한국기계가공학회지, 제20권, 제12호, pp. 36～43(2021.12) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 20, No. 12, pp. 36~43(2021.12) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2021.20.12.036

Determination of Feed System and Process Conditions for Injection Molding of Automotive Connector Part with Two Warpage Design Characteristics

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

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

두 개의 휨 설계특성을 갖는 자동차 커넥터 부품의 사출성형을 위한 피드 시스템 및 공정조건의 결정

유만준*, 박종천**,#

*금오공과대학교 대학원 기계공학과, **금오공과대학교 기계공학과

(Received 02 September 2021; received in revised form 18 September 2021; accepted 09 October 2021)

ABSTRACT

In this study, the optimal feed system and process conditions that can simultaneously minimize each warpage occurring in the two shape features of the 2P Header HSG, a connector part for automobiles, were determined through injection molding simulation analysis. First, we defined each warping deformation of the two features geometrically and quantified them approximately using the injection molding simulation data. For design optimization, a full factorial experiment was conducted considering the feed system, resin temperature, and packing pressure as design variables, and a follow-up experiment was conducted based on the analysis of the average warpage. In this study, an optimal design was generated considering both the warpage result and resin-saving effect. In the optimal design, the warpages of the two shape features were predicted to be 0.18 and 0.29 mm, and these warpages were found to meet the allowable limit of warpage, which is 0.3 mm, for part assembly.

Key Words : Injection Molding(사출성형), Simulation Analysis(시뮬레이션 해석), Shape Features(형상특징), Warpage(휨), Feed System(피드 시스템), Process Conditions(공정조건), Optimization(최적화)

1. Introduction

Warpage[1] is a defect in which the shape of the injection product is deformed because of uneven shrinkage of the resin filled in the product cavity during the injection molding process. Therefore, warpage should be eliminated or minimized as much as possible for the sake of esthetics and assembly with other parts. In general, warpage is greatly affected by

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

the shape of the product, the feed system consisting of gate(s) and runner(s) and sprue, cooling channels, and process conditions[1,2]. Studies have been performed to minimize or reduce the warpage of injection products by optimizing the design factors related to the warpage characteristics[3–9].

The 2P Header HSG is a type of automotive connector that is mounted on the panel of a hybrid or an electric vehicle. It transmits high currents and high voltages to the inverter or electric motor from the plug housing, which is a mating component assembled therein. In the 2P Header HSG, because both the flat part attached to the automotive panel and the hole part where the plug housing is inserted require waterproofing and dustproofing after assembly, it is necessary to minimize the warping deformation in these two shape features. The purpose of this study was to determine the optimal design for the feed system and process conditions that simultaneously minimize each warpage that occurs in the two geometric features of the 2P Header HSG using injection molding simulation analysis.

To quantify the warpage, each shape of the warpages of the two features was defined geometrically, and the warpages were measured in an approximate manner using injection molding simulation data. In addition, for design optimization, a full factorial experiment[10] was performed using the feed system, resin temperature, and packing pressure as design variables. A follow-up experiment was conducted by analyzing the effects of the design variables from the warpage results.

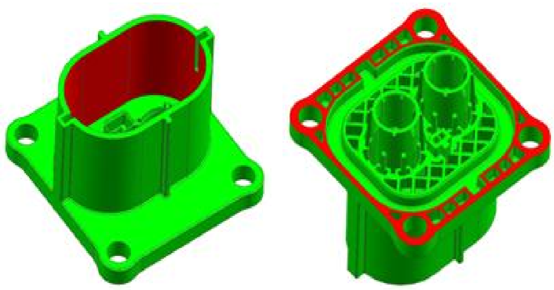
In this study, the optimal feed system and process conditions were determined by considering both the warpages predicted in the two features and the economics of part production. For the feed system, it was confirmed that a design alternative adopting a two-point gate was provided the best warpage size and resin scrap reduction. In the optimal design, the warpages in the flat and hole parts were predicted to be 0.18 and 0.29 mm, respectively. These warpages meet the upper limit of 0.3 mm for assembling parts.

