STUDY ON WARPAGE OF CD & DVD DISCSSUBSTRATE BY INJECTION MOLDING PROCESS

Hoang Van Thanh[*], Tran Dinh Son[**]

The University of Danang, University of Science and Technology;
[*]hvthanh@dut.udn.vn, [**]hoangvanthanh_03c1b@yahoo.com

Abstract - This research investigated the optimization of injection molding parameters for the minimum warpage of CD & DVDdisc substrate of Polycarbonate (PC). CD & DVD disc substrate was first designed by Pro/E 5.0. The Moldflow Plastics Insight 6.1 is used to mesh and simulate the warpage. In order to find out recommended parameters, the study used Taguchi technique in decreasing warpage of CD & DVD substrate. Parameters or factors employed are mold temperature, melt temperature, packing pressure, packing time, and cooling time. An ANOVA table was used to examine the significance of parameters. Results of variance analysis show that packing time is considered as the most significant parameter for the minimum warpage of CD & DVD disc substrate. Cooling time and mold temperatureare found as the second and third most significant parameters in this study. The recommended parameters were established and then verified by the injection molding simulation and the minimum warpage obtained was 0.1627mm.

Key words - CD & DVD production; injection molding process; warpage; Taguchi Method; parameters.

1. Introduction

Compact Discs (CDs) and Digital Versatile Discs (DVDs) are electro-optical devices. Nowadays, CD& DVD discs are widely used in recording or reading data. The warpage of CD & DVD discs plays an important role in their working quality [1]. The quality mainly depends on CD & DVD production by injection molding process. Some results of previous studies show relating to CD & DVD production. Shia-Chung Chen et al. [2] studied mold temperature variation for assisting micro-molding of DVD micro-featured substrate. Pulsed cooling technology has been successfully employed in low cycle time molding cases to either reduce cycle time or improve part qualities without a cycle time increase, or both. Cheng-Hsien Wu et al. [3] investigated the application of injection molding and injection compression molding processes to produce diffraction gratings. Grating made by injection compression molding has a much smaller warpage than that made by injection molding. Jeong Ho Moon et al. [4] developed coatings for optical discs in high-density digital versatile disc system (HD-DVD). The result shows that HD-DVD has good optical and mechanical properties.

Those studies above have improved the qualities of the CD & DVD. The objective of this study is to investigate injection molding parameters affecting warpage of CD&DVD substrate products using Taguchi method thanks to simulation. This problem needs to be made better at disc manufacturing Company, Hoa Cam Industrial Zone, Danang [5].

2. Experimental Set-up and Method

2.1. Material and injection molding machine

The material used in this study is PC (Panlite L-1225-LM) supplied by Teijin Chemical Ltd. Figure 1 illustrates the relationship of specific volume, temperature and pressure of PC material. Simulation set-up of an electrical injection machine is from Welltec Machinery Ltd. The mesh model is established with solid mesh number of 150968 as shown in Figure 2.

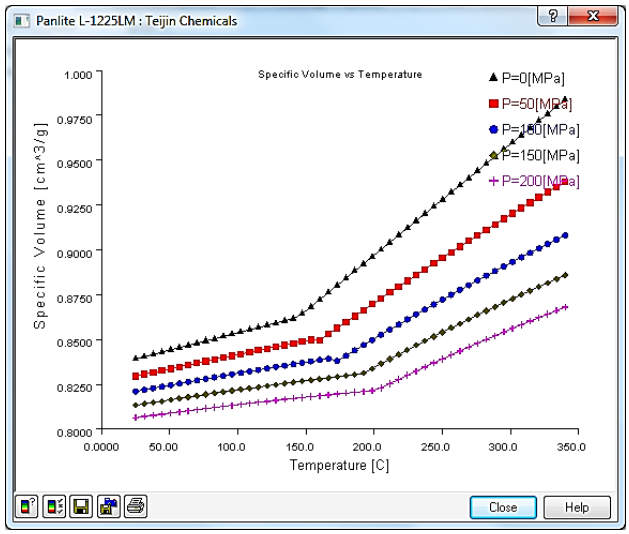

Figure 1. *pVT property of PC material*

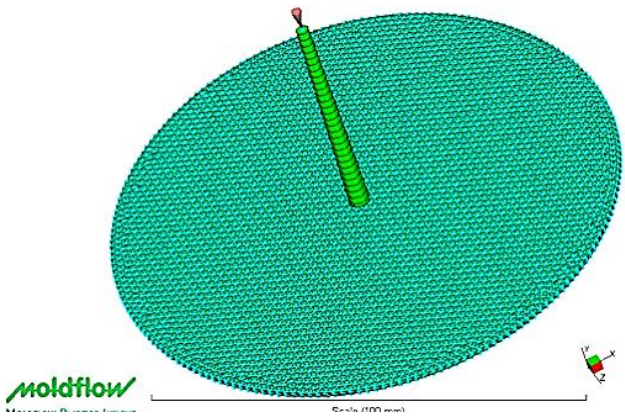

Figure 2. *Mesh model*

2.2. Design of experiment

Table 1. *The control factors and levels of Taguchi experiments*

Factors	Levels		
	1	2	3
Mold temperature A (0C)	70	80	90
Melt temperature, B (0C)	290	310	330
Packing pressure, C (MPa)	10	12	14
Packing time, D (s)	1.5	2.5	3.5
Cooling time, E (s)	2	3	4

