Injection molding optimization of a plastic housing for automobile internal rear-mirror camera

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Injection molding optimization typically focuses on optimization of processing conditions such as injection time, melt temperature, mold temperature, and so on. Seldom has been done towards optimization of both processing conditions and part geometry. To address this problem, this paper takes a plastic housing used for holding the automobile internal rear-mirror camera as an example, to study the methodology for optimization both the molding conditions, including mold temperature, injection pressure and gate location, as well as the thickness of the part's bottom plate. The orthogonal array experimental design approach is proposed to prepare the experiments, where the Moldflow CAE simulations are employed for each of the experimental runs. The study shows promising results in reducing the weld line defects that are commonly found in the production of this kind of plastic housing, which also demonstrates the effectiveness of the proposed methodology.

Introduction

Injection molding is the most commonly used method for production of plastic parts. To produce high quality plastic products, it is necessary to optimize the molding processing conditions. For this purpose, a lot of optimization methodologies have been proposed, such as by employing Genetic Algorithm [1-3], Particle Swarm Optimization [4-6], and other optimization algorithms [7-9]; or by using AI techniques to exploit expert knowledge [10-12]; or by using Design of Experiment method to accomplish experimental trials [13-14], and so on and so forth.

Even though it is often useful by direct optimization of processing conditions, it is however also often not so effective by only optimization of processing conditions, given that injection molding is a rather complicated process, where a lot of molding defects might occur, such as warping, meld lines, weld lines, sink marks, air traps, etc. Sometimes, it might not be possible to acquire high quality plastic products by taking into account of processing conditions alone. Furthermore, sometimes it is more effective by simply making some slight adjustment to part geometry, provided that such adjustment does not affect part functionality and other design requirements. For example, it is known that uneven part thickness may easily lead to sink marks, one of the severe quality defects that cause part appearance unacceptable to the customers. It is usually not feasible to completely eliminate sink mark defect by only optimizing the molding conditions. On the contrary, if we modify the part geometry by making it a constant wall thickness, this defect may no longer occur at all.

As such, it is necessary to optimize both the processing conditions and part geometry in order to accomplish high quality injection molded products. An overview of literature reveals that the work in this area is scarce. As an initial attempt, this paper takes a plastic housing used for holding the camera on the automobile internal rear-mirror as an example to study the methodology in injection molding optimization of both the processing conditions and the part geometry.

1. Injection molding CAE simulation

1.1. Analysis of the plastic housing

Fig. 1 shows the plastic housing to be studied in this research. The material of the part is ABS. The outside diameter of the part is 30mm, the inside diameter is 24mm, the diameter of the three rings which surround the center ring is 4mm. The height of the part is 6mm in total, where the bottom plate's thickness is 2mm. By employing Moldflow software for simulation of the injection molding process, we can see there are a lot of weld lines on it, as shown in Fig. 2. Weld lines are severe quality defect for this kind of plastic part, because they greatly reduce the part strength which is of high necessity, given the fact that the part is to be used for holding the camera in a vibrating environment, i.e. in an automobile.

Since the part is of varied wall thickness, to address the above problem, it might be is necessary to modify the part thickness and optimize the process conditions simultaneously, without, of course, affecting the function of the product.

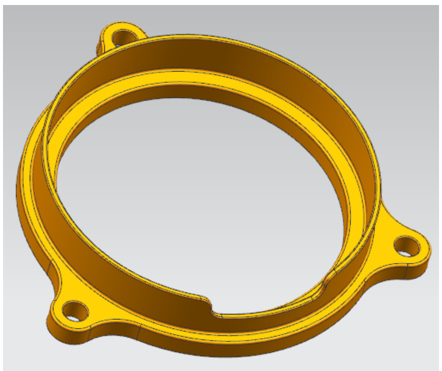

Fig.1 The geometric structure of the plastic housing

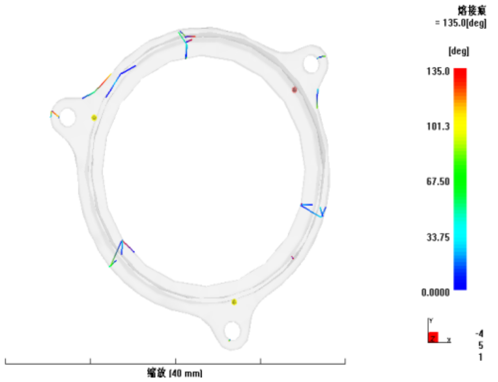

Fig.2 The weld lines in the plastic housing from simulation result

1.2. Optimization variables

Generally, the main factors affecting the generation of weld lines in an injection molded plastic part include such things as injection pressure, mold temperature and gate number, whereby the uniformity of part thickness will also affects the weld lines. Uneven thickness of the wall can cause uneven shrinkage during the cooling process which will lead to the occurrence of the weld lines.

