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Optimization of Injection Molding Process Parameters for Improved Moldability of Plastic Stand Necks

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Abstract

With the increasing popularity of OLED TVs, the demand for them and OLED TV stands, has been increasing. OLED TV stands are typically manufactured via a plastic injection molding method, and are more likely to possess dimensional errors than other products fabricated via injection molding because of their increased thickness and size. In this study, plastic injection molding experiments were conducted and analyzed to improve the moldability of OLED TV stand necks. The main factors affecting the moldability were derived and analyzed, and the optimal process conditions were derived within the process range as based on the analysis results. the correlations between the slope and flatness of the stand and its process variables were studied via regression analysis.

Keywords: Moldability, Design of experiment, RSM, Plastic stand neck

INTRODUCTION

With the increasing popularity of OLED TVs, the demand for them and OLED TV stands, has been increasing. OLED TV stands are typically manufactured via a plastic injection molding method, and are more likely to possess dimensional errors than other products fabricated via injection molding because of their increased thickness and size[1-2].

Such errors can result in uneven weight distribution of the TV, making it susceptible to becoming damaged, as only a marginal amount of force is needed to create an imbalance. The typical steps of an injection molding process entail melting, filling, cooling, and extraction [3]. The melting step involves pulverizing and heating to liquefy the plastic fillet, and the filling step entails filling the inside of the mold with molten resin. During this time, the molten resin is poured into the mold via a runner system, and the charging properties of the molten resin are determined by the runner system and the design/process of the product. The cooling step entails solidifying the plastic resin inside the mold to create the product. During the cooling step, the design/process of the cooling channel determines the surface quality, shrinkage, and cycle time of the product. The extraction step removes the sufficiently cooled and solidified product from the mold.

Thus, the manufacturing of injection molded products is a multi-step process in which the product quality, moldability, and production time are determined by the process and design variables in each step.

In this study, plastic injection molding experiments were conducted and analyzed to improve the moldability of OLED TV stand necks. The most important features of a stand neck were designed such that its primary function of support, and more specifically, flatness and slope, was achieved; this was the aim of this experiment. The main factors affecting the moldability were derived and analyzed, and the optimal process conditions were derived within the process range as based on the analysis results. Furthermore, the correlations between the slope and flatness (response variable) of the stand and its process variables (independent variables) were studied via regression analysis.

RESEARCH METHOD

Process conditions and ranges

The injection material used in this study to mold the OLED TV stand necks was a thermoplastic resin; additionally, an impact-resistant, heat-resistant, weather-resistant, self-extinguishing, and transparent polycarbonate was used. Basic test results revealed pressure and time to be the main process parameter affecting the shape (flatness and slope) of the injection-molded products. Among these process parameters, holding pressure is a process that forms the shape via a mold clamping force and cylinder pressure when the mold is completely filled with resin; this parameter yields the most significant influence on the moldability. Holding pressure is applied throughout two stages of the stand neck fabrication; the first stage applying holding pressure was excluded, as its effect on the shape was negligible.

Finally, the process parameters were determined as follows: 1) the first-stage holding pressure time, 2) the second-stage holding pressure, 3) the second-stage holding pressure time, and 4) the cooling time.

Table 1 presents the main injection molding process parameters and the corresponding ranges.

The device used to produce stand necks was an injection molding machine from Haitian Co. Lt (Toggle method, mold force: 1300 tons). Fig. 1 shows the mold and the injection molding machine for the stands and Fig. 2 shows OLEV TV plastic stand neck products.

Table 1: Process parameters and range

Group	Factors	Level		
		1	2	3
A	1st Holding pressure time(sec)	5	10	15
B	2nd Holding pressure(bar)	60	70	80
C	2nd Holding pressure time(sec)	55	65	75
D	Cooling time(sec)	55	65	75

(a)Mold (b) Injection molding machine

Figure 1: Injection mold and Injection molding machine

Figure 2: OLED TV plastic stand neck

Design of response surface experiments

Based on the derived process parameters and ranges, the Box-Behnken design, which employs a response surface analysis methodology, was implemented for experimental design.

The design of response surface experiments is a method used to determine the correlation between the design and response variables as based on empirical and analytical data, and to derive the optimal conditions. RSM(Response surface method) can efficiently estimate the first and second terms, and can be implemented when the range of all factors is certain. Furthermore, it can be useful when the number of experiments at the vertex of the experimental model is excessive. The design of experiments and analysis of results were performed using the commercially available software application, MINITAB[4-6].