Table 2. *Design Table L_{27} of Experimental Method*

Test No.	A	B	C	D	E
	Mold temp.	Melt temp.	Packing pressure	Packing time	Cooling time
1	1	1	1	1	1
2	1	1	1	1	2
3	1	1	1	1	3
4	1	2	2	2	1
5	1	2	2	2	2
6	1	2	2	2	3
7	1	3	3	3	1
8	1	3	3	3	2
9	1	3	3	3	3
10	2	1	2	3	1
11	2	1	2	3	2
12	2	1	2	3	3
13	2	2	3	1	1
14	2	2	3	1	2
15	2	2	3	1	3
16	2	3	1	2	1
17	2	3	1	2	2
18	2	3	1	2	3
19	3	1	3	2	1
20	3	1	3	2	2
21	3	1	3	2	3
22	3	2	1	3	1
23	3	2	1	3	2
24	3	2	1	3	3
25	3	3	2	1	1
26	3	3	2	1	2
27	3	3	2	1	3

The control parameters selected in this study are mold temperature (A), melt temperature (B), packing pressure (C), packing time (D), and cooling time (E) [6, 7, 8]. Table 1 shows the control factors and levels of Taguchi experiments.

In order to evaluate the effects of the injection molding parameters to the warpage of the CD& DVD substrate, an L_{27} orthogonal array [9] of three levels with 5 parameters shown as Table 2, was used for experimental design. Twenty seven treatments were performed and each one was simulatedone time.

The quality characteristic is warpage. The signal-to-noise (S/N) ratio is usually used to justify the effects of parameters. In this investigation, the minimum warpage is desired. Therefore, the quality characteristic for warpage is Smaller-The-Better (STB) expressed as the equation 1 [9].

$$\eta_{STB} = -10log\left[\frac{1}{n}\sum_{i=1}^{n} y_i^2\right] \quad (1)$$

Where η_{STB} is the Signal-to-Noise ratio for STB, y_i is the experimental value of i^{th} part and n is the total number of experimental parts. This study selected n of 1 (n=1). According to the Taguchi's technique, a smaller Signal-to-Noise value indicates better quality characteristic. Therefore, the objective of this experiment is to minimize the Signal-to-Noise value (η_{STB}). It means that desired values are minimum warpage.

3. Result and Discussion

Table 3. *The Taguchi L_{27} orthogonal array withExperimental results for warpage*

Test No.	A	B	C	D	E	Warpage	S/N ratio (dB) η_{STB}
1	70	290	10	1.5	2	0.2178	13.2388
2	70	290	10	1.5	3	1.213	-1.6772
3	70	290	10	1.5	4	1.213	-1.6772
4	70	310	12	2.5	2	0.2268	12.8871
5	70	310	12	2.5	3	0.3120	10.1169
6	70	310	12	2.5	4	0.3120	10.1169
7	70	330	14	3.5	2	8.901	-18.9888
8	70	330	14	3.5	3	8.901	-18.9888
9	70	330	14	3.5	4	0.2396	12.4103
10	80	290	12	3.5	2	0.2255	12.9371
11	80	290	12	3.5	3	1.599	-4.0770
12	80	290	12	3.5	4	1.599	-4.0770
13	80	310	14	1.5	2	0.2285	12.8223
14	80	310	14	1.5	3	0.2288	12.8109
15	80	310	14	1.5	4	0.2288	12.8109
16	80	330	10	2.5	2	0.2321	12.6865
17	80	330	10	2.5	3	0.2331	12.6492
18	80	330	10	2.5	4	0.2331	12.6492
19	90	290	14	2.5	2	0.2303	12.7541
20	90	290	14	2.5	3	1.735	-4.7860
21	90	290	14	2.5	4	1.735	-4.7860
22	90	310	10	3.5	2	0.3059	10.2884
23	90	310	10	3.5	3	11.46	-21.1837
24	90	310	10	3.5	4	11.46	-21.1837
25	90	330	12	1.5	2	0.2301	12.7617
26	90	330	12	1.5	3	0.2325	12.6715
27	90	330	12	1.5	4	0.2325	12.6715

