491
14	2	2	2	3	1	2	1	3	1.0524
15	2	2	3	1	2	3	2	1	1.0780
16	2	3	1	3	2	3	1	2	1.4865
17	2	3	2	1	3	1	2	3	1.2802
18	2	3	3	2	1	2	3	1	1.0394

Table 3 Levels average warpage for main effects

Factor Level	A	B	C	D	E	F
1	0.9178	1.0687	1.0980	1.0167	0.9976	1.2098
2	0.9856	1.0299	1.0434	1.0490	1.0450	1.0525
3	1.2572	1.0619	1.0192	1.0949	1.1180	0.8982
Δ (Max-Min)	0.3395	0.0388	0.0787	0.0781	0.1204	0.3116
Rank	1	6	4	5	3	2

orthogonal array, the six design factors were arranged sequentially from the second to the seventh column, where three-level factors can be placed.

Table 2 lists the warpage results estimated by performing simulations under 18 different design conditions. Fill+Pack+Warp analyses in Autodesk Moldflow Insight[11] were performed to predict the warpage of the cover housing. The packing time and cooling time, which were not considered as design factors, were set to 6 and 15 s, respectively. In addition, cooling analysis was not performed separately, assuming uniform mold cooling.

The average warpage value at each design factor level was calculated, and the analysis of means(ANOM)[9,12] results are shown in Table 3. Fig. 4 is a graphical representation of the main effect of the average warpage based on the analysis of the means presented in Table 3. In the means analysis, the design factor with a large difference in the average warpage levels corresponds to the design factor with a large influence on warpage. Accordingly, as shown in Table 3 and Fig. 4, A(gate position) is the design factor that has the greatest influence on warpage, followed by F(packing pressure), E(mold temperature), C(fill time), D(melt temperature), and B(gate diameter).

Because warpage in injection-molded products must be minimized, the optimal design condition for the design factors can be seen as a combination of the levels at which the warpage is the smallest. Therefore, based on the main effect, the optimal combination of design factors and their levels that minimize warpage is $A_1 B_2 C_3 D_1 E_1 F_3$. The design factor levels and their values under the optimal design conditions were as follows: gate position at level 1(type-1), gate diameter at level 2(1.0 mm), injection time at level 3(1.2 s), melt temperature at level 1(250℃), mold temperature at level 1(40℃), and packing pressure at level 3(100% of the maximum injection pressure).

3.3 Confirmation experiment

It can be seen that the optimal design condition predicted by the main effect analysis does not match one of the experiments in the L_{18}-orthogonal array in Table 2. Therefore, it is necessary to estimate the warpage under optimal design conditions, and a simulation experiment was required to confirm the reliability of the estimated value.

In this study, the warpage estimate under the optimal design condition was calculated using the additive model[9,13] given by the following equation:

$$\begin{aligned} y_{A1B2C3D1E1F3} = m &+ (m_{A1} - m) + (m_{B2} - m) \\ &+ (m_{C3} - m) + (m_{D1} - m) \\ &+ (m_{E1} - m) + (m_{F3} - m) \quad (1) \end{aligned}$$

