

Modeling of the Cell Gap Process Characteristic on the Polymer Substrate for Flexible Liquid Crystal Display Applications

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Abstract

The modeling for the cell gap process characteristic on the flexible liquid crystal display (LCD) process was investigated by response surface methodology (RSM). D-optimal design is carried out to build the design matrix. The analysis of variance (ANOVA) technique was used to analyze the significance level. The statistical analysis was used to verify the response surface model. The desirability function was used in the design-space optimization.

1. Introduction

There have been researched for flexible liquid crystal display (LCD) using polymer substrate, which can be applied to the mobile display applications [1-2]. Due to the superior flexibility, low density, and light weight, the flexible LCD using the polymer substrate has emerged in the display application industry [3]. However, the disadvantage for the polymer substrate such as the thermal instability is also considered. Those factors are influenced by the manufacturing process conditions. The process variables are difficult to be controlled in order to maintain the desired characteristics. Therefore, the manufacturing process variations need to be characterized and the process condition having the desired result could be found.

RSM for the manufacturing applications has been investigated by several researchers. Gaston et al. applied to the optimization of IC process by D-optimal design and response surface methodology [4]. Villavilla *et al.* presented the process model for the etch rate and the etch yield using response surface methodology [5].

In this paper, the response surface methodology is applied the cell gap fabrication process for the flexible LCD application. ANOVA was performed to analyze the relationship between the process variables and the responses. The response surface methodology was then used to build the models for the cell gap. Finally, the optimized process condition for the control label

process variables was determined via the desirability function. The methodology can be applied to maintain the high-quality panel characteristics for the flexible LCD manufacturing.

2. Experiments

The polycarbonate (PC) film (200 μ m) is used as a substrate. In order to measure the cell gap of the flexible LCD, the cell was fabricated as a sandwich with an anti-parallel structure, and the 4- μ m spacers were used in this experiment to maintain a uniform space between the two polymer plates. The spacers were positioned at the space between the two polymer films by spraying, and the numbers of spraying spacers are 2, 6, and 10, respectively. The other polymer substrate using the printing sealant was then covered on the substrate that the spacers were sprayed. The pressing machine was then pressed with the 0.3-mm sheet. The pressures are 0.07, 0.13, and 0.19 kg per cm², respectively. The cell gaps were measured by MCPD-3000 (OTSKA EIEC-TRONICS, Japan) at the two points in which the 1/4 location deviated from the center.

3. Modeling Scheme

3.1 D-optimal design

In order to characterize the cell gap, the three process parameters, which are the spray number of the spacer, the pressure of the press machine, and the number of 3-mm sheet, are extracted with respect to the controllable experimental conditions. The process parameters with specific ranges are summarized in Table 1. The design matrix of the D-optimal design is summarized in Table 2. The order of the experimental runs has been randomized to avoid statistically the effect of irrelevant factors.

Table 1. Summary of process conditions

Factors	Symbol	Unit	Value
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Spray number	N	EA	2-10
Pressure	P	Kg/cm ²	0.07-0.19
Sheet	S	EA	0-2

Table 2. D-optimal design matrix

Run	N	P	S
1	0	1	-1
2	0	-1	1
3	1	1	0
4	1	0	-1
5	0	1	1
6	1	-1	0
7	-1	0	-1
8	1	0	1
9	0	0	0
10	-1	1	0
11	1	0	-1
12	1	-1	0
13	0	-1	-1
14	0	0	0
15	-1	-1	0
16	-1	1	1

3.2 Response surface methodology

The general second-order model is defined as the following equation [6];

$$y = b_0 + \sum_{i=1}^k b_i x_i + \sum_{i=1}^k b_{ii} x_i^2 + \sum_{i < j=2}^k \sum b_{ij} x_i x_j + e \quad (1)$$

where y is the response variable, n is the number of independent process factors, x 's are the process factor values, and b 's are the model coefficients. Those model coefficients are calculated by the least square estimation.

3.3 Desirability function

The desirability function is used as the one of the optimization approaches for the multiple responses. The technique is to convert each response into an individual desirability function (d_i), which varies in

the range $0 \leq d_i \leq 1$. If the response value is at its target value, then $d_i = 1$, and if the response value is outside an acceptable region, then $d_i = 0$.

The process variables that maximize the overall desirability are extracted to satisfy the desired response variable. The overall desirability is defined as:

$$D = (d_1 \cdot d_2 \cdot \dots \cdot d_m)^{1/m} \quad (2)$$

where m is the number of responses.

The two-sided desirability function is used in this study.

4. Results and discussion

The p-values for each process parameter are summarized in Table 3. Those values are evaluated by ANOVA under the statistical significance level of 95 % ($\alpha = 0.05$). It means that the spray number of the spacer and the pressure of the press machine are significant for the cell gap. However the sheet number is insignificant statistically for the cell gap.

Table 3. The summary of statistical significance

Factor	Statistical significance	
	Cell gap 1	Cell gap 2
N	0.003	0.048
P	0.004	0.021
S	0.640	0.228

The R-squared values for each model are 89.0 % and 89.2 %, respectively. Therefore, the response surface models are in good agreement with the experimental data.

