

# Design of Feed System and Process Conditions for Automobile Lamp Garnish Lens with Injection Molding Analysis

Jong-Cheon Park<sup>\*,#</sup>, Man-Jun Yu<sup>\*\*</sup>, Ki-Yoon Park<sup>\*\*\*</sup>

<sup>\*</sup>Department of Mechanical Engineering, KIT, <sup>\*\*</sup>Department of Mechanical Engineering, Graduate School, KIT, <sup>\*\*\*</sup>Component Solution Research/Engineering Division, LG Electronics

## 사출성형 해석을 이용한 자동차 램프 가니쉬 렌즈의 유동기구 및 공정조건의 설계

박종천<sup>\*,#</sup>, 유만준<sup>\*\*</sup>, 박기윤<sup>\*\*\*</sup>

<sup>\*</sup>금오공과대학교 기계공학과, <sup>\*\*</sup>금오공과대학교 대학원 기계공학과, <sup>\*\*\*</sup>LG전자

(Received 3 September 2019; received in revised form 14 September 2019; accepted 26 September 2019)

### ABSTRACT

In this study, we design the feed system and process conditions for a lamp garnish lens of an automobile. For this purpose, four design alternatives are presented and injection molding simulation analyses are performed. The optimal feed system is selected by considering the formability of the product and the cost of mold manufacture. The product formability is assessed by the weld line, warpage, sink mark and the maximum injection pressure, whereas the mold-making cost is estimated by the number of valve gates in the hot runner system. To improve the product formability, process conditions are optimized using an experimental design approach named one-factor-at-a-time. No weld line is generated as a result of the optimization. In addition, it is found the warpage and sink mark are reduced while the maximum injection pressure is increased, compared with those before the optimization.

**Keywords** : Injection Molding Analysis(사출성형해석), Lamp Garnish Lens(램프 가니쉬 렌즈), Feed System(유동기구), Process Conditions(공정조건)

### 1. Introduction

The injection molding process is widely applied in the production of high strength, high precision and high performance products in various industries due

to its unique advantages and continuous development of new materials. In particular, computer simulations are increasingly contributing to the development and production of injection-molded products and molds, with the accuracy of quality predictions increasing<sup>[1-6]</sup>.

The lamp garnish lens of an automobile is an injection-molded product that is assembled and installed with the rear lamp of the automobile. Since

# Corresponding Author : cadpark@kumoh.ac.kr

Tel: +82-54-478-7297, Fax: +82-54-478-7319

Copyright © The Korean Society of Manufacturing Process Engineers. This is an Open-Access article distributed under the terms of the Creative Commons Attribution-Noncommercial 3.0 License (CC BY-NC 3.0 <http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

the product must have high transparency and excellent surface gloss, surface defects such as weld line and sink mark should be avoided as much as possible, and warpage defect should be minimized for product assembly.

In this research, injection molding simulation analysis is used to select a feed system suitable for the automobile lamp garnish lens product and to determine the optimal process conditions. To this end, we will present four design alternatives for the feed system employing hot runner system. Next, with the simulation using Moldflow<sup>[7]</sup>, we analyze the moldability of the product and then determine the optimal feed system in consideration of the economics of mold manufacturing. The research also optimizes the process conditions for the product and feed system using an experimental design approach, improving the formability of the product.

## 2. Lamp Garnish Lens Model and Feed System Design

### 2.1 Lamp garnish lens

Fig. 1 shows a three-dimensional shape of the lamp garnish lens(LGL) of an automobile. The product is symmetrical in the longitudinal direction, has a U-shaped cross section and is bent in the height direction. Further, ribs for ultrasonic welding are placed inside the product. The dimensions of the product measured by the bounding box are 797mm,

