

Uniform Adhesion Method of Curved Large-Area Materials in Vacuum Chamber

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Abstract

This paper describes the optimal design method of vacuum chamber for lamination of curved and large displays. Existing lamination equipments have produced flat displays by contacting surface-to-surface, but as the display for vehicles has expanded and the need for surface-to-surface adhesion of curved materials has increased, the technology to distribute uniform surface-to-surface adhesion pressure for curved materials has become essential. In this paper, design variables and levels are set, and a set of optimal design variables is found with the Taguchi experimental plan to perform finite element analysis. From this, it is intended to secure competitiveness in the vehicle display market by proposing a design plan capable of curved surface-to-surface adhesion and proposing a plan to find the optimal design variable of the lamination equipment.

Author Keywords

Lamination; Taguchi experimental plan; finite element analysis; curved and large display.

1. Introduction

Amid the expansion of vehicle displays in the display industry, screen enlargement, curved display, and high definition are underway. [1] In particular, since the lamination process is essential to improve screen visibility, it is essential to respond to the lamination process in line with the trend of curved and large-scale products. The technology surface-to-surface lamination solutions for flat and large size products in vacuum chamber are already secured, but the technology for curved products are more needed, and equipment development is essential. This paper introduces a study on the optimal design of a lamination equipment to secure surface adhesion uniformity when curved display lamination. First, the vertical adhesion force position applied by the cylinder was selected, and finite element analysis was performed to check the contact pressure of the adhesion surface between the adhesion units to determine the arrangement of the cylinders. Factors were set to effectively transmit vertical adhesion force between products, and the main characteristic factors were identified and optimized using the Taguchi experimental plan. As a result, a simulation result of maximizing the curved surface contact pressure uniformity was obtained, and based on this, a curved surface lamination equipment was manufactured. From this, a good level was confirmed in the internal evaluation in which the level of uniform lamination could be confirmed.

2. Curved adhesion mechanism

In the case of curved materials, for a single vertical force, the force per unit area, that is, the pressure, acts in a vertical direction with respect to the curved surface. In Figure 1, the force starting from F_v acts as F_a in the normal direction on the curved surface, and as it moves from the material center to the side, the slope, that is, the θ value, increases, so the pressure received from the side is lower than the pressure received from the center. Therefore, it is essential to design a structure that minimizes the pressure deviation between the center part and the side part.

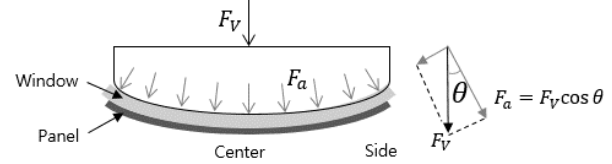


Figure 1. Mechanism of Force

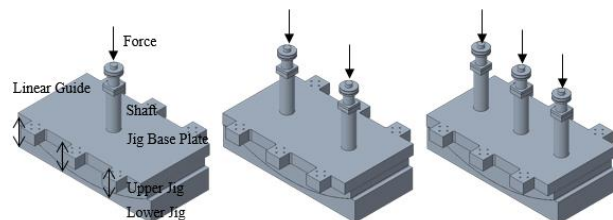
F_v is the vertical force applied by the cylinder in the vacuum lamination equipment. If a plurality of adhesion cylinders are distributed and arranged, pressure is expected to be uniformly transmitted to curved materials, but considering economic feasibility and ease of setting, the design is required in a minimum quantity of cylinder. Therefore, a finite element analysis was performed on the pressure in the normal direction of the material according to the position and quantity of cylinder, and the contact pressure uniformity. The following equation was used to calculate uniformity.

$$\text{Uniformity (\%)} = \left(1 - \frac{\max - \min}{\max + \min}\right) * 100 \quad (1)$$

3. Determination of Vertical Force Position

3.1 Finite Element Analysis Model

The vacuum lamination equipment is largely divided into upper and lower unit. The upper unit consists of cylinder, shaft, jig base plate, linear motion guide, upper jig, and other components. The lower unit consists of the jig base plate, lower jig, and other components. Existing lamination equipments are usually placing one cylinder in the center of the product, but it is important to determine the position and quantity of cylinders because this equipment must press the front of a large-sized product. In addition, it was expected that vertical force transfer would take place at the top and the contact pressure distribution would vary depending on the upper unit combination. Therefore, lower unit is simply composed of only the lower jig, and the modeling was created as follows. The physical properties of the model are shown in Table 1.