2. Product and Design Goals

Fig. 1 shows the geometry of the 2P Header HSG. The dimensions of this product are 68.0 mm in length, 66.0 mm in width, 56.5 mm in height, and 0.5 to 2.8 mm in thickness.

The 2P Header HSG is bolted to the panel of an automobile, and it transmits high currents and high voltages to the panel from a plug housing, which is a counterpart component assembled therein. The curved surface area marked in red in Fig. 1(a) is the part where the plug housing with a built-in seal, such as an O-ring or waterproof gasket, is closely assembled. This is referred to hereinafter as “Feature-A.” The cross section of Feature-A is a running track-like profile that connects two semicircles with a radius of 16.2 mm and a center-to-center distance of 19.4 mm with two parallel straight lines. In addition, the flat surface area marked in red in Fig. 1(b) is the part that is assembled on the panel and contacted. This part is referred to as “Feature-B.”

After the final assembly of the 2P Header HSG, Feature-A and Feature-B must be waterproof and dustproof, so the warping deformation of these two features should be minimized. When warping deformation of molded product exceeds a certain limit, the deformation can be compensated for by using the elasticity of the polymer material during assembly.



(a) (b)

Fig. 1 Geometric shape of 2P Header HSG((a) top view, (b) opposite view)

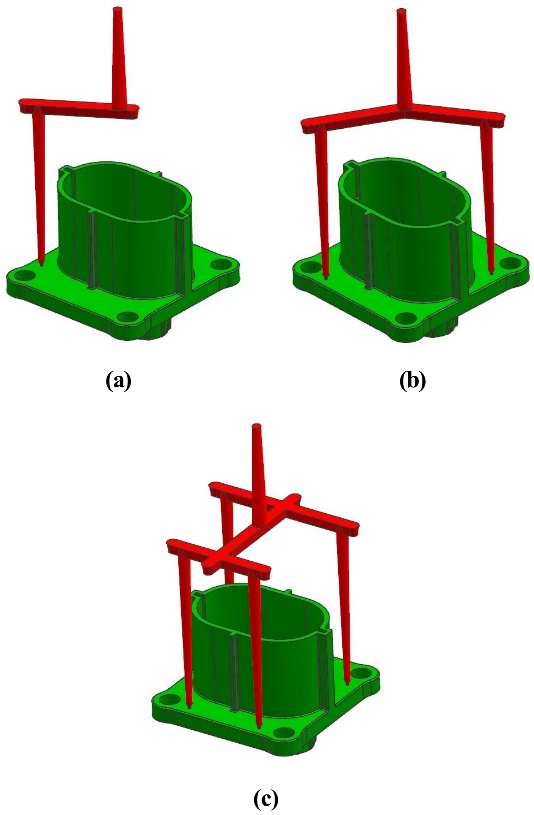


Fig. 2 Three design alternatives considered as feed system((a) Case 1, (b) Case 2, (c) Case 3)

However, because breakage could occur because of the pressure applied during the assembly of parts, there is inevitably a limit to the deformation correction using material elasticity. Therefore, it is necessary to minimize the warpages of Feature-A and Feature-B in the injection molding analysis stage.

3. Design Alternatives for Feed System

In general, the design factor that has the greatest influence on the warpage of injection-molded products is the feed system of the mold cavity. The feed system delivers the molten resin from the nozzle of the injection machine to the product cavity and consists of a sprue, runner(s), and gate(s).

