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Minimizing Thin Glass Deflection in Flexible Display Manufacturing via Pin Map Optimization

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Abstract

Flexible displays are being used in mobile phones and wearable devices. Their manufacturing process involves polyamide coating the carrier glass, followed by heating and sintering processes. Given that the heating efficiency in this process decreases if the carrier glass is thick, thin carrier glasses—raised by support pins—are used. However, as carrier glasses become thinner, defects start to occur during the process because of glass deflection. To characterize and solve this problem, the impact of the number of support pins and their spacing intervals have been analyzed via simulation. Additionally, validating experiments were conducted, in which the resulting glass deflection was measured with a laser displacement sensor. The obtained results enabled the identification of the number of pins and spacing intervals required to minimize deflection, and a regression equation was proposed.

Keywords: Optimization, Minimizing, Deflection, Flexible Display, DOE, Pin Map

INTRODUCTION

Flexible display technology has developed greatly in recent years. Unlike existing displays, flexible displays are thin, bendable, and flexible like paper. The flexible display market has now entered a strong growth phase. These displays have been used in mobile phones and wearable devices, and are expected to be applied throughout the entire information technology industry in the future [1, 2]. The manufacturing of flexible display consists of a coating process with polyamide material on carrier glass, followed by heating and sintering of the polyamide and carrier glass. The heating efficiency of this process decreases as the carrier glass becomes thicker, because of radiant heat. Therefore, thin carrier glasses are used [3]. However, as the carrier glass becomes thinner, defects start to appear because of expansion and shrinkage if the glass is in direct contact with the heater. To avoid the direct contact between the hot plate and glass, and thus solve the above-mentioned problem, support pins are used to raise the carrier glass during the heating process. However, if too many support pins are used, stains can occur because of the non-uniform heat distribution caused by the pins during the drying process (in which radiant heat is used) and can cause product defects. On the other hand, if the number of pins is too small, the glass may deflect under its own weight, leading to a polyamide concentration on the deflected areas and, therefore, to a sintering process that does not ensure constant thickness, which leads to the appearance of defects. Therefore, the number and arrangement of the carrier glass support pins must be optimized, in order to minimize the defect rate of plastic liquid crystals. In this study, a finite element analysis was conducted to determine the number of support pins (and their spacing intervals) that minimizes deflection; experimental glass deflection measurements were also conducted using a laser displacement sensor. The simulation and experimental results were compared to verify the validity of the pin arrangement optimization.

DESIGN AND SIMULATION OF THE PIN MAP

Pin arrangement for various numbers of pins

The simulations were conducted using both the quantity and position of the support pins as parameters, and analyzing the deflection of the thin glass resulting from each particular pin map. The number of support pins was set to 4, 5, 6, and 8, and the initial pin positions were set at each edge of the carrier glass (see Fig. 1). The simulations then proceeded by moving the pins in 10 mm unit steps in the x- and y-axis directions, toward the center of the carrier glass.

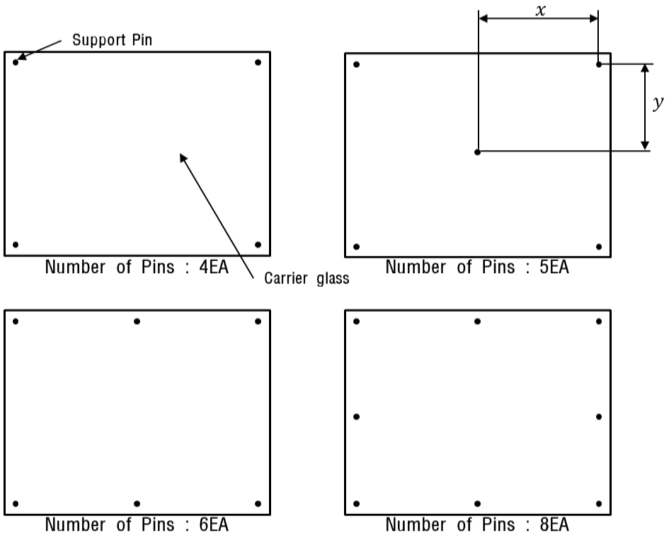


Figure 1: Pin arrangement for various numbers of pins

Boundary conditions

In this study, the ANSYS 16.2 finite element analysis software package was used. The simulation was conducted based on a glass size of 470 × 370 × 0.5 t, which corresponds to a second-generation display. The physical properties of general soda lime glass were used, and for the deflection under dead weight the standard Earth gravity (9806.6 mm/s²) was defined. In addition, a fixed support condition was applied to each support pin. Table 1 summarizes the physical properties of the glass.