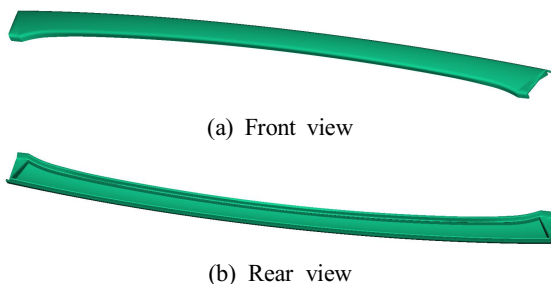


Fig. 1 3D shape of LGL(Lamp Garnish Lens)

51mm and 62mm in length, width and height, respectively. The wall thickness is 2.4mm and the rib thickness is 1.45mm to 1.65mm. Ribs have a maximum thickness near the left and right ends of the product.

### 2.2 Design alternatives for the feed system

The selection criteria for the feed system of LGL are the formability of the product and the manufacturing cost of the mold. Weld line<sup>[8]</sup>, warpage<sup>[8]</sup>, sink mark<sup>[8]</sup> and maximum injection pressure<sup>[9]</sup> are considered as properties for evaluating the product formability. It is necessary to avoid weld line in the product. Warpage and sink mark on both ends of the product should be minimized and maximum injection pressure should also be minimized.

Considering the appearance and shape features of LGL, the types and positions of gates applicable to mold design are limited. Fig. 2 shows a unit feed system designated to be applied to LGL, which adopts valve gate type of hot runner system. The structure of this unit feed system consists of cold gate, cold runner, cold sprue, hot gate, hot runner, and hot sprue. Fig. 3 presents four design alternatives that can be employed as the feed system of LGL in consideration of the mold manufacturing. Table 1 shows the design dimensions of the four feed systems.

Case-1 is a design where a single gate is placed in

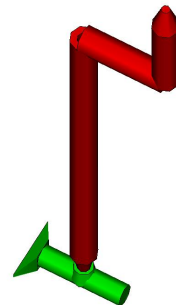
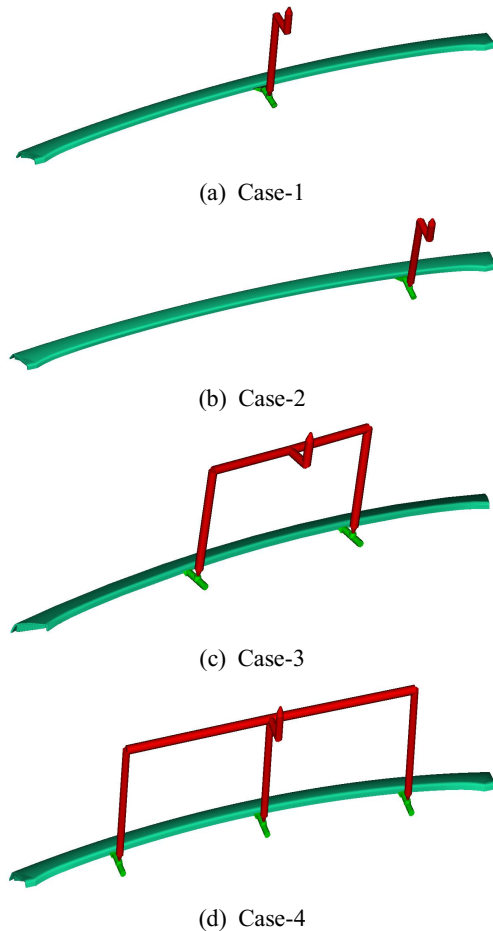


Fig. 2 Structure of unit feed system



**Fig. 3 Four design alternatives of LGL feed system**

the center of the product. Case 2 is designed with a single gate about 250mm away from the center of the product. This design is not part of the general design rules, but is proposed based on the mold design and production experience for LGL-like products. Case-3 is a two-point gate design with two unit feed systems symmetrically placed on the left and right side of the product center. In this design, a long weld line was initially expected in the center of the product due to the two gates. However, this design is presented to consider installing a local rapid heating device in the mold to eliminate the weld line, provided that other molding properties are expected to

