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Dimensional Optimization of Electric Component in Ultra Thin-wall Injection Molding by Using Moldflow Simulation

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초박육 사출성형에서 Moldflow 시뮬레이션을 활용한 전자부품의 형상 최적화

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ABSTRACT

Micro-structure components applied to various disciplines are steadily demanded with lighter weight and better quality. This is because that ultra thin-wall injection molding has been paid attention with a lot of benefits such as cost reduction, shorter process period, and so forth. However, this technology is complicate and difficult to obtain high quality of products compared with conventional injection molding due to warpage caused by uneven shrinkage and molecular orientation. Since warpage of products directly affects product quality and overall performance of devices, it is essential to predict deformation behavior to achieve high precision of molded products. Therefore, this study aims to find out adequate thin-wall mold design for FPC connector housing by employing Moldflow simulation before application. In addition, experimental research is performed by using a fabricated mold structure based on simulated results to prove accuracy and reliability of the suggested simulation for warpage analysis.

Keywords : Micro-electric Component(소형 전자부품), Ultra Thin-wall Plastic Injection Molding(초박육 사출성형), Dimensional Optimization(형상 최적화), Moldflow Simulation(Moldflow 해석)

1. Introduction

The interest in reducing weight, material cost and size of plastic products has pushed toward developing technology of thin-wall plastic injection molding. In micromechanics, microelectronics, and biomedical industries, demand for portable and compact devices have significantly increased[1,2]. This phenomenon requires to produce miniaturized size of internal printed circuit board(PCB) modules with high level of integration. Therefore, flexible printed circuit(FPC) connectors which join PCB modules have a crucial role to transmit electric signals adequately. However,

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small sized thin-wall FPC connector housing tends to loose contact to boards in comparison with conventional ones due to warpage affected by various reasons in the injection molding process. As a consequence, it brings out many problems with increasing electrical resistance and disconnecting electric signals. Hence, it is necessary to enhance structural stability of the thin-wall plastic housing to deal with connecting signals safely.

The FPC connector housings fabricated by injection molding with high temperature and pressure need different mold designs dependent on the diverse shape of products. However, it has difficulty in manufacturing all of the mold structures and experiments in practice. Therefore, it needs to analyze and predict an optimal structure with less deformation prior to fabrication in order to reduce burden of cost and time. In previous studies, they have carried out numerical analysis of warpage for thin-wall plastic products and evaluated the effects of various factors, for instance packing pressure and time, mold temperature as well as melt temperature. On the other hand, few papers have evaluated reliability by comparing difference between simulated models and actual products of miniaturized electric parts[3-5].

Therefore, this study analyzes warpage of the FPC connector housing with a variety of dimensional parameters employing Moldflow as computer aided engineering to derive the optimal structure. In addition, an actual plastic model would be fabricated using a new mold structure, and deflection is measured to verify reliability of simulations.

2. Simulation Conditions

2.1 Material

Liquid crystal polymer(LCP) used in this study is widely applied in automobile, aeronautical and electric industries as a new material. It has outstanding features such as thermal characteristic and mechanical strength in solidified state as well as low viscosity in molten state. In addition, this polymeric material is widely adopted in the injection molding due to high resistance of corrosion to the mold structure compared to metallic materials. In experimental study for verification of the simulation analysis, LCP S475 is used and mechanical properties are listed in Table 1.

Table 1 Mechanical properties of LCP S475

Properties	Values
Density(g/cm^3)	1.65
Tensile strength(MPa)	140
Tensile elongation(%)	1.8
Flexural strength(MPa)	180
Flexural modulus(MPa)	12,500
Flexural strain(%)	2.5

2.2 Simulation Methods

In the injection molding process, warpage of fabricated components is inevitably induced due to various reasons such as residual stress, temperature change and so forth. Since it has an influence on overall quality of products, it is important to propose the optimum methodology at design stage in order to minimize deformation in process.