Table 1: Glass physical properties

Property	Value
Modulus of elasticity [GPa]	69.2
Density [kg/㎥]	2,730
Poisson’s ratio	0.23

SIMULATION AND RESULTS

Deflection dependence on the support pin shape

Before analyzing the deflection dependence on the pin map, simulations were conducted to determine the effects of the support pins shape and thickness on the glass deflection. The contact area between the support pins and the glass varies with the support pin tip shape, which affects the drying process. The smaller the contact area, the smaller the effect on the dry condition. Therefore, the pin tip was set to a spherical shape, as shown in Fig. 2. The effect of the spherical shape of the pin tip on deflection was then analyzed. The variable design parameter in this simulation was the tip diameter. The simulation results confirmed that the support pin tip radius did not affect deflection (the difference in deflection for the different radii was less than 0.01 mm). The radius of the support pin tips was therefore set to 2.5 mm during the remainder of this study. Fig. 2 shows the glass deflection obtained for different pin tip diameters.

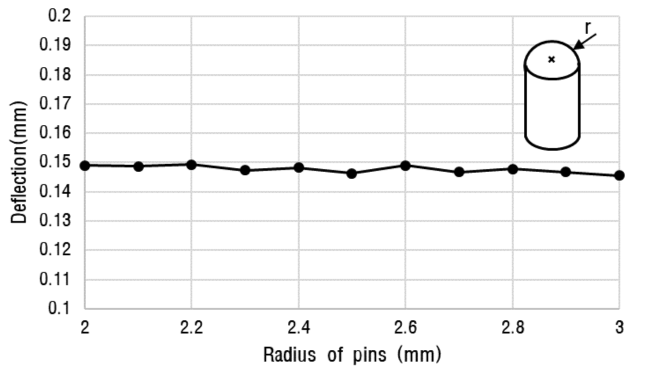


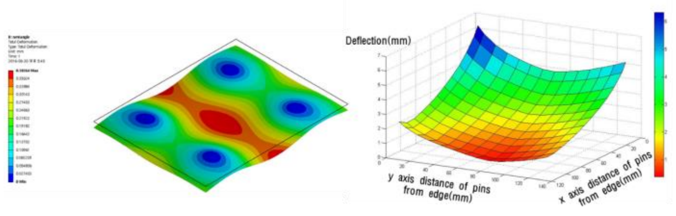
Figure 2: Glass deflection for different pin tip diameters

Deflection dependence on the pin map

The simulations designed to evaluate the impact of the number of pins and their interval spacing were then performed.

Case1) Four pins

With four support pins, the minimum deflection occurred when the pins were placed at 100 mm intervals in the x-axis and at 80 mm intervals in the y-axis of the pin map; the obtained minimum deflection was 0.384 mm.

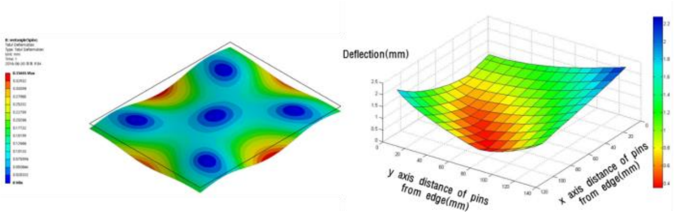


(a)Quantum (b)3D

Figure 3: Results and deflection pattern obtained with four support pins

Case2) Five pins

With five support pins, the minimum deflection occurred when the pins were placed at 90 mm intervals in the x-axis and at 70 mm intervals in the y-axis of the pin map; the obtained minimum deflection was 0.355 mm.

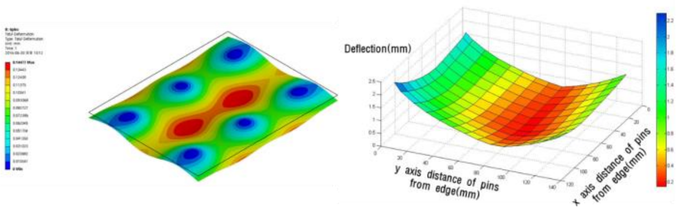


(a)Quantum (b)3D

Figure 4: Results and deflection pattern obtained with five support pins

Case3) Six pins

With six support pins, the minimum deflection occurred when the pins were placed at 60 mm intervals in the x-axis and at 80 mm intervals in the y-axis of the pin map; the obtained minimum deflection was 0.145 mm.