(a) Cylinder 1EA (b) Cylinder 2EA (c) Cylinder 3EA

Figure 2. Modeling of Lamination Chamber

Table 1. Material Properties

Material	Young's Modulus (GPa)	Density (kg/m ³)	Poisson's Ratio
AL6061	68.9	2,700	0.33
S45C	205	7,850	0.27

Table 2. Condition and Constraint

Cylinder	Pitch(mm)	Force	Lower Jig	Upper Jig
(a) 1EA	-	High Force		Z Axis Free
(b) 2EA	450	High Force	Fixed	X,Y Axis Fixed
(c) 3EA	300	High Force		

3.2 Finite Element Analysis

Considering the product maximum size, the cylinder pitch was set to 450mm for 2EA and 300mm for 3EA. The upper jig moves along the linear motion guide while the vertical force is transmitted and contacts the lower jig to form a pressure. The linear motion guide gave a free condition in the Z-axis direction and a fixed condition in the X and Y directions. Table 2 shows the factors and conditions. The curvature variable between the upper and lower jigs was fixed to particular radius and configured in the lower jig concave form and the upper jig convex form, and the analysis was performed under the contact condition.

3.3 Finite Element Analysis Results and Reviews

Figure 3 shows the contact pressure graph and contour of one center line to compare the contact pressure between the upper and lower jig. As expected in Equation (1), the contact pressure value tends to decrease toward the side, and in particular, when composed of one or two cylinders, it is confirmed that the contact pressure shows an area close to zero, that is, an unattached area. Therefore, it was confirmed that at least three adhesion cylinders are required to bond the entire product. But as can be seen from the graph and contour, even if three cylinders are used, the pressure decreases significantly as the unattached area occurs and moves to the side. Therefore, in order to maximize the uniformity of pressure, a study for uniform adhesion was conducted.

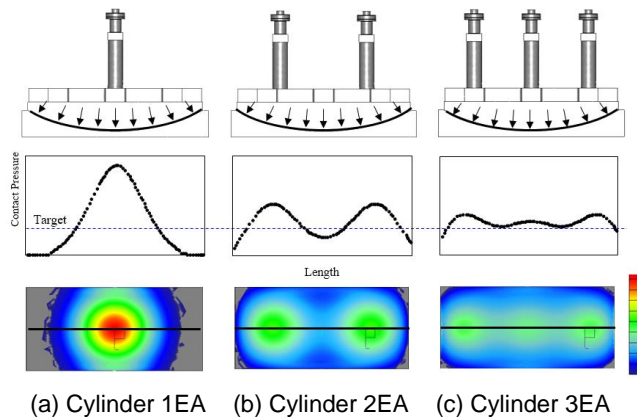


Figure 3. Contact Pressure

4. A Study on the Uniform Distribution of Adhesion Force in Normal Direction
4.1 Design Variable

In order to maximize the effect within a limited equipment size, a pressure distribution method was required without departing from the outer size of the pressurized positioning model, and it was decided to implement a uniform contact pressure through the optimal number and arrangement of shafts. In order to effectively arrange the shaft, it was separated into two groups. First group shaft disposed outside the vacuum chamber between the cylinder and the upper jig, and second group shaft configured inside the vacuum chamber. Shaft was set as design variables such as first group shaft diameter (A), shaft pitch (B), second group shaft diameter (C), shaft X direction pitch (D), and shaft Y direction pitch (E). Each design variable is set to level 3, and it is written in Table 3. Contact pressure data according to the length of one center line and one side line 150mm apart from the center line were secured, and uniformity was calculated according to Equation (1) and set as objective function.

4.2 Application of Taguchi Experimental Planning

The Taguchi Experimental Planning was applied to proceed with the optimal design of the variables. The Taguchi method is an optimization technique that selects an optimal design combination in consideration of the average and deviation of the characteristic value distribution, and it is possible to design to maximize the signal to noise ratio to have insensitivity. In this experiment, the objective function, uniformity, was set as a characteristic value. [2] Since the purpose is to increase the uniformity, the analysis was conducted with large the better characteristics. The S/N ratio equation is as follows.

$$S/N \text{ Ratio} = -10 \log\left(\frac{1}{n} \sum_{i=1}^n \frac{1}{y_i^2}\right) \quad (2)$$

The orthogonal array table was reviewed based on the design variables and levels. The principle of orthogonalization is to minimize the number of experiment sizes [3], and the standard type is set for the third level of the fifth factor, the L27 (3¹³) orthogonal array table was selected and it is shown in Table 4.