Table 4. *Response table for S/N Ratios, STB for warpage*

Level	Mold temp.	Melt temp.	Pack. pressure	Pack. time	Cool. time
1	1.9376	1.9833	1.7545	9.6037	9.0430
2	9.0236	4.3873	8.4454	8.2542	-0.2738
3	1.0231	5.6136	1.7843	-5.8737	3.2150
Delta (Δ)	8.0005	3.6303	6.6910	15.4774	9.3168
Rank	3	5	4	1	2

Table 5. *ANOVA for significant parameters of warpage*

Source	**SS**	**dof**	**MS**	**F**	**P**
A. Mold. temp.	345.16	2	172.58	1.88	0.185
B. Melt temp.	61.39	2	30.69	0.33	0.721
C. Pack. pres.	267.42	2	133.71	1.46	0.263
D. Pack. time	1322.90	2	661.45	7.20	0.006
E. Cool. time	398.82	2	199.41	2.17	0.147
Error	1470.31	16	91.89		
Total	3866.01	26			

Table 3 shows the experimental results, and S/N ratios of the warpage of 27 different experimental conditions. The results represent large deviations of test 7, 8 and 23, 24 in comparison with others S/N ratios, but the deviations only occur at the runner system. The response is warpage in mm. The values in Table 4 are calculated by means of the mean value of all experiments that are the same level. The Delta (Δ) is defined as the equation (2). The value of delta (Δ) reflects the significance rank of each factor.

$$\text{Delta } (\Delta) = \max(S/N) - \min(S/N) \quad (2)$$

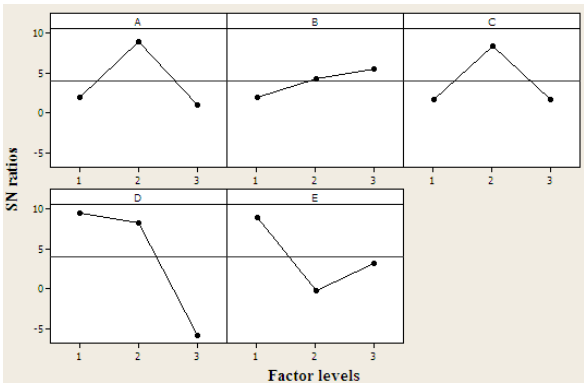

Figure 3. *S/N plot of experimental results for Warpage*

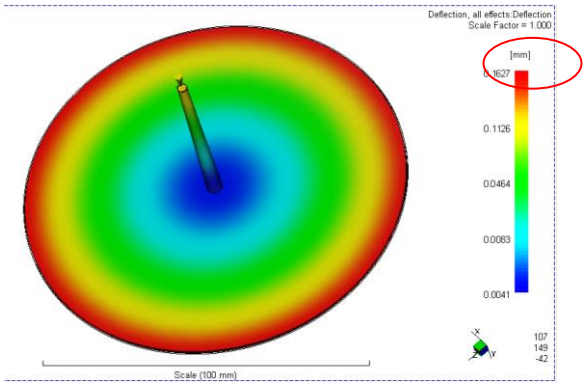

Figure 4. *The warpage after verification*

Figure 3 is the Signal-to-Noise ratio plot of experimental results for warpage testing. It is obvious that warpage decreases with the increase in packing time and with the decrease in melt temperature. Mold temperature, packing pressure, and packing time increasing from level 2 to level 3 lead to the decrease in warpage. The warpage increases when levels of mold temperature, melt temperature, and packing pressure are from level 1 to level 2. Recommendedsetting of parameters is $A_2B_3C_2D_1E_1$, i.e., A = 80 ^{0}, B = 330^{0}C, C = 12 MPa, D = 1.5 s, and E = 2 s. Table 5 is the results of the ANOVA analysis and the packing time is the most significant parameter with a confidence level of 99%.

Verification test of recommendedparameters:

According to Figure 3, the verification parameters are A_2 B_3 C_2 D_1 E_1, namely, mold temperature of 80^{0}C, melt temperature of 330^{0}C, packing pressure of 12 MPa, packing time of 1.5 s, and cooling time of 2 s. After experiment with these verification parameters, experimental results show that minimum total warpage 0.1627mm. It can be clearly seen that these values are much lower in comparison with the warpages of CD & DVD substrate in 27 tests before verification. Figure 4 is illustration of warpage of CD&DVD substrate after verification test.

4. Conclusion

This study has investigated the effect of injection molding parameters to warpage of CD & DVD substrate due to Taguchi L_{27} orthogonal array. With the recommended parameters achieved from the experimental design, packing time is the most significant parameter for reduction of the warpage problem. Longer packing time results in the lower warpage. Cooling time and mold temperature have been found as the second and third most significant parameters in this study.

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