**Table 1 Design dimensions of feed systems**

| Design Case                            |                 | 1 & 2    | 3                           | 4                           |
|--|-----------------|----------|-----------------------------|-----------------------------|
| No. of applied unit feed systems       |                 | 1        | 2                           | 3                           |
| Distance between unit feed systems(mm) |                 | -        | 262                         | 239                         |
| Cold feed system                       | gate            | type     | Fan / tapered rectangular   | Side / tapered rectangular  |
|  |                 | W×H (mm) | start: 30×1.8<br>end: 10×10 | start: 15×1.8<br>end: 10×10 |
|  |                 | L(mm)    | 6                           | 4                           |
|  | runner          | type     | non-tapered circular        |                             |
|  |                 | Φ(mm)    | 10                          |                             |
|  |                 | L(mm)    | 40                          |                             |
|  | sprue           | type     | tapered circular            |                             |
|  |                 | Φ(mm)    | start: 12, end: 9           |                             |
|  |                 | L(mm)    | 7                           |                             |
|  | Hot feed system | gate     | type                        | tapered circular            |
| Φ(mm)                                  |                 |          | start: 6<br>end: 10         | start: 4<br>end: 10         |
| L(mm)                                  |                 |          | 10                          |                             |
| runner                                 |                 | type     | non-tapered circular        |                             |
|  |                 | Φ(mm)    | 12.6                        |                             |
|  |                 | L(mm)    | 240                         | 662                         |
| sprue                                  |                 | type     | tapered circular            |                             |
|  |                 | Φ(mm)    | start: 12.6, end: 4         |                             |
|  |                 | L(mm)    | 12                          |                             |

be good in the simulation results. Case-4 is a three-point gate design with three unit feed systems, one in the center of the product and the other two arranged symmetrically on the left and right side of the product center.

On the other hand, among the feed systems that show good product formability from the analysis results, the design with the smallest number of valve gates in the hot runner system is most preferable in consideration of the manufacturing cost of the mold.

### 3. Injection Molding Analysis and Optimal Feed Design

#### 3.1 Injection molding analysis

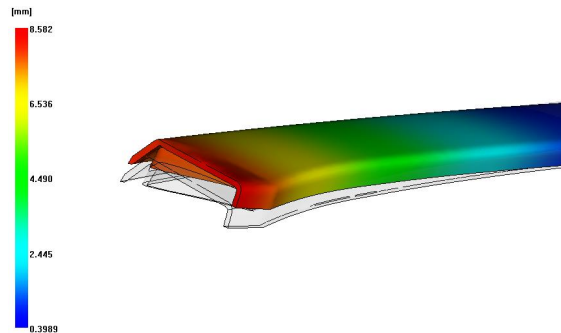
Finite element models were created for the LGL and four feed systems, and injection molding simulation and analysis were performed. The product model consisted of 76,370 triangular elements of the dual domain type<sup>[7]</sup>, and the feed system consisted of 53 to 185 one-dimensional elements of beam type. The resin used was PMMA-IH830C provided by LG Chem., and the fill-pack-warp module of Moldflow was used as a simulator. As the process conditions, the injection time was set at 3 seconds, the resin temperature at 260°C, the mold temperature at 80°C, the packing pressure at 60MPa, the packing time at 5 seconds, and the cooling time at 30 seconds. In this study, no cooling analysis was carried out assuming uniform cooling of the mold.