Figure 3: Combination and measurement of OLED TV stand neck and jig

EXPERIMENTAL RESULTS AND ANALYSIS

Injection molding tests and dimensional measurements

After mounting the injection molded stand onto a dedicated jig, the flatness and slope of the stand were measured using a thickness gauge and bevel protractor with height gauge. Fig. 3 shows the measurements of the slope and flatness after mounting the stand onto the jig, and Fig. 4 shows the flatness and slope of the stand neck following the design of experiments and molding.

Table 2: Design of experiments and results

Run.	A	B	C	D	Flatness(mm)	Slope(°)
1	5	60	65	65	1.2	90.5
2	15	60	65	65	1.2	90.5
3	5	80	65	65	1.9	91.1
4	15	80	65	65	1.9	91.1
5	10	70	55	55	1.5	90.8
6	10	70	75	55	1.8	91.0
7	10	70	55	75	1.5	90.6
:	:	:	:	:	:	:
26	10	70	65	65	1.5	90.9
27	10	70	65	65	1.5	90.9

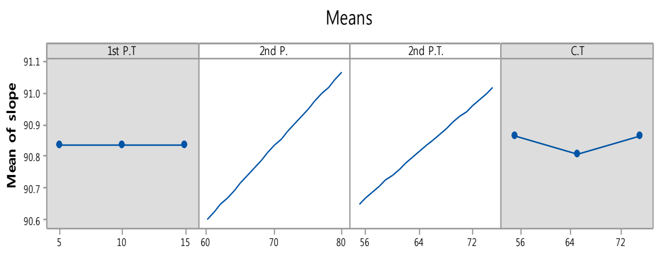
Analysis and review of results

Based on the results shown in Table 2, the P value for each term was confirmed, and the response surface model was fit by pooling the values one at a time from the largest P value.

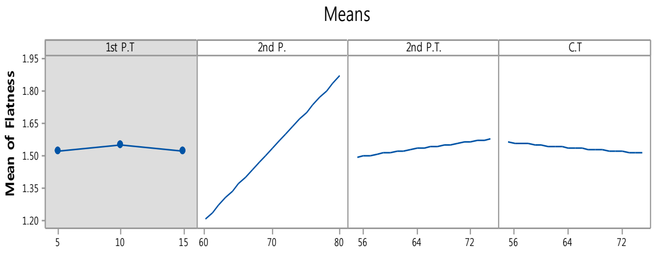
The P value here represents the magnitude of the effect against error, and the increasing %R-squared value represents the decreasing pure-error. As a result, the value of R-sq was found to be 96.12% (flatness) and 87.04 (slope).

Analysis of the main effects on the flatness and slope according to the process parameters confirmed that the most influential factors were the second-stage holding pressure and time. In addition, the cooling time was found to affect the flatness via interaction with the second-stage holding pressure time.

Fig. 4 shows the main effects of process parameters on the slope and flatness, and Fig. 5 illustrates the corresponding interaction.