Table 1 Design dimensions of feed systems

Feed system		Case 1	Case 2	Case 3
Number of gates		1	2	4
Weight of feed system(g)		2.76	4.54	8.06
Gate	type	pin point / tapered circular		
	Φ(mm)	start: 1.2, end: 2.5		
	L(mm)	2.3		
Runner(1st)	type	tapered circular		
	Φ(mm)	start: 2.5, end: 5		
	L(mm)	68.7		
Runner(2nd)	type	non-tapered trapezoidal		
	T×B×H (mm)	5×3.6×4		
	L(mm)	31.06	63.74	129.5
Sprue	type	tapered circular		
	Φ(mm)	start: 6, end: 3.5		
	L(mm)	44		

Three design alternatives, as shown in Fig. 2, were considered to design a feed system that can minimize the two warpages of the 2P Header HSG and that can be applied to a three-plate mold. Case 1 is a feed system that adopts a one-point gate, Case 2 is a two-point gate, and Case 3 is a four-point gate. Table 1 shows the shapes and dimensions of the design elements applied to each feed system.

4. Injection Molding Analysis and Design Optimization

Injection molding analysis was performed to determine the optimal design for minimizing the warpages among the feed systems, as shown in Fig. 2. First, a finite-element model with 886,804 tetrahedral elements and 158,577 nodes was created for the product model. The average aspect ratio of the resulting tetrahedral elements was 4.94. For feed systems, 58 beam-type elements were generated in Case 1, 101 in Case 2, and 188 in Case 3. As an example, the finite-element model generated for Case 1 is shown in Fig. 3. The fill–pack–warp module of the Moldflow Insight[11] was used for injection molding analysis.

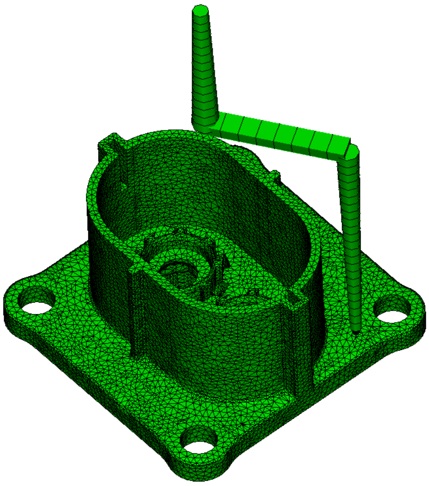


Fig. 3 Finite element model for Case 1

Table 2 Material properties of Ultramid A3WG5

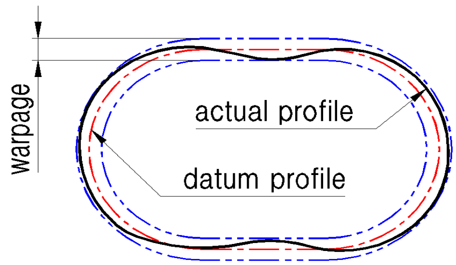
Property	Unit	Value
Elastic modulus	MPa	9,653
Shear modulus	MPa	1,329
Poisson's ratio	-	0.39
Specific heat	J/kg-C	2,230
Thermal conductivity	W/m-C	0.22
Melt density	g/cm^3	1.1912
Transition temperature	℃	230

The resin used for the analysis was Ultramid A3WG5. Table 2 lists the basic properties of the resin. The resin and mold temperatures recommended by the Moldflow Insight were 290°C and 85°C, respectively. However, a cooling analysis was not performed separately because the cooling of the mold was assumed to be uniform. For this assumption, the practical constraint that warpage optimization based on cooling analysis requires a large experimental scale and considerable computation time owing to the large number of iterations of the experiment was considered.

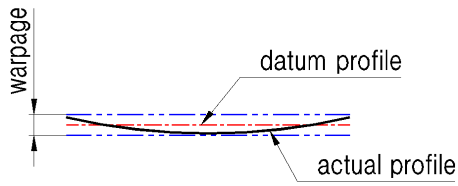
To select the optimal feed system, a full factorial experiment was conducted with resin temperature and packing pressure as three-level process variables. The three-level values of the resin temperature were 280°C, 290°C, and 300°C, and the three-level values of the packing pressure were 80%, 90%, and 100% of the maximum injection pressure. Other process conditions were set automatically or fixed to constant values in consideration of product formability and productivity. The injection time was set to automatic, the mold temperature was set to 60°C, the packing time was 7 s, and the cooling time was 30 s.