### 3.2 Analysis results and optimal feed system

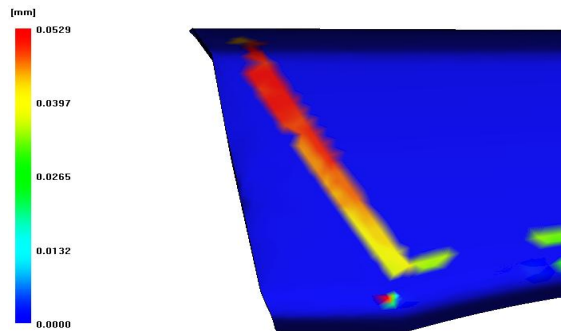
Table 2 shows the simulation results for weld line, warpage, sink mark and maximum injection pressure. Here, the warpage is defined as the maximum displacement at all finite element nodes of the product. The sink mark is the maximum estimate of surface indentation due to the thick ribs at both ends of the product where packing pressure transmission may be insufficient. In Case-1, no weld line was generated. However, it has been found that this design has structural limitations on resin filling and pressure transmission, which is attributed to the long flow length of resin, 400mm, from the gate. As a result, the maximum injection pressure was raised up to 107.9MPa, exceeding the design limit of 100MPa.

**Table 2 Simulation results for design alternatives**

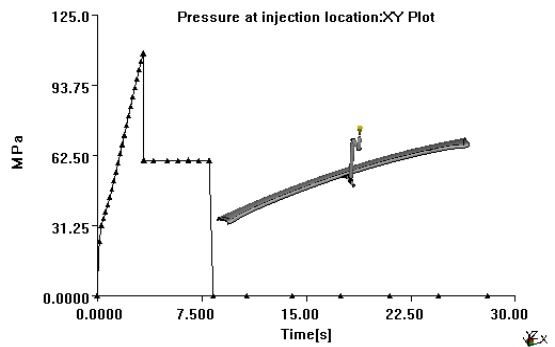
| Design | Weld line (mm) | Warpage (mm) | Sink mark (mm) | Max. inj. pressure (MPa) |
|--------|----------------|--------------|----------------|--------------------------|
| 1      | 0              | 8.582        | 0.0529         | 107.9                    |
| 2      | 0              | 7.844        | 0.0629         | 146.3                    |
| 3      | Approx. 70     | 9.121        | 0.0463         | 80.3                     |
| 4      | 0              | 9.155        | 0.0435         | 74.2                     |



(a) Warpage



(b) Sink mark

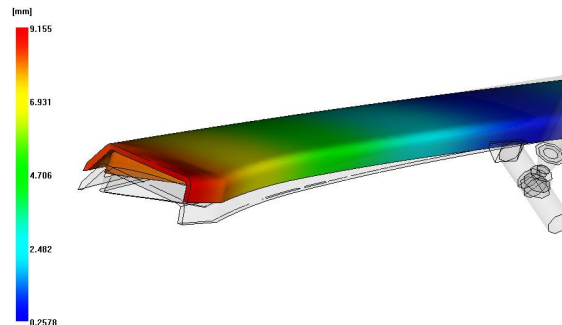


(c) XY plot of injection pressure

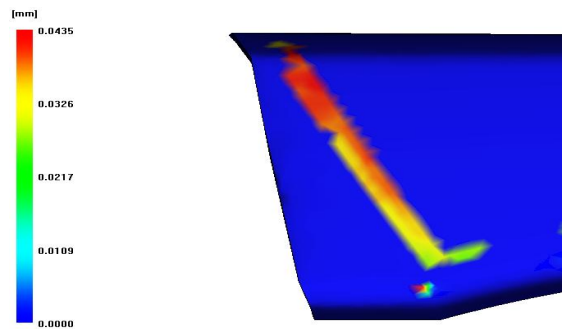
**Fig. 4 Simulation results for Case-1**

In addition, the sink mark showed a depth of 0.0529mm due to insufficient transmission of packing pressure, and the warpage was 8.582mm. Fig. 4 shows the simulation results for warpage, sink mark and maximum injection pressure for Case-1. In Case-2, also, there was no weld line in the product. The warpage was 7.844mm, the best among other