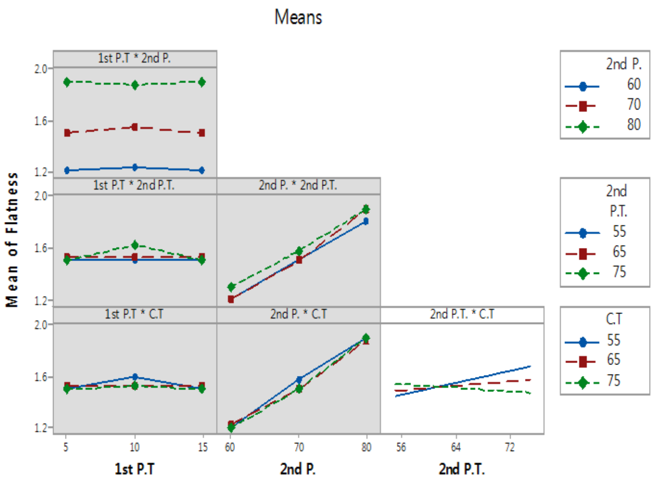


(a) Main effects plots for flatness

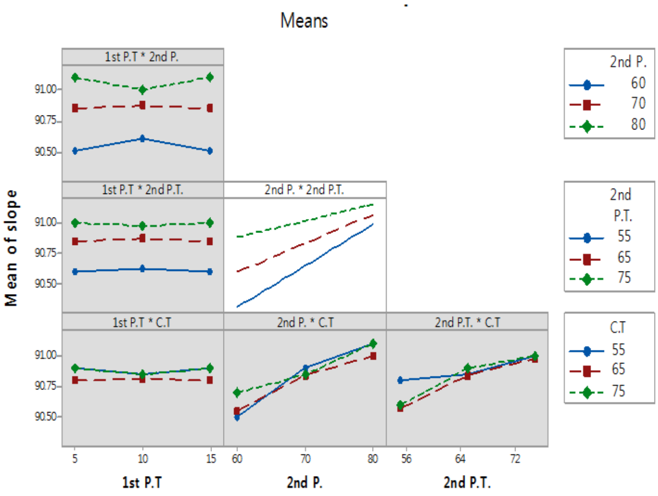


(b) Main effects plots for slop

Figure 4: Main effects plot for response values



(a) Interaction plot for flatness



(b) Interaction plot for slope

Figure 5: Interaction plot for response values

Based on the analysis results, similar to the effects of the first-stage holding pressure being determined as negligible as based on the basic testing results obtained while deriving the main process, the effects of the first-stage holding pressure time on the moldability were found to be insignificant. Although the significance of the cooling time was moderately low, it was maintained without pooling as a function required for the second interaction. This phenomenon is due to the fact that the shape of the product did not change after a certain amount of cooling time. Tables 3 and 4 present the results of dispersion analysis on flatness and slope, respectively.

Table 3: Analysis of variance for flatness

	DF	Adj SS	Adj MS	F-value	P-value
Term	4	1.38417	0.34604	136.35	0.000
Linear	3	1.36167	0.45389	178.85	0.000
B	1	1.33333	1.33333	525.37	0.000
C	1	0.02083	0.02083	8.21	0.009
D	1	0.00750	0.00750	2.96	0.100
Quadratic Interaction	1	0.02250	0.02250	8.87	0.007
C × D	1	0.02250	0.02250	8.87	0.007
Error	22	0.05583	0.00254		
Total	26	1.440			
S 0.0503774	R^2	96.12%	R^2(adj)	95.42%	

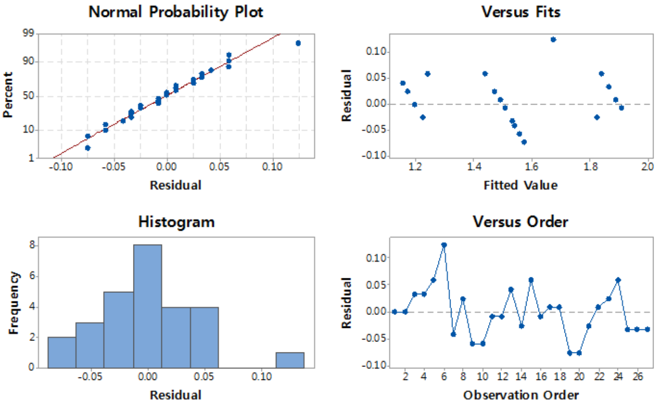
Table 4: Analysis of variance for slope

	DF	Adj SS	Adj MS	F-value	P-value
Term	3	1.09667	0.36555	51.48	0.000
Linear	2	1.05667	0.52833	74.40	0.000
B	1	0.65333	0.65333	92.00	0.000
C	1	0.40333	0.40333	56.80	0.000
Quadratic Interaction	1	0.04000	0.04000	5.63	0.026
B × C	1	0.04000	0.04000	5.63	0.026
Error	23	0.16333	0.00710		
Total	26	1.26000			
S 0.0842701	R^2	87.04%	R^2(adj)	85.35%	

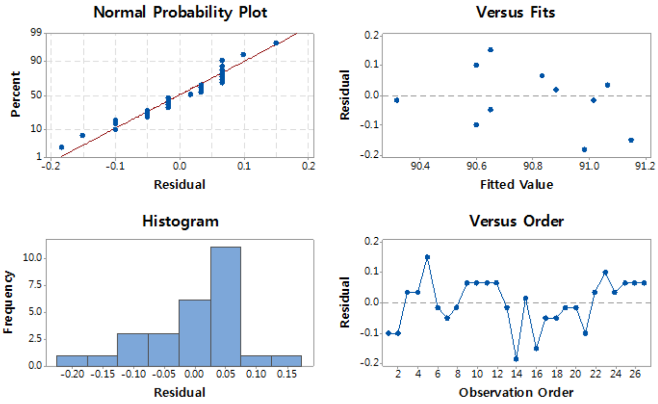
In order to evaluate the compatibility of the response surface model, residual analysis and variance analysis coefficients of determination were implemented. Fig. 6 shows the standardization residuals for the flatness and slope obtained via the response surface analysis method.