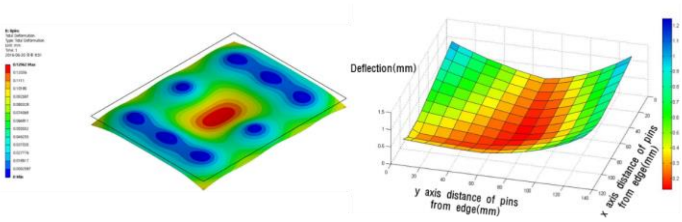


(a)Quantum (b)3D

Figure 5: Results and deflection pattern obtained with six support pins

Case4) Eight pins

With eight support pins, the minimum deflection occurred when the pins were placed at 70 mm intervals in the x-axis and at 70 mm intervals in the y-axis of the pin map; the obtained minimum deflection was 0.130 mm.



(a)Quantum (b)3D

Figure 6: Results and deflection pattern obtained with eight support pins

Review of the simulation results

The difference in deflection between four and five support pins was approximately 0.03 mm, which represented a relatively modest variation. The difference in deflection between six and eight support pins was approximately 0.015 mm, a value identically modest. Based on these results, the two options of four and six pins were selected for the experimental evaluation of the support pin arrangements; in this experiment, the measurements were obtained using a laser displacement sensor.

EXPERIMENTAL MEASUREMENT OF DEFLECTION

Experimental setup

The measurement data obtained using a left-and-right transport module (for position) and a laser sensor (for deflection) were transferred to a personal computer through an RS232 communication port, where it was then graphically represented and analyzed using the measurement program. The sensor used to measure the glass deflection was a laser displacement sensor that can measure transparent objects (CD-33-30N-422; Optex). Fig. 7 shows a schematic diagram of the experimental setup. The sensor specifications are summarized in Table 2.

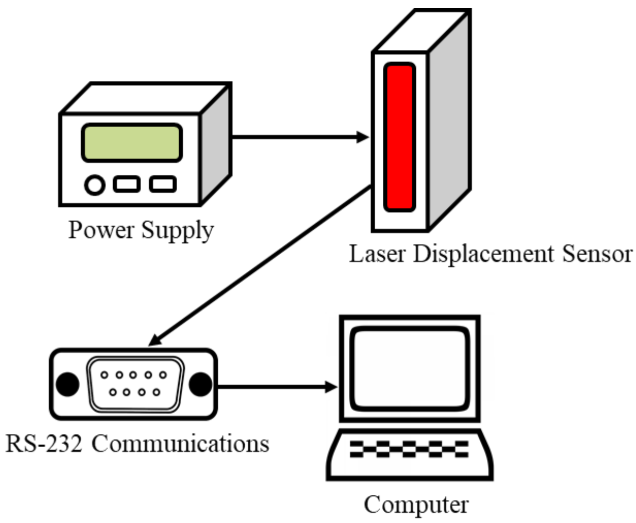


Figure 7: Experimental setup schematic diagram

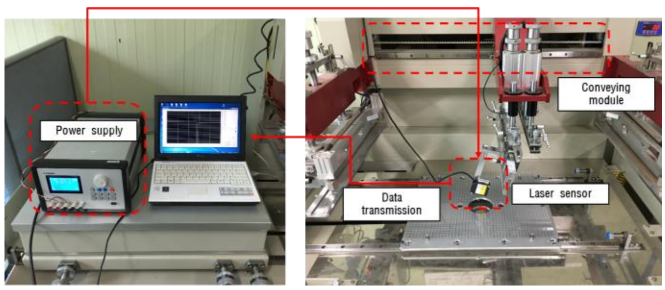


Figure 8: Deflection measurement system

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Table 2: Laser displacement sensor specifications

Item	Value
Resolution [μm]	1
Measuring rate [mm]	±2
Communication method	RS422
Baud rate [bps]	9600 / 19200 / 38400 / 76800
Transmission code	ASCII
Data length [bit]	8
Stop bit length [bit]	1