Beside the product structure, the mold temperature, injection pressure, and gate number in molding process will affect the count of weld lines [15]. This is because, if the mold temperature is too low, the temperature gradient of the molten plastic along the wall will be too large, which will cause the difference between the internal and surface temperature in cooling; if the temperature is too high, the cooling time will be too long in the later phase of the molding, and the temperature difference of the cooling cycle will be too large [16]. Due to these reasons, this paper takes injection pressure, mold temperature, molding temperature, gate number and bottom plate thickness of the part to be the optimization variables.

2. The optimization of both process conditions and part thickness

2.1. Selection of optimization method

This paper proposes to use the orthogonal array experimental method [17-18] to carry out the simulation analysis with the above-mentioned four optimization variables. Each of the four factors (variables) has three levels of variation. The thickness levels of the bottom plate are selected according to the design requirement of the plastic part (including structural strength, load requirement, etc.), where they are 1.5 mm, 2.0 mm, 2.5 mm, respectively. According to the requirement of plastic material ABS, the mold temperature is selected to be 25 ℃,50℃,70℃, respectively. Similarly, the injection pressure is selected to be 130 MPa, 140 MPa, 150 MPa, respectively; and the number of gates is chosen to be 1, 2, 3, respectively. The experimental factors and levels are shown in Table 1.

Table 1

Experimental factors and their levels

level	Injection pressure （Factor.A）/MPa	Mold temperature （Factor.B） /℃	Number of gates （Factor.C） /	Bottom plate thickness （Factor.D）/mm
1	130	25	1	1.5
2	140	50	2	2.0
3	150	70	3	2.5

2.2. Experimental result and analysis

The experimental design is carried out using $L_9(3^4)$ orthogonal array. The experimental scheme and results are shown in Table 2. Since the weld lines represent the most significant type of molding defects for this kind of plastic part, the number of weld lines is chosen as the experimental indicator. The trends of all factors, i.e. factors A-D, affecting the weld lines are shown in Figure 3.

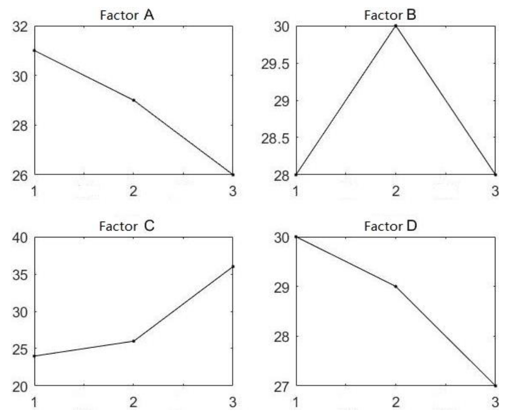

Fig.3 The influence of the factor level on the weld lines

In Table 2, the range *R* reflects the range of variation of the experimental indicator, namely, the weld line, when the factors change horizontally. The larger the *R*, the greater the influence of this factor on the experimental indicator, therefore the more important the factor is. According to the results of all values of *R*, it can be seen the result is C>A>B>D, in the order of importance. According to the experimental result, the optimization result is $C_3A_1D_1B_2$, that is to say, the injection pressure should be 130 Mpa, the mold temperature should be 50℃, the number of gates should be 3, and the bottom plate thickness should be 1.5 mm.

Table 2

Orthogonal experimental scheme and results

Experiment	Factor.A	Factor.B	Factor.C	Factor.D	Count of weld lines
1	1	1	1	1	9
2	1	2	2	2	10
3	1	3	3	3	12
4	2	1	2	3	8
5	2	2	3	1	13
6	2	3	1	2	8
7	3	1	3	2	11
8	3	2	1	3	7
9	3	3	2	1	8
T_1	31	28	24	30	T=86
T_2	29	30	26	29	
T_3	26	28	36	27	
Excellent level	1	2	3	1	
R	5	2	12	3	
Order of excellence	C>A>D>B				

Remarks：T_i is the sum of the experimental results of the *i*-th level of a factor, and *R* is the range of variation

Since the above optimization result, i.e. $C_3A_1D_1B_2$, is not included within the given experimental runs shown in Table 2, it is necessary to carry out a further experiment to verify the result. After applying Moldflow simulation analysis, it has been verified that the count of weld lines is reduced to be 7, and the overall length of weld lines is also shorter, which means that the defect of weld lines has indeed been reduced to a minimum.