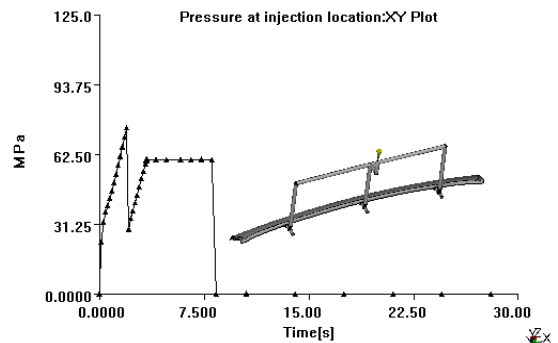
design cases. But the imbalance between the left and right flows of the resin due to the eccentricity of the gate position was identified as the main problem. As a result, the maximum injection pressure rose to  $146.3\text{MPa}$ , much higher than  $107.9\text{MPa}$  of Case-1. In the case of the sink mark, the estimate was small on the right side of the product with high resin pressure and sufficient packing pressure, but on the left with insufficient resin pressure and packing pressure, the estimate was very large,  $0.0629\text{mm}$ . Case-1 and Case-2 all have only one valve gate, so if you only consider the manufacturing cost of the mold, it would be the most preferred design. In both designs, however, the maximum injection pressure exceeds the design limit of  $100\text{MPa}$ , so a narrow tolerance for the adjustment of process conditions in the injection molding machine is expected and an injection molding machine with a higher clamping force may be required. Furthermore, these high injection pressures can cause flashes<sup>[8]</sup> on the parting surface of the mold, leading to defects in the appearance of the product. In Case-3 employing the two-point gate, the flow length of the resin was shorter than that of Case-1 and Case-2, and the flow balance was satisfactory. As a result, the maximum injection pressure was significantly lowered to  $80.3\text{MPa}$  and the sink mark improved to  $0.0463\text{mm}$ , but as expected, there was a serious weld line of about  $70\text{mm}$  in the center of the product. In order to eliminate the weld line, we considered the implantation of a local rapid heating device in the mold, but it was concluded that the solution was not efficient compared to the expected formability due to the complexity of the mold structure and the high mold-making costs. In Case-4 with the three-point gate, the valve gate in the middle of the product was opened first, and the left and right valve gates were set to open when the melt flow fronts reached the left and right gates. As a result, no weld line was generated. In addition, Case-4 has the shortest flow length and good flow balance, resulting in the best



(a) Warpage



(b) Sink mark



(c) XY plot of injection pressure

**Fig. 5 Simulation results for Case-4**

formability in terms of maximum injection pressure and sink mark properties among the four design alternatives. The maximum injection pressure was  $74.2\text{MPa}$ , the sink mark and warpage were  $0.0435\text{mm}$  and  $9.155\text{mm}$ , respectively. Fig. 5 shows simulation results for Case-4. In Case-4, the maximum injection pressure is lower than that of other design

alternatives, so the tolerance for adjusting process conditions is relatively wide and the appearance defects caused by flashes on the parting surface of the mold is less likely. Case-4 requires three valve gates, so it is the most unfavorable design in terms of mold manufacturing costs, but it was evaluated as the most advantageous design in view of expected quality relative to cost. Therefore, in this study, we selected the design of Case-4 as the feed system of LGL and optimized the process conditions to further improve the molding properties of LGL.

#### 4. Determination of Process Conditions

A traditional experimental design called one-factor-at-a-time(OFAT)<sup>[10]</sup> was used to determine the optimal process conditions. The OFAT approach is widely used in many areas to set up levels of design factors by conducting experiments, especially under time-constrained situations. This method will experiment by changing one factor at a time until the best level is found, with the other factors fixed. The factor is set to this level. The other factor then change until the optimal level is established and is always fixed at this level. The process repeats for the remaining factors. The process conditions and their three levels to be optimized by the OFAT approach are listed in Table 3. In this study, a total of 11 experiments were performed using the OFAT approach to obtain the optimal process conditions.