Factorial experimental design

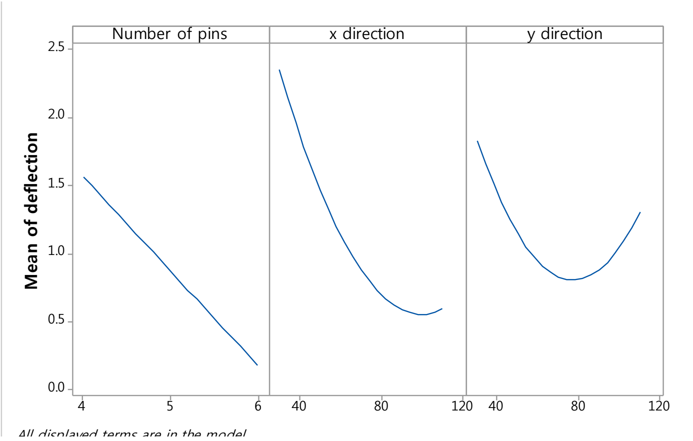
The experiment to evaluate the thin glass deflection as a function of the pin arrangement interval was designed using a full factorial design. The number of pins and the interval between pins in the x- and y-directions were set as the design parameters, deflection being the response parameter. For the ranges of the design parameters, two levels for the number of pins, and nine levels for the intervals in the x- and y-directions were used, based on the previously obtained simulation results. Table 3 presents the experimental design and the obtained results.

Table 3: Experimental design and obtained results

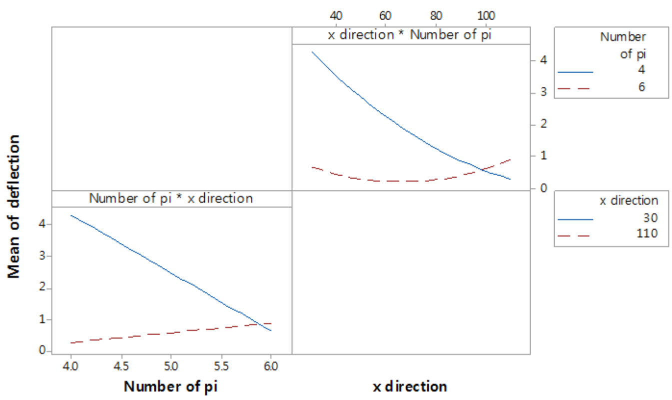
Std Oder	Run Oder	Pt Type	Block	Number of pins	x direction	y direction	Deflection
1	14	1	1	4	30	30	*
2	85	1	1	4	30	40	*
3	31	1	1	4	30	50	*
4	23	1	1	4	30	60	*
⋮							
11	29	1	1	4	40	40	4.301
12	40	1	1	4	40	50	4.180
13	71	1	1	4	40	60	4.129
⋮							
159	13	1	1	6	110	80	0.484
160	157	1	1	6	110	90	0.526
161	87	1	1	6	110	100	0.668
162	20	1	1	6	110	110	0.845

ANALYSIS RESULTS

The results of the deflection analysis showed that all the design parameters affected deflection; as expected, the number of pins was found to be the parameter with the largest effect on deflection. One important aspect of these results is the analysis of interactions between the different parameters. An interaction exists (and is indicated by non-parallel lines) when an effect results from the combination of two or more specific factors. The interaction analysis was conducted with the main purpose of obtaining an equation expressing the interaction between factors, and thus expressing the effects of complex parameters. Fig. 9 shows the analysis results for the main effect and the interactions. The interaction analysis results shown in Fig. 9(b) show that there is an interaction between the number of design pins and the pin interval in the x-direction



(a)Main effects plot for deflection



(b)Interaction plot for deflection

Figure 9: Main deflection effect and interaction diagram

Based on the above results, a regression analysis was then conducted. The regression equation that represents deflection as a function of the design parameters can be written as:

$$\text{Deflection} = 20.259 - 2.6249n - 0.20854x - 0.07127y + 0.000370x^2 + 0.000462y^2 + 0.026598\times n\times x \quad (1)$$

where x is the pin interval in the x-direction, y is the pin interval in the y-direction, and n is the number of pins.

The obtained significance probabilities (P-value) of the design parameters were 0.05 or lower, which means that they were significant. In the analysis of residuals, the result of the normality test was R2 = 0.927, which confirms the expected normal distribution; the homogeneity of the variance test showed that all values were randomly distributed. Furthermore, no variation in trend was observed depending on the order of observations. Therefore, the analysis results verified the validity of the model.