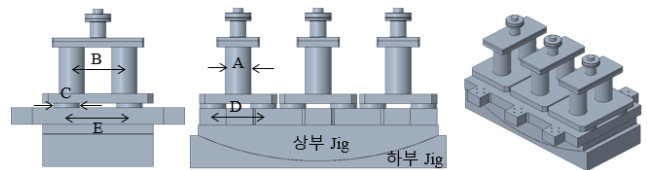


Figure 4. Contact Pressure

Table 3. Design Factor Level

	A(mm)	B(mm)	C(mm)	D(mm)	E(mm)
Level 1	60	0	60	0	160
Level 2	80	150	80	120	240
Level 3	100	200	100	190	320

Table 4. Orthogonal Array [L27(3¹³)]

No.	A	B	C	D	E	Uniformity (%)
1	1	1	1	1	1	50.0
2	1	1	1	1	2	44.1
3	1	1	1	1	3	5.3
4	1	2	2	2	1	66.2
5	1	2	2	2	2	77.9
6	1	2	2	2	3	47.9
7	1	3	3	3	1	80.1
8	1	3	3	3	2	78.6
9	1	3	3	3	3	59.8
10	2	1	2	3	1	67.7
11	2	1	2	3	2	88.8
12	2	1	2	3	3	58.4
13	2	2	3	1	1	57.0
14	2	2	3	1	2	64.7
15	2	2	3	1	3	38.7
16	2	3	1	2	1	65.1
17	2	3	1	2	2	69.2
18	2	3	1	2	3	35.7
19	3	1	3	2	1	58.9
20	3	1	3	2	2	76.2
21	3	1	3	2	3	58.2
22	3	2	1	3	1	76.2
23	3	2	1	3	2	75.4
24	3	2	1	3	3	39.5
25	3	3	2	1	1	53.6
26	3	3	2	1	2	53.3
27	3	3	2	1	3	28.2

4.3 Experimental Result and Review

A total of 27 CAE case was conducted according to the orthogonal array table, and the physical properties were shown in Table 1. Based on the analysis results, the uniformity of the side part and the center part, which are characteristic values, was calculated, and the main effect on the average and the main effect on S/N were calculated through Minitab and is shown in Table 4. The result is also shown in Table 5-6 and Figure 5.

Factors that greatly affect the S/N ratio were in the order of E, D, and C, and factors A and B had relatively little effect. Since the C and D factors have a high average of characteristic values at level 3, and the E factor has a low average of characteristic values at level 2, the C factor 3, the D factor 3, and the E factor 2 were selected as optimal conditions according to large the better characteristics. In

the case of factor A and factor B, according to the Taguchi method, selecting factor A at level 2 and factor B is the optimal condition for increasing uniformity.

The actual equipment was applied at 3 levels of factor A and 3 levels of factor B. Factors A and B were judged to be factors that did not significantly affect the S/N ratio, and factor A had a low average of characteristic values at level 2, but when comparing Von Mises Stress, the results were lower at level 3 (40.1 MPa) compared to level 2 (51.4MPa), so it was decided to level 3 in consideration of the safety rate. In the case of factor B, the average of the evaluation value was low at level 2, but the first group shaft, factor B, was determined to be level 3 because the parts for vacuum sealing surround the shaft, and the work space between the shaft and the shaft is required to fasten the bolt of the parts, and the larger the pitch, the easier the workability.

Based on the above results, the final design plan was determined to be 3 level of factor A, 3 level of factor B, 3 level of factor C, 3 level of factor D, and 2 level of factor E and The final application factor is indicated in Figure 6. As a result, it was confirmed that the uniformity of 59% was improved compared to the vertical adhesion model.