Because it is difficult to define accurately the geometry of the warping deformation occurring in each feature and calculate the actual warpage value, the warpages were quantified in an approximate manner.

First, in the case of Feature-A, the warpage was measured by calculating the distorted size of the outer edge profile — that is, the datum profile — showing the greatest deformation. The sampled nodes in the datum profile move to different positions depending on the degree of shrinkage of the resin at each node point. At this time, when the datum profile is offset inward and outward to include all the moved sampled



(a)



(b)

Fig. 4 Quantification of warpage((a) Feature-A, (b) Feature-B)

nodes, the minimum distance between the two offset profiles is defined as the warpage of Feature-A.

Next, for Feature-B of the planar shape, the warpage was measured by calculating the flatness from the deflection shape of the plane according to the analysis result. Specifically, the warpage was defined as the difference between the maximum and minimum deflections at the nodes sampled on the outer boundary edge with the largest deflection. Fig. 4 is a two-dimensional representation of the concept used to quantify the warpages of Feature-A and Feature-B.

Table 3 shows the results of analyzing the warpage by performing a full factorial experiment for each feed system. Here, A and B are the warpage of Feature-A and the warpage of Feature-B, respectively. Fig. 5 is a plot analyzing the average warpage value for each level of design variables, specifically, the feed system, resin temperature, and packing pressure, based on the warpage results in Table 3.

Regarding the feed system, in Case 1, the warpage of Feature-A was as negligible as 0.284 mm, while that of Feature-B was as high as 0.450 mm, demonstrating a significant imbalance between the two warpages.

Table 3 Full factorial experiment and warpage results

Experiments			Case 1		Case 2		Case 3	
#	T_{melt} (℃)	P_{pack} (%)	A (mm)	B (mm)	A (mm)	B (mm)	A (mm)	B (mm)
1	280	80	0.31	0.46	0.43	0.42	0.43	0.38
2	280	90	0.30	0.45	0.39	0.40	0.40	0.37
3	280	100	0.26	0.44	0.38	0.39	0.39	0.37
4	290	80	0.30	0.46	0.42	0.41	0.41	0.39
5	290	90	0.29	0.45	0.40	0.40	0.40	0.38
6	290	100	0.27	0.44	0.36	0.39	0.39	0.38
7	300	80	0.29	0.46	0.39	0.41	0.40	0.40
8	300	90	0.28	0.45	0.39	0.40	0.38	0.39
9	300	100	0.26	0.44	0.38	0.39	0.38	0.38