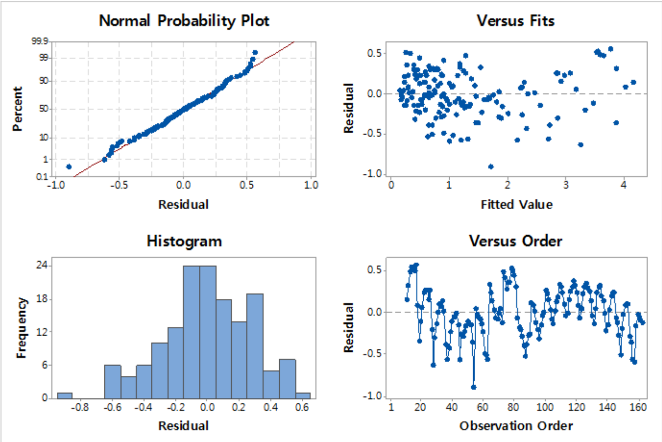


Figure 10: Results of the residual analysis

Table 4: Results of the variance and regression analyses

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	6	151.425	25.2374	310.35	0.000
Number of pins	1	93.820	93.8202	1153.73	0.000
x-direction	1	42.609	42.609	523.97	0.000
y-direction	1	12.915	12.9153	158.82	0.000
x-direction × x-direction	1	5.792	5.792	71.23	0.000
y-direction × y-direction	1	10.968	10.968	134.88	0.000
Number of pins × x-direction	1	58.211	58.2112	715.84	0.000
Error	145	11.791	0.0813	-	-
Total	151	163.216	-	-	-

S	R-sq	R-sq(adj)	R-sq(pred)
0.285165	92.78%	92.48%	91.90%

The pin interval resulting in the minimum deflection was obtained using a response optimizer. For four support pins, the optimal spacing was x = 110 mm and y = 77.4 mm; for six support pins, the optimal spacing was x = 66.3 mm and y = 76.8 mm. With the optimal spacing, the predicted deflection values were 0.249 mm (with four support pins) and 0.140 mm (with six support pins). Measurements were then conducted with the optimal spacing, and the obtained deflections were 0.232 mm (four pins) and 0.130 mm (six pins). The error was therefore of 7 %, indicating the consistency of the results.

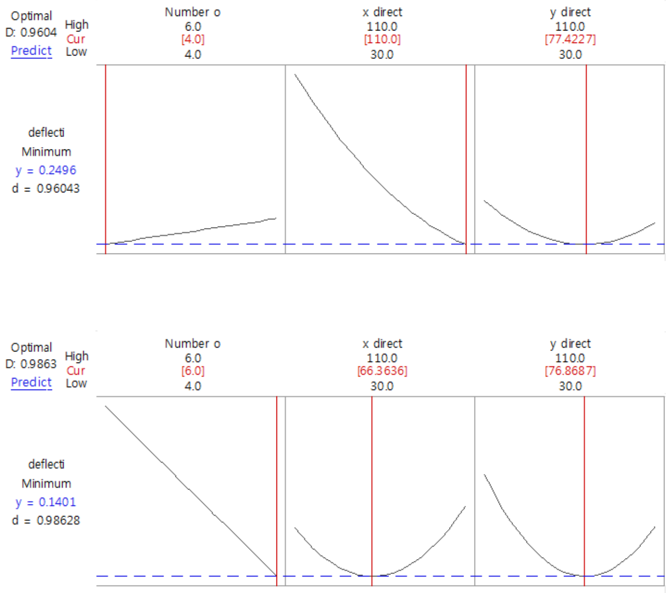


Figure 11: Optimum spacing obtained using a response optimizer

CONCLUSION

In this study, a basic simulation was conducted using finite element analysis; based on the obtained results, an experiment was performed, using a full factorial design, in which the deflections of thin glass were measured using a laser displacement sensor under different number of support pins and pin map arrangements. From the obtained results, the following conclusions could be drawn:

(1) The design plan was established using a full factorial design, and a main effect analysis was conducted. It was verified that both the number of pins and the pin intervals in the x- and y-directions affected deflection.

(2) The interaction analysis demonstrated that there was an interaction between the number of pins and the pin interval in the x-direction.

(3) A regression analysis was conducted based on the experimental results, resulting in a regression equation that can predict deflection according to the design parameters. The pin interval resulting in the minimum deflection was determined using the regression equation, and measurements were conducted to verify the consistency of the obtained results.

ACKNOWLEDGEMENTS

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