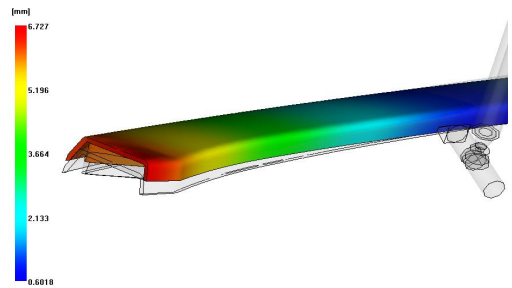
Table 4 shows the process conditions before and after the optimization. Fig. 6 illustrates the simulation

**Table 3 Process conditions and their three levels**

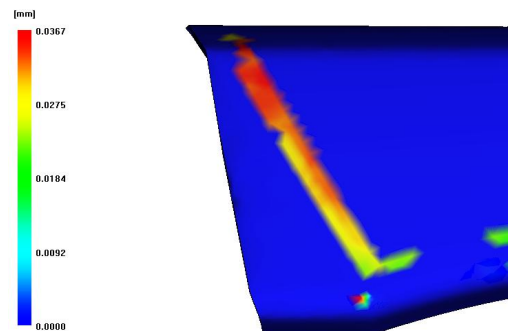
| Process condition | Description (unit)    | Level |     |     |
|-------------------|-----------------------|-------|-----|-----|
|                   |                       | 1     | 2   | 3   |
| $t_{fill}$        | Filling time(sec)     | 3     | 4   | 5   |
| $T_{melt}$        | Melt temperature(°C)  | 240   | 260 | 280 |
| $T_{mold}$        | Mold temperature(°C)  | 70    | 80  | 90  |
| $P_{pack}$        | Packing pressure(MPa) | 50    | 60  | 70  |
| $t_{pack}$        | Packing time(sec)     | 4     | 5   | 6   |

**Table 4 Process conditions before and after optimization**

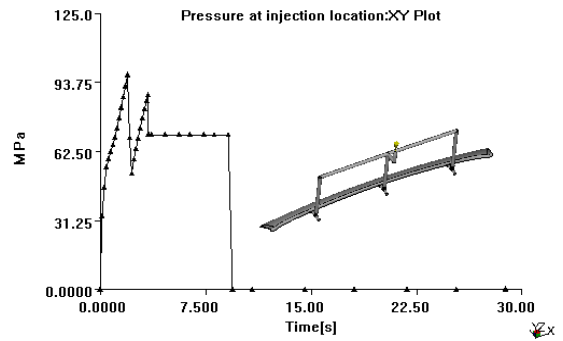
| Process condition | Unit | Before optimization | After optimization |
|-------------------|------|---------------------|--------------------|
| $t_{fill}$        | sec  | 3                   | 3                  |
| $T_{melt}$        | mm   | 260                 | 240                |
| $T_{mold}$        | mm   | 80                  | 90                 |
| $P_{pack}$        | sec  | 60                  | 70                 |
| $t_{pack}$        | °C   | 5                   | 6                  |



(a) Warpage



(b) Sink mark



(c) XY plot of injection pressure

**Fig. 6 Simulation results under optimized process conditions**

**Table 5 Comparison of simulation results before and after process conditions optimization**

| Optimization | Weld line (mm) | Warpage (mm) | Sink mark (mm) | Max. inj. pressure (MPa) |
|--------------|----------------|--------------|----------------|--------------------------|
| Before       | 0              | 9.155        | 0.0435         | 74.2                     |
| After        | 0              | 6.727        | 0.0367         | 96.9                     |

results of molding properties under the optimized process conditions. Table 5 shows a quantitative comparison of simulation results before and after the optimization. Under the optimal process conditions, both warpage and sink mark decreased, but the maximum injection pressure increased. This appears to be the result of a trade-off between molding properties that compete with each other during the optimization process. The warpage was  $6.727\text{mm}$ , which was  $2.428\text{mm}$  less than before the optimization, and the reduction rate was 26.5%. The sink mark decreased by  $0.0068\text{mm}$ , and the decrease rate was 15.6%. The reduction in both warpage and sink mark appears to be due to increased packing pressure and packing time at the optimal process conditions. On the other hand, the maximum injection pressure was  $22.7\text{MPa}$  higher than before the optimization, but it did not exceed the design limit of  $100\text{MPa}$ . The increase in the maximum injection pressure seems to be due to the reduced fluidity of resin, especially as the resin temperature was lowered by  $20^\circ\text{C}$  than before the optimization.