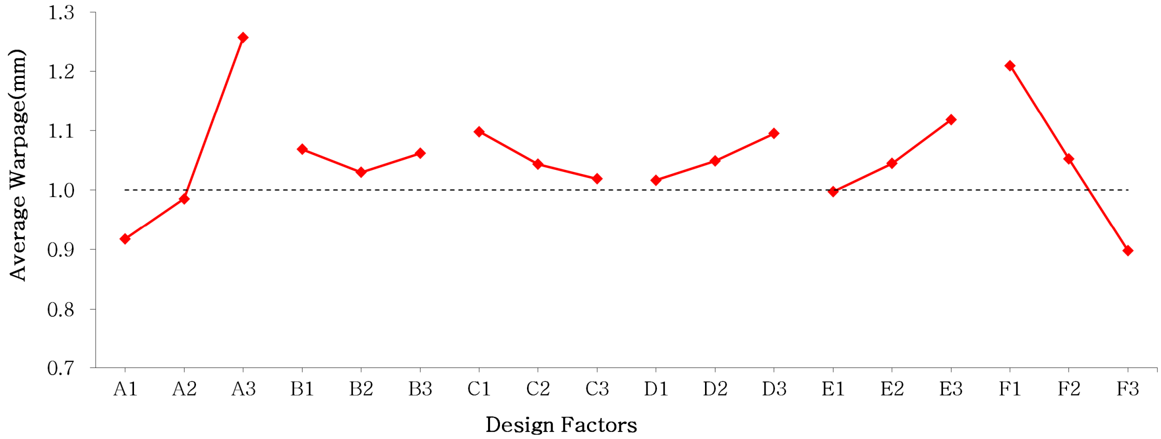


Fig. 4 Main effects plot for warpage

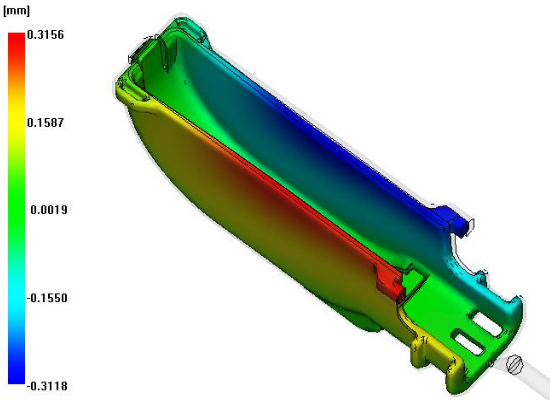


Fig. 5 Warpage for optimal design

Where m is the average warpage for the 18 design conditions in the main experiment in Table 2, with a value of 1.0535 mm. m_{PQ} is the average warpage for design factor P and level Q.

Using Equation (1), the warpage estimated for the optimal design condition, $A_1B_2C_3D_1E_1F_3$, was 0.6119mm.

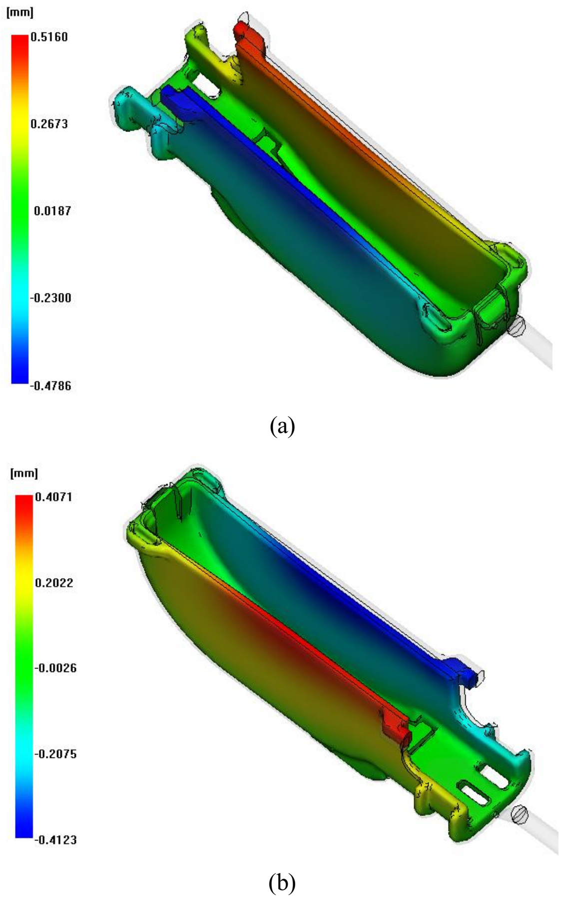
A confirmation experiment for the optimal design condition was conducted using Moldflow Insight. Fig. 5 shows the simulated warpage under the optimal design condition as an image at three magnifications. The warpage obtained from the simulation is 0.6274mm. Under optimal design conditions, the warpage difference between the experimental and estimated results was only 0.0155mm, and the error was quite small(approximately 2.5%), indicating that the experimental value of warpage is very close to the estimate.

To verify the reliability of the additive model for other design conditions, warpage was estimated for each of the 18 design conditions listed in Table 2. The minimum, maximum, and mean errors between the estimated and experimental values were 0.2%, 4.2%, and 1.9%, respectively, confirming the high reliability of the established additive model.

3.4 Comparison of warpage results

The warpage under the optimal design condition was compared with the warpages obtained under two different comparable design conditions.

The design condition was the first to be compared, a combination of the design factors and their second levels, as shown in Table 1. The warpage under the initial design conditions is predicted to be 0.9946 mm. The second condition for comparison is the 11th design condition, with the smallest warpage among the experimental conditions in Table 2. The predicted warpage for this design condition was 0.8194 mm. Fig. 6 shows the predicted warpage for each of the two



(a)

(b)

Fig. 6 Warpages for two comparable designs: (a) initial design and (b) best design in L_{18}-orthogonal array experiments

Table 4 Comparison of warpages

Design	Initial	Best in L_{18}-OA exp.	Optimum
Level	$A_2B_2C_2D_2E_2F_2$	$A_1B_2C_1D_1E_3F_3$	$A_1B_2C_3D_1E_1F_3$
Warpage (mm)	0.9946	0.8194	0.6274

compared design conditions as a three-magnification image.