Conclusion

Through the analysis of the structure of the plastic housing for automobile internal rear-mirror camera and the factors affecting the molding quality of the product from the injection molding process, an optimization method taking into account both processing conditions and part geometry is proposed, which exploited the orthogonal array experimental design approach. The result shows that, by modification of the part thickness and variation of the process conditions, the defect of weld lines can been reduced drastically, thereby improving the strength of the plastic housing to ensure the camera is fixed firmly to the automobile internal rear-view mirror. The optimization methodology may be applied to other injection molding problems as well, where it might be necessary to optimize both the injection molding process conditions and the part geometry so as to achieve most promising optimization result. In the future, we shall further conduct a comparative study of both optimization methods, namely, one with and one without considering the part geometry as the optimization variable. This is not trivial as it is not easy to make two optimization methods comparable, given that not only different number but also different type of optimization variables are involved for both situations.

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References

1. Deng Y-M., Zhang Y., Lam Y.C. A hybrid of mode-pursuing sampling method and genetic algorithm for minimization of injection molding warpage [J]. Materials & Design, 2010, 31(4): 2118-2123.
2. Liu X., Yang Y., Dong L., et al. Optimization design of double-toggle clamping unit of all electric injection molding machine based on genetic algorithm [J]. Plastics, 2016, 45(5): 17-21. (In Chinese)
3. Wahjudi A., Soepangkat B.O.P., Arriyani Y.F. Optimization of cable ties injection molding process using back propagation neural network and genetic algorithm (BPNN-GA) [J]. Applied Mechanics & Materials, 2016, 836:159-164.
4. Rui S.A. modified adaptive particle swarm optimization algorithm [C]. IEEE International Conference on Computational Intelligence and Security, 2017:511-513.
5. Xu G., Yang Z.T., Long G.D. Multi-objective optimization of MIMO plastic injection molding process conditions based on particle swarm optimization [J]. International Journal of Advanced Manufacturing Technology, 2012, 58(5-8):521-531.
6. Chen W., Han X.H., Zhou X.H., et al. Hybrid optimization approach for gas-assisted injection molding based on metamodeling and particle swarm algorithm [J]. Advanced Materials Research, 2010, 97-101(7):3353-3356.
7. Akbarzadeh A., Sadeghi M. Optimization of shrinkage in plastic injection molding process using statistical methods and SA algorithm [J]. Applied Mechanics & Materials, 2012, 110-116(9):4227-4233.
8. Huang F.L., Chen S.S., Gu J.M. Optimization of processing parameters in injection molding based on adaptive ant colony algorithm [J]. Advanced Materials Research, 2011, 179-180:304-310.
9. Farshi B., Gheshmi S., Miandoabchi E. Optimization of injection molding process parameters using sequential simplex algorithm [J]. Materials & Design, 2011, 32(1):414-423.
10. Parasuraman S., Oyong A.W., Lestari J.V. AI Techniques to estimate muscle force and joint torque for upper

extremity[J]. Key Engineering Materials, 2011, 467-469:788-793.
11. Sharma S., Pandey S.K. Integrating AI techniques in requirements phase: A literature review [J]. IJCA Proceedings on 4th International IT Summit Confluence 2013 - The Next Generation Information Technology Summit, 2013, Confluence 2013(2):21-25.
12. Raglend I.J., Veeravalli S., Sailaja K., et al. Comparison of AI techniques to solve combined economic emission dispatch problem with line flow constraints [J]. International Journal of Electrical Power & Energy Systems, 2010, 32(6):592-598.
13. Dang X-P. General frameworks for optimization of plastic injection molding process parameters [J]. Simulation Modelling Practice and Theory, 2014, 41: 15-27.
14. Xie L., Ziegmann G. Visualizing analysis for weld line forming in micro injection molding by experimental method [J]. Microsystem Technologies, 2009, 15(6):913-917.
15. Chen R.S., Hua Y.S., Huang D.Y. Modified theory of welding line and optimal design of material parameter for a thin part in the injection mould [J]. Journal of Polymer Engineering, 2011, 44(2):147–159.
16. Shuaib N.A., Nasir S.M., Fathullah M., et al. The influence of different mold temperature on warpage in a thin shallow injection molding process [J]. International Review of Mechanical Engineering, 2012, 6(1):11-16.
17. López A., Aisa J., Martinez A., et al. Injection molding parameters influence on weight quality of complex parts by means of DOE application: Case study [J]. Measurement, 2016, 90: 349-356.
18. Wu S.-T., Liu H.-B., LI X.-F. Multi-objective optimization of injection molding process of automobile bumper based on orthogonal experimental method [J]. China Plastics Industry, 2012, 40(8): 60-64. (In Chinese).