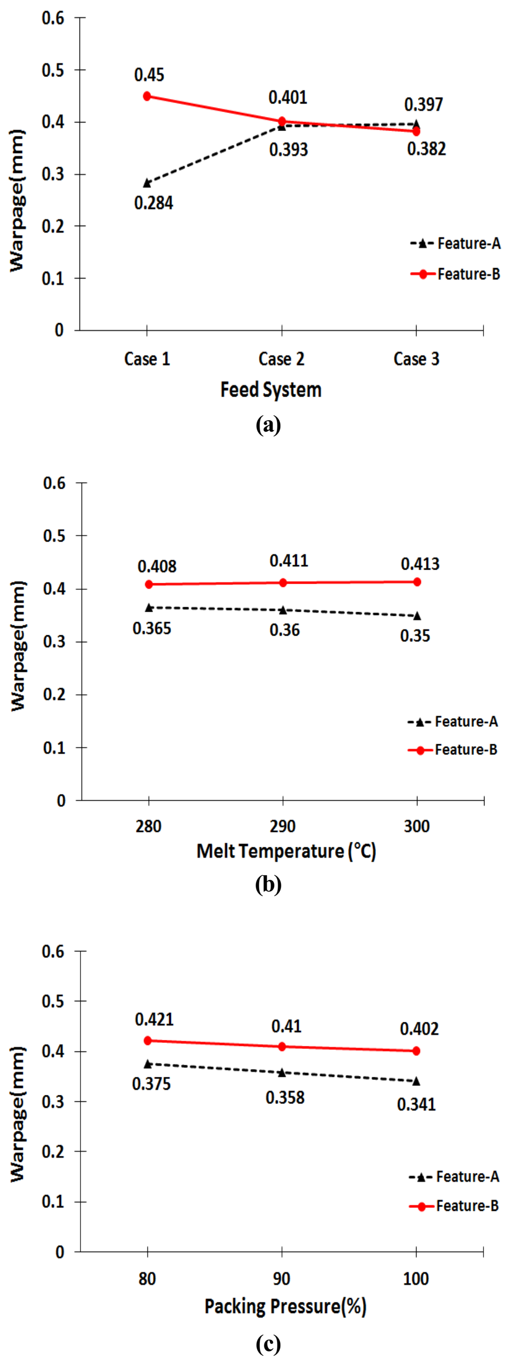


Fig. 5 Line plots of mean warpages by design level((a) feed system, (b) melt temperature, (c) packing pressure)

Table 4 Additional experiments and warpage results

Experiments		Case 2		Case 3	
#	P_{pack}(MPa)	A(mm)	B(mm)	A(mm)	B(mm)
1	70	0.33	0.38	0.32	0.37
2	90	0.28	0.36	0.28	0.35
3	110	0.25	0.34	0.24	0.33
4	130	0.22	0.31	0.20	0.31
5	150	0.18	0.29	0.17	0.29

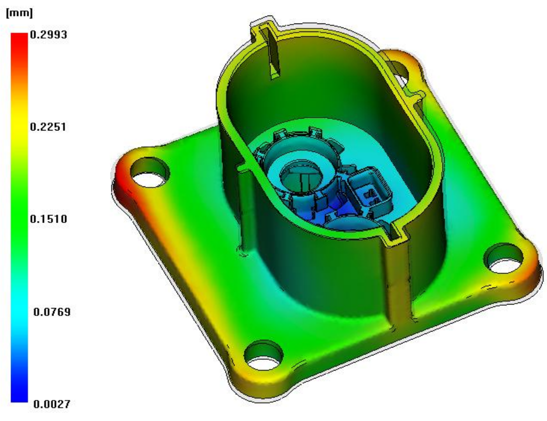
Meanwhile, Cases 2 and 3 were no better than Case 1 in terms of individual warpage, although in both cases, the warpage difference between the two features was quite negligible. Therefore, considering that each warpage of Feature-A and Feature-B should be minimized, Cases 2 and 3 are more appropriate as a feed system than Case 1. When comparing Cases 2 and 3, Case 3 is expected to have relatively better warpage results than Case 2, but the difference seems to be insignificant.

Meanwhile, for resin temperature, it has been observed that as the temperature rises, the warpage of Feature-A decreases, while that of Feature-B increases. However, the range of change in the warpages is so minute that it is negligible. Accordingly, it is analyzed that resin temperature has a limited effect on the warpages of the two features.

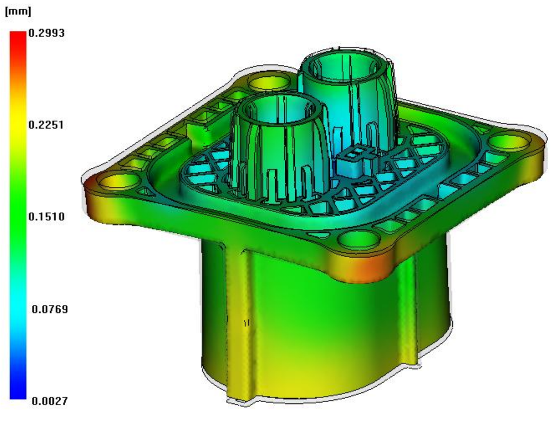
Conversely, in the case of packing pressure, as pressure increases, the warpages of both features tend to decrease consistently. This implies that if packing pressure greater than the maximum packing pressure set under the current experimental conditions can be applied, the two warpages can be further reduced.