In order to detect the outlier of the data, the standardized residuals were calculated as follows [7]:

$$d_i = \frac{e_i}{\hat{S}}, \quad i = 1, 2, \dots, n. \quad (4)$$

where e_i is the residual and \hat{S} is a square root of the mean square error.

Generally, the standardized residuals should be in the interval $-3 \leq d_i \leq 3$, any standardized residual with out of the range is potentially unusual data for the response model to be fitted. The calculated

standardized residuals were plotted in the Fig. 1 (a). As shown in Fig. 1 (a), the standardized residual for the models are distributed between -3 and 3 . There are no special patterns and features.

The relationships between the measured values and the predicted values are appeared in Fig. 1 (b). It appears to be almost linear indicating that the predicted model is fitted well against the cell gap as the response variable under the statistical significance level.

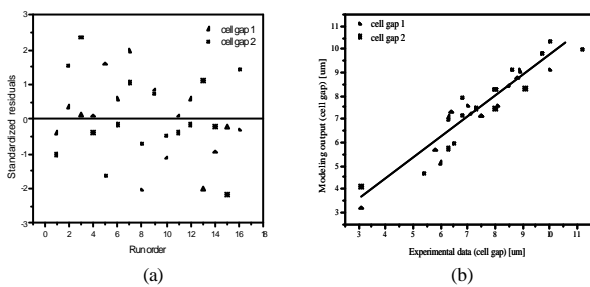


Fig. 1. The modeling results: (a) standardized residual plot, (b) the measured values vs. the predicted values.

The response surface plots for the each measured point are illustrated in Fig. 2. As the spray number of spacer and the press pressure of machine are increased in Fig. 2 (a), the cell gap is also increased steeply at the number of the 3-mm sheet, which is not significance factor under the statistical significance level, is fixed as 1. The small variation was observed through the curvature around the center between the measured points in the Fig. 2 (b). The variation represents that the spacers between the plastic substrates are increased on the limited space as the spray number of spacer is increased. The curvature variation on the response plot may be one of the process fluctuations, which can be occurred due to the measured location. The variation can be originated from the arrangement of the spacers in the vacancy. As the pressure of press machine is decreased, the spacers are rearranged in the vacancy sites. Therefore, the uniformity of the cell gap can be improved when the spray number of spacer and the pressure of the press machine are decreased.

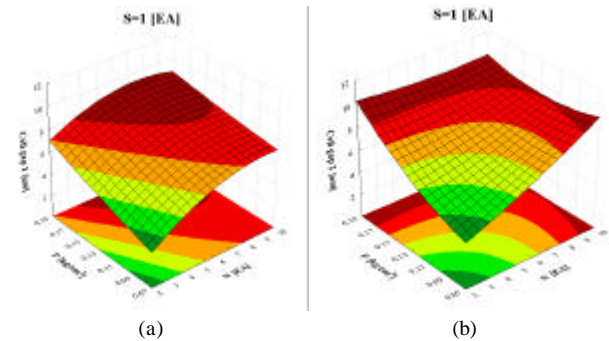


Fig. 2. The response surface plots: (a) at the first point, (b) at the second point.

The overlaid contour plots for the measured cell gap points are shown in Fig. 3 at the fixed values that are the number of sheet as 0, 1 and 2. The overlaid regions between upper and lower bound explain that the desired response value can be obtained by the condition that is in the acceptable region within the bounded conditions.

Based on the results, it is found that the second position has better uniformity of the cell gap than the first point. Therefore, the variation of the cell gap could be influenced by the uncontrollable process fluctuation and the measurement error.

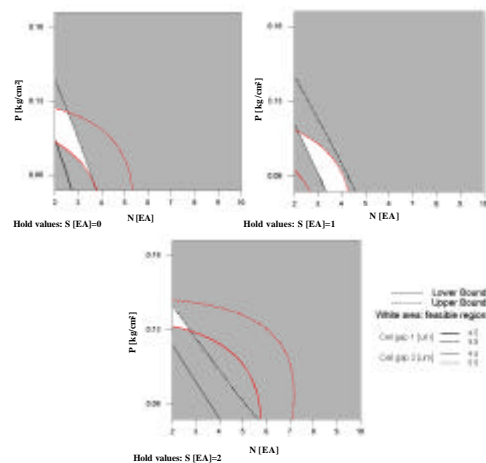


Fig. 3. The overlaid contour plots

5. Conclusion

In this paper, the statistical response surface models for the cell gap fabricated on a polycarbonate film have been presented and the optimized process recipe was examined. In order to build the model, the D-

optimal design was used and the response surface methodology was then carried out. The optimized process conditions for the desired response were determined using the desirability function. It is confirmed that the desired response can be obtained by the process using the optimized recipe with the statistical variation. This modeling methodology can allow us to characterize the cell gap manufacturing process as well as the statistical variation of the process.

6. Acknowledgements

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7. References

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