This paper adopts a simulation approach which could reduce time and cost at the initial stage to predict warpage of FPC connector housing. Since geometry of the product is also a crucial factor for deflection, it is important to set dimensional values. Following dimensions are obtained from previous manufactured data and expert's advice. The shape of the conducted product in this study is represented in Fig. 1. Total length along the x-axis and A are fixed as 30mm and 0.3mm respectively. The geometry of the product is also an crucial factor for deflection.

Other dimensions which affect quality of the thin-wall plastic part are listed in Table 2.

In order to verify the effect of product shape on warpage behavior and increase high predictive accuracy rate in comparison with experimental results,

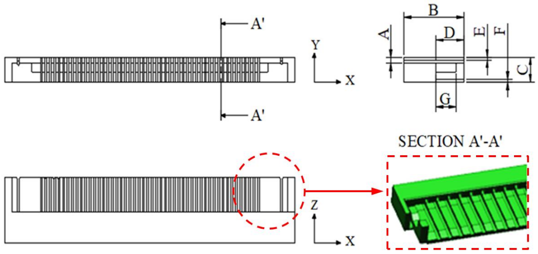


Fig. 1 Basic design of FPC connector housing

Table 2 Product dimensions for warpage analysis

No.	Dimensions(mm)						
	A	B	C	D	E	F	G
1	0.3	3.9	1.3	1.6	0.15	0.15	1.15
2	0.3	2.9	1.3	1.6	0.15	0.15	1.15
3	0.3	3.4	1.0	1.6	0.15	0.15	1.15
4	0.3	3.4	1.6	1.6	0.15	0.15	1.15
5	0.3	3.4	1.3	2.1	0.15	0.15	1.15
6	0.3	3.4	1.3	1.1	0.15	0.15	1.15
7	0.3	3.4	1.3	1.6	0.1	0.15	1.15
8	0.3	3.4	1.3	1.6	0.2	0.15	1.15
9	0.3	3.4	1.3	1.6	0.15	0.1	1.15
10	0.3	3.4	1.3	1.6	0.15	0.2	1.15
11	0.3	3.4	1.3	1.6	0.15	0.15	1.4
12	0.3	3.4	1.3	1.6	0.15	0.15	0.9

deflection in both of y and z-directions is predicted by employing Autodesk Moldflow Insight based on six different design parameters. From Fig. 2 which illustrates an evaluated method for y-directional warpage, quantities of bending deformation are measured based on reference points on the xy plane. In addition, torsional deformation in z-direction is simulated based on the yz plane.

In Moldflow simulation, there are three mesh types for analysis which include midplane, 3D, and dual domain. Since each type has different characteristics the proper type should be selected taking into account manufactured products and molding process[6]. In this study, 3D mesh analysis is applied to the molded parts with tetrahedral elements considering complicated shape of housing. Global edge length sets 0.15mm.

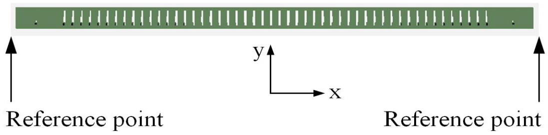


Fig. 2 Warpage measurement method in y-direction

Table 3 Simulated conditions for warpage analysis

Items		Conditions
Mesh type		3D mesh
Global edge length		0.15
Tetra layer		6
Mold temperature(^{o}C)		100
Injection material		LCP S475
Injection time(sec)		0.08
Velocity/Pressure switch-over(%)		98
Pack/Holding control	1^{st} time(sec)	0.03
	2^{nd} time(sec)	0.10
	1^{st} press.(kg/cm^2)	300
	2^{nd} press.(kg/cm^2)	250
Cooling time(sec)		2.00

Other parameters related to the injection molding process, which are 100^{o}C of mold temperature, 0.08s of injection time, and 2s of cooling time are listed in Table 3.