The following results of analysis of the residuals for the slope and flatness were observed: (a) the distribution of the residuals in the regularity graph is a normal distribution because it resembles a linear form; (b) the object plot shows that there is no particular abnormality in the distribution based on the average line; and (c) the histogram shows a symmetrical bell shape with one vertex, indicating normal distribution.

Additionally, because the plot of residual vs. fit does not show any linear or constant regularity, it can be assumed to have normal distribution. These findings validate the analysis of experimental results.



(a) Residual plots for flatness



(b) Residual plots for slope

Figure 6: Residual plots for response values

A polynomial regression analysis was performed to derive an empirical equation to predict the flatness and slope of the stand necks. A regression equation containing the interaction terms was derived by pooling the less significant terms and including only the significant effects in the model. The results of the regression analysis showed that the probability of significance $P \leq 0.05$ and the adjusted coefficients of determination were 95.42% (flatness) and 85.35% (slope), respectively. Therefore, this regression model can be considered applicable[7].

$$\text{Flatness: } -4.08 + 0.03333 \times B + 0.0529 \times C + 0.0462 + C - 0.000750 \times C \times D$$

$$\text{Slope: } 83.46 + 0.0883 \times B + 0.0883 \times C - 0.001 \times B \times C$$

Where,

A : 1^{st} Holding pressure time(sec)
B : 2^{nd} Holding pressure(bar)
C : 2^{nd} Holding pressure time(sec)
D : Cooling time(sec)

Deriving the optimal conditions

To ensure satisfactory flatness and slope of the TV stand necks, optimization was performed using a reaction optimization tool. The slope should be 91.2° with respect to the OLED TV stand neck, and the flatness should be minimal. From the results of the analysis, the second-stage holding pressure, second-stage holding pressure time, and cooling time were determined to be 61.75 bar, 75 s, and 75 s, respectively. The corresponding values of flatness and slope are 1.2 mm and 90.9067°, respectively, with a satisfaction level of 0.82. Fig. 7 shows the optimal conditions for the design variables required to achieve the target values of the response variables via Minitab.

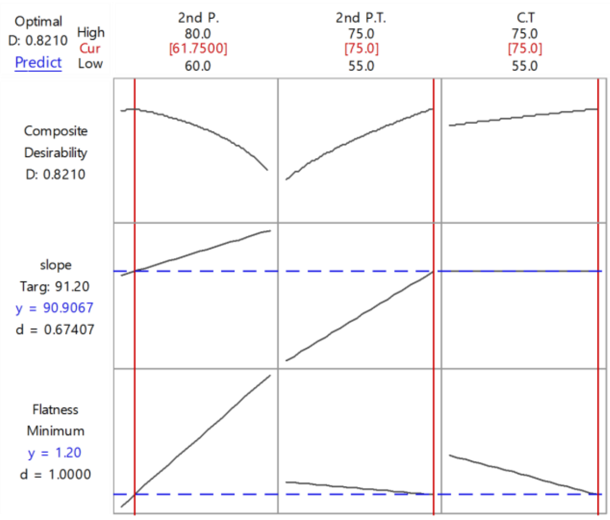


Figure 7: Optimization plot

CONCLUSIONS

In this study, injection molding was performed to improve the moldability of OLED TV stand necks. The main process parameters and ranges affecting moldability were established, and the optimal process parameters were derived within the established ranges.

Among the main factors affecting the moldability of the stand necks, the first-stage holding pressure and time were found to yield negligible effects on the moldability, as observed from the results of basic testing and the response surface analysis, and thus can be omitted from consideration.

The main effects and interactions were analyzed according to the application and analysis of the response surface experimental design; additionally, a regression equation that is able to predict the dependent variables according to the design variables was derived from the results.

The terms with low significance were eliminated as error terms, and the validity of the regression equation was confirmed through variance analysis. Finally, the optimal process conditions for improving the moldability were derived by using the reaction optimization tool.

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