In this study, based on the analysis for the results of the full factorial experiment above, additional optimization experiments were performed on the feed systems of Cases 2 and 3 using packing pressure as a single process variable. Resin temperature was set to 290℃, which is an intermediate level value. For further experiments, five levels of packing pressure were set, with the level values being 70 MPa, 90 MPa, 110 MPa, 130 MPa, and 150 MPa. This level range was determined by considering the capacity of the injection machine and the fact that the maximum injection pressures were 52.44 MPa and 50.68 MPa in Cases 2 and 3, respectively, at a resin temperature of 290℃. Table 4 demonstrates the results of additional experiments.

As previously estimated, as the packing pressure increased, the warpages of both Feature-A and Feature-B were found to further decrease. Comparing Case 2 and Case 3, the warpages in Case 3 were slightly better than those of Case 2 at all levels of



(a)



(b)

Fig. 6 Warpage results simulated in optimal design((a) Feature-A, (b) Feature-B) packing pressure, but there was no significant difference. As the packing pressure increased, the warpages of Case 3 and Case 2 showed almost the same numerical results. When the packing pressure was increased to 150 MPa, it was found that the warpages of Feature-A and Feature-B in both Case 2 and Case 3 satisfied the allowable limit of warpage, 0.30 mm.

Meanwhile, comparing the scrap weights of the feed systems shown in Table 1, the scrap amount of Case 2 employing the two-point gate is 4.54 g, but that of Case 3 that adopts the four-point gate is 8.06 g. Therefore, Case 2 has the advantage of reducing the amount of resin scrap by about 43.6% compared to Case 3. Accordingly, based on the warpage prediction results above and the analysis of resin economics, we decided Case 2 as the optimal design for the feed system. In addition, the optimal conditions for the process variables were determined to be the resin temperature of 290℃ and the packing pressure of 150 MPa. Under the optimal design conditions, the warpage of Feature-A was 0.18 mm and that of Feature-B was 0.29 mm. Fig. 6 shows the warpage results simulated under the optimal process conditions for the feed system of Case 2.

5. Conclusions

In this study, the feed system and process conditions to simultaneously minimize the warpages of the two shape features in the 2P Header HSG, a connector part for automobiles, were optimized through a full factorial experiment and subsequent experiments based on the injection molding analysis. The conclusions of this study are as follows;

1. The warpages of Feature-A and Feature-B, which are independent from each other, were defined geometrically, and the two warpages were quantified in an approximate manner using the injection molding analysis data and used for design optimization.
2. As a result of the average analysis of the warpages obtained by the full factorial experiment, the feed systems with the two-point gate and the four-point gate were suitable to minimize the two warpages at the same time. In addition, it was found that the resin temperature had little effect on the two warpages, while the packing pressure was an influencing factor.
3. To determine the optimal design, follow-up experiments were conducted for the two-point gated feed system and the four-point gated feed system, with packing pressure as the single process variable. Considering the warpage results and the economics of the resin, the optimal design was decided with the two-point gated feed system, the resin temperature of 290℃, and the packing pressure of 150 MPa. In the optimal design conditions, the warpage of Feature-A was 0.18 mm and that of Feature-B was 0.29 mm. It was confirmed that both warpages of Feature-A and Feature-B satisfies the allowable limit of 0.3 mm for component assembly.

Acknowledgment

This research was supported by Kumoh National Institute of Technology(2019-104-064).

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