3. Warpage Analysis

The Moldflow simulations for warpage analysis of FPC connector housing were carried out based on determined dimensional parameters and conditions as listed in Table 2 and Table 3 respectively.
Table 4 showed the simulated results of warpage behavior in two different directions. In order to observe dimensional changes in aspects of direction and shape, warpage simulation in y-direction was displayed with 20 of scale factor as shown in Fig. 3. As can be seen in y-directional warpage, the maximum value obtained in no. 7, about 0.195mm

Table 4 Simulated results of warpage in directions

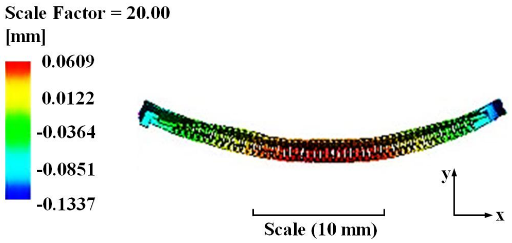
No.	y-direction(mm)	z-direction(mm)
1	0.079	0.073
2	0.057	0.058
3	0.065	0.063
4	0.065	0.058
5	0.059	0.070
6	0.091	0.069
7	0.195	0.049
8	0.051	0.066
9	0.041	0.069
10	0.115	0.071
11	0.070	0.068
12	0.069	0.055

while minimum value was 0.041mm in no. 9.

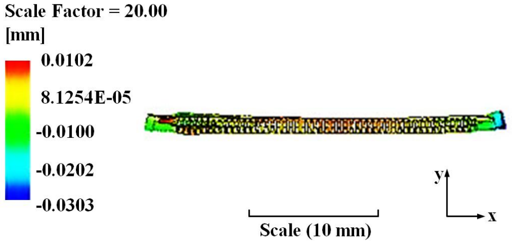
Molecular orientation was one of the main factor to generate warpage of the thin-wall plastic part. To verify correlation between molecular orientation and warpage, molecular orientation distribution along material flow was performed in Moldflow as shown in Fig. 4. In analysis of molecular arrangement, at high degree close to 1, molecules were aligned uniformly to material flow from left to right, so it resulted in minimized distortion of the product. In contrast, random arrangement of orientation which was close to 0 led to increasing the level of warpage. In simulation no. 7 represented in Fig. 4(a), inconsistent molecular orientation with low degree about 0.69 over the product was contributed to the maximized warpage in the y-direction. However, in case of no. 9 shown in Fig. 4(b) relatively high degree with 0.99 of molecular orientation gave less warpage value.

Therefore, it convinced that molecular alignment had significant influence on the warpage problem.

Fig. 5 showed results of theoretical simulation in z-direction. Minimum distortion was about 0.049mm in no. 7, which was 1.5 times less than maximum value in no. 1 corresponding to 0.073mm. According to the results from conducted simulations, warpage in y-direction was the vital factor for product performance compared with values in z-direction. In contrast, the values of z-directional deflection were almost same in each condition. It seemed that the ratio of width and height was quite small compared to the ratio of width and length in the xy plane. Therefore, it indicated that z-directional warpage had the little effect of product stability.