Table 4 summarizes a comparison between the optimal design condition and the other two design conditions. The warpage obtained under the optimal design condition was the smallest at 0.6274 mm, and it was found to be significantly reduced compared with the warpages under the two design conditions. Specifically, the warpage decreased by 0.3672 mm compared to the initial design condition and by 0.1920 mm compared to the 11th orthogonal array experiment. Reduction rates were 36.9% and 23.4%, respectively.

4. Conclusions

In this study, design optimization based on injection molding simulation was performed for the design factors, including gates and process conditions, to minimize the warpage of the cover housing for automobiles. The conclusions of this study are as follows:

1. As a result of the $L_{18}(2^1 \times 3^7)$-orthogonal array experiment and means analysis, the gate position was the most influential design factor on the warpage, followed by the packing pressure, mold temperature, fill time, melt temperature, and gate diameter.
2. Through analysis of the main effect, the optimal combination of the design factors and their levels that minimized the warpage was $A_1B_2C_3D_1E_1F_3$, and the warpage for the optimized design condition was estimated to be 0.6119mm using the additive model.
3. Based on the simulation, a confirmation experiment was conducted on the optimal design condition, and the warpage was found to be 0.6274 mm. The difference between the experimental and estimated results was only 0.0155 mm(error of 2.5%), indicating that the experimental value of the warpage was very close to the estimated value.
4. It was confirmed that the warpage under the optimal design condition was significantly improved compared to the initial design condition and the best design condition of the L_{18}-orthogonal array experiment. Warpage reduction rates were 36.9% and 23.4%, respectively.

Acknowledgment

This research was supported by Kumoh National Institute of Technology(202001000001).

References

1. Shoemaker, J., Moldflow Design Guide: A Resource for Plastics Engineers, Hanser Gardner Publications, Inc., pp. 173-190, 2006.
2. Malloy, R. A., Plastic part Design for Injection Molding, Hanser, pp. 63-84, 1994.
3. Erzurumlu, T. and Ozcelik, B., "Minimization of Warpage and Sink Index in Injection-Molded Thermoplastic Parts Using Taguchi Optimization Method," Materials and Design, Vol. 27, pp. 853-861, 2006.
4. Guo, W., Hua, L., Mao, H. and Meng, Z., "Prediction of Warpage in Plastic Injection Molding based on Design of Experiments," Journal of Mechanical Science and Technology, Vol. 26, No. 4, pp. 1133-1139, 2012.
5. Oliaei, E., Heidari, B. S., Davachi, S. M., Bahrami, M., Davoodi, S., Hejazi, I. and Seyfi, J., "Warpage and Shrinkage Optimization of Injection-Molded Plastic Spoon Parts for Biodegradable Polymers Using Taguchi, ANOVA and Artificial Neural Network Methods," Journal of Materials Science & Technology, Vol. 32, pp. 710-720, 2016.
6. Kitayama, S., Yokoyama, M., Takano, M. and Aiba, S., "Multi-Objective Optimization of Variable Packing Pressure Profile and Process Parameters in Plastic Injection Molding for Minimizing Warpage and Cycle Time," International Journal of Advanced Manufacturing Technology, Vol. 92, pp. 3991-3999, 2017.
7. Song, Z., Liu, S., Wang, X. and Hu, Z., "Optimization and Prediction of Volume Shrinkage and Warpage of Injection-Molded Thin-Walled Parts Based on Neural Network," International Journal of Advanced Manufacturing Technology, Vol. 109, pp. 755-769, 2020.
8. Yu, M. J. and Park, J. C., "Determination of Feed System and Process Conditions for Injection Molding of Automotive Connector Part with Two Warpage Design Characteristics," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 20, No. 12, pp. 36-43, 2021.
9. Fowlkes, W. Y. and Creveling, C. M., Engineering Methods for Robust Product Design: Using Taguchi Methods in Technology and Product Development, Addison-Wesley Publishing Company, pp. 125-145, 1995.
10. Peace, G. S., Taguchi Methods: A Hands-On Approach To Quality Engineering, Addison-Wesley Publishing Company, pp. 114-128, 1995.
11. Shin, N. H., Oh, H. S. and Kang, S. G., The Optimization of Injection Molding Process by CAE, Daekwangseorim, Seoul, pp. 327-422, 2010.
12. Phadke, M. S., Quality Engineering Using Robust Design, AT&T Bell Laboratories, pp. 41-47, 1992.
13. Yang, C. and Hung, S. W., "Optimising the Thermoforming Process of Polymeric Foams: An Approach by Using the Taguchi Method and the Utility Concept," International Journal of Advanced Manufacturing Technology, Vol. 24, pp. 353-360, 2004.