## 5. Conclusion

The contents and conclusions of this study are as follows.

1. Considering the mold manufacturing, we presented four design alternatives that can be applied as a feed system for the lamp garnish lens product of an automobile. Based on the simulation results, the product formability(weld line, warpage, sink mark and maximum injection pressure) and mold

manufacturing cost(number of valve gates) were analyzed for each design alternative, and the feed system with three gates was selected as the optimal design.

2. The OFAT approach was applied to determine the optimal process conditions for the product. Under the optimal conditions, three conflicting molding properties such as warpage, sink mark and maximum injection pressure were compromised. That is, the warpage was reduced by  $2.428\text{mm}$ , improved by 26.5%, and the sink mark was reduced by  $0.0068\text{mm}$ , improved by 15.6%. However, the maximum injection pressure increased by  $22.7\text{MPa}$  and showed an increase rate of 23.4%, but it did not exceed the design limit of  $100\text{MPa}$ .
3. In the case of warpage characteristics, it is necessary to consider the modification of the product shape for further reduction. In the future, we plan to conduct research that takes into account the shape parameters of the product, as well as the feed system and process conditions.

## Acknowledgment

This research was supported by Kumoh National Institute of Technology(2017-104-089)

## References

1. Lee, J. and Kim, J., "Micro Genetic Algorithm Based Optimal Gate Positioning in Injection Molding Design," Journal of mechanical science and technology, Vol. 21, pp. 789-798, 2007.
2. Vietri, U., Sorrentino, A., Speranza, V. and Pantani, R., "Improving the Predictions of Injection Molding Simulation Software," Polymer Engineering and Science, Vol. 51, No. 12, pp. 2542-2551, 2011.
3. Cho, S. B., Park, C. H., Pyo, B. G. and Choi, D.

- H., "Determination of Valve Gate Open Timing for Minimizing Injection Pressure of an Automotive Instrument Panel," Transactions of KSAE, Vol. 20, No. 4, pp. 46-51, 2012.
4. Wang, X., Zhao, G. and Wang, G., "Research on the Reduction of Sink Mark and Warp of the Molded Part in Rapid Heat Cycle Molding Process," Materials and Design, Vol. 47, pp. 779-792, 2013.
  5. Park, C. W., Lee, B. Y. and Lee, S. M., "Study of Injection Molding Process of Shift Lever Using Injection Molding Analysis," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 14, No. 6, pp. 7-13, 2015.
  6. Azaman, M. D., Sapuan, S. M., Sulaiman, S., Zainudin, E. S. and Khalina, A., "Optimization and Numerical Simulation Analysis for Molded Thin-Walled Parts Fabricated Using Wood-Filled Polypropylene Composites via Plastic Injection Molding," Polymer Engineering and Science, Vol. 55, No. 5, pp. 1082-1095, 2015.
  7. Shin, N. H., Oh, H. S. and Kang, S. G., The Optimization of Injection Molding Process by CAE, Daekwangseolim, Seoul, pp. 327-422, 2010.
  8. Shoemaker, J., Moldflow Design Guide: A Resource for Plastics Engineers, Hanser Gardner Publications, Inc., pp. 173-245, 2006.
  9. Kim, K. H. and Park, J. C., "Robust Design of Gate Locations and Process Parameters for Minimizing Injection Pressure of an Automotive Dashboard," Journal of the Korean Society of Manufacturing Process Engineers, Vol. 13, No. 6, pp. 73-81, 2014.
  10. 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. 126-129, 1995.