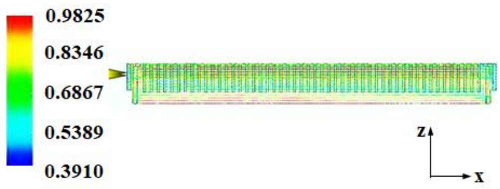


(a) Max. warpage in simulated no. 7

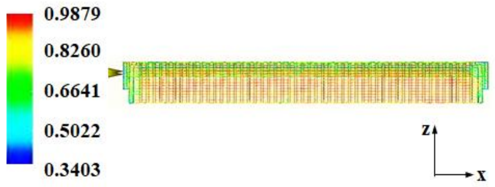


(b) Min. warpage in simulated no. 9

Fig. 3 Simulated warpage analysis in y-direction

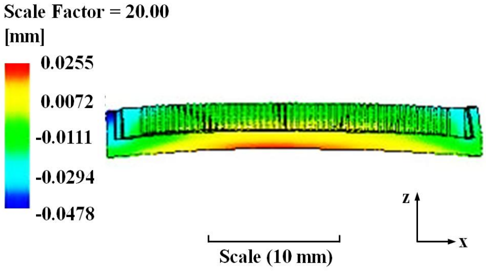


(a) Molecular orientation distribution in no. 7

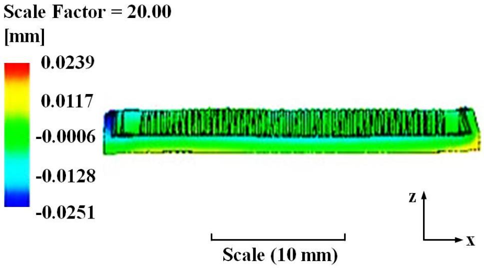


(b) Molecular orientation distribution in no. 9

Fig. 4 Molecular orientation in y-direction



(a) Max. warpage in simulated no. 1



(b) Min. warpage in simulated no. 7

Fig. 5 Simulated warpage analysis in z-direction

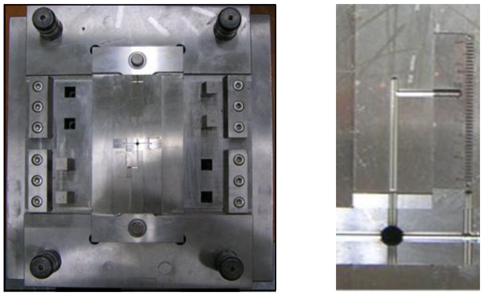


Fig. 6 Fabricated injection mold structure

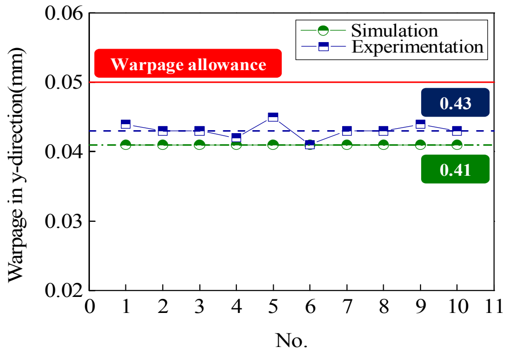


Fig. 7 Results from simulation and experimentation

4. Experimental Verification

Based on the warpage simulations in y-direction, the optimal dimensions with minimum deflection of FPC connector housing were derived from simulated no. 9 corresponding to A of 0.3mm, B of 3.4mm, C of 1.3mm, D of 1.6mm, E of 0.15, F of 0.1mm, and G of 1.15mm.

To verify applicability and feasibility of warpage simulations in practice, an injection mold structure for the ultra thin-wall electric component which was shown in Fig. 6 was manufactured based on conducted results. The fabricated mold and core materials were SM55C and PD613 respectively. The type of mold was two plate slide with submarine gate and its dimension was 200 × 240mm. 10 sets of samples were tested by new injection mold with same process parameters as listed in Table 3 by using an electric injection molding machine(SE18DUZ, Sumitomo) to achieve high level of dimensional accuracy compared with warpage prediction obtained from simulations. Experimental material was LCP S475 as mentioned in section 2.1. After fabrication, warpage in y-direction was measured by an optical microscope(MF-A2010, Mitutoyo).

Fig. 7 showed compared results between simulation analysis and experimentation. In comparison with predicted simulation results as 0.41mm, the averaged warpage of fabricated samples was about 0.043mm corresponding to 95.1% of accuracy rate. Although experimental results were not completely accurate, it was clearly noted that simulated prediction was the useful and reliable method to analyze warpage of ultra thin-wall parts in the injection molding process.

5. Conclusions

In order to save cost and improve stability of products, it is important to predict an optimal structure prior to fabrication. In this study, dimensional warpage of FPC connector housing was simulated applying Moldflow with various dimensional conditions and then simulated results were compared results from experimentation to exhibit consistency between both approaches. As a results, the following conclusions can be drawn :

1. Minimum and maximum deflection in y-direction were about 0.041mm in simulated no. 9 and 0.195mm corresponding in no. 7 respectively. In contrast, minimum and maximum warpage in z-direction were observed no. 7 as 0.049mm and no. 1 as 0.073mm respectively.
2. According to results, z-directional warpage could not affect product performance compared with the values in y-direction.
3. The difference of warpage quantity between Moldflow simulation and experiments was about 0.02mm with 4.9% of error rate. Therefore, it was concluded that the simulation approach was feasible to apply warpage analysis in ultra thin-wall injection molding process.

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