Table 5. S/N Ratio of each levels

Levels	A	B	C	D	E
1	33.4	33.4	32.5	31.4	36.0
2	35.4	35.3	35.2	35.6	36.7
3	34.8	34.9	35.9	36.6	30.9
GAP	1.9	1.9	3.4	5.2	5.8
Rank	5	4	3	2	1

Table 6. Average of each levels

Levels	A	B	C	D	E
1	56.7	56.4	51.2	43.9	63.9
2	60.6	60.4	60.2	61.7	69.8
3	57.7	58.2	63.6	69.4	41.3

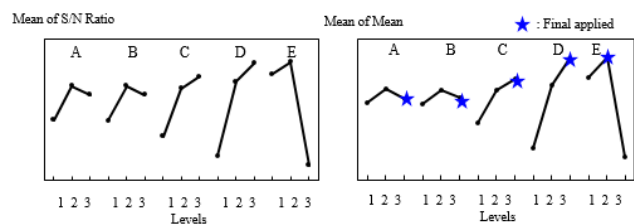
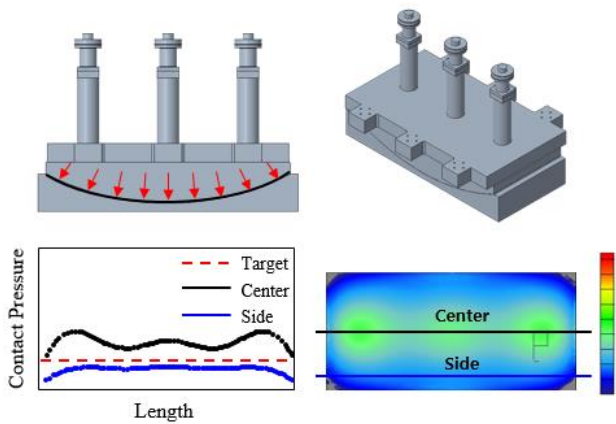
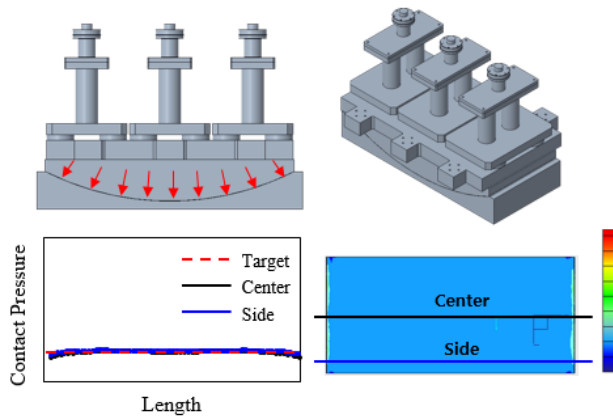


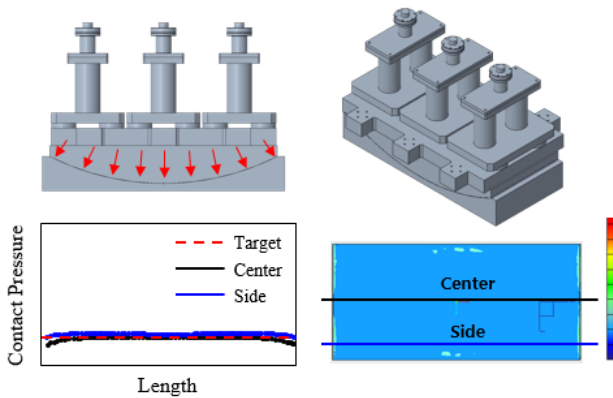
Figure 5. Main Effects Graph



(a) Vertical adhesion model



(b) Optimal Design of Taguchi Method



(c) Final design

Figure 6. Contact Pressure

4.4 Experimental Verification

Based on the study, the results of the experiment were verified by manufacturing the lamination equipment. One of the differences between the analysis model and the actual equipment is that the film cushion for buffering is located on each material contact surface of the upper jig and the lower jig. There are many ways to buffer materials, but in this case, thin cushion was used for surface-to-surface adhesion of uniform curved materials.

5. Conclusion

In this paper, the analysis of the pressurized positioning model was performed for uniform lamination of curved materials, and the factor and factor levels of the structure between the cylinder and the upper jig were determined, and the optimal design was performed using the Taguchi experimental planning method. Based on this, the production of a curved lamination equipment was carried out, and the feasibility of the design was verified by checking pressure level of pressure sheet and bubble level of the curved lamination products. From this, the design method conducted in this study can be an effective plan when it is necessary to manufacture lamination equipments for large and curved displays in the future.

- The position and quantity of the cylinders were determined by checking the contact pressure through finite element analysis.
- In order to increase the adhesion uniformity, design factors and levels were determined, and an experimental plan was performed according to the Taguchi experimental planning method.
- The optimal design value was derived by checking the S/N ratio and average of the analysis results, and the final design variable value was determined for equipment application.
- The validity of the experiment was verified through the production.

6. References

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