International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 18 (2015) pp 39751-39754

Identification of the edge corner deflection related to the process variables on the glass edge sealing using double torch

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Abstract
Experimentally, this paper was to establish the factors like gas flow rate supplied by the torch, feedrate of torch, and distance between the corner part of glass and torch which affected the edge corner of glass most as independent variables, and to perform the corner joint experiment through the design of experiment. In addition, this study in the influence analysis was conducted according to the process parameters through the analysis of variance and regression analysis using the values of deflection on the corner part, and according to the mathematical formula was deduced showing the relationship between the deflection and process parameters.

Keywords: Glass edge corner, Double torch, Deflection, Mathematical deflection model, Design of Experiment (DOE)

1. Introduction

Glass substrate sealing technology recently has been utilized in various industries. In particular, this technology is being applied to display devices and dye-sensitized solar cell devices. Display devices account for more than 10% of the electronics industry, which includes communications and information electronic appliances. Dye-sensitized solar cells, a form of next-generation solar cells, are recognized for their ease of installation on building windows. However, the increasing usage of organic matter in these devices has led to more active research on glass sealing processes[1].

The frit-based process can cause cracks in the glass due to residual stress since the coefficient of expansion is different for the frit and the glass. This process also has a lower sealing strength compared to the glass melting process[2]. The process of laser sealing in a vacuum chamber can result in decreased processed efficiency because light is blocked when oxidized glass is deposited on the laser lens[3].

The edge-sealing process involves sealing is accomplished using a hydrogen mixed gas torch by opening the furnace top after aligning two sheets of glass and heating for a certain period of time. Y. Kim used one torch to perform edge sealing edge by edge, and presented a mathematical model for the shape model of the edge cross-section. To shorten manufacturing time, recent studies have focused on double-sided sealing of edges[4]. When two torches are used, the edge corner parts are doubly exposed to heat, and is thus more susceptible to deformation than when using a single torch.

Therefore, this study performed basic tests to verify the greater deflection occurring in the edge corner parts of glass, and developed a mathematical model for deflection estimation. Through basic tests, the factors affecting glass edges such as the gas flowrate, the feedrate of the torch, and the distance between the glass edge part and torch were set as independent variables. Design of Experiment (DOE) was used to perform a total of nine tests, consisting of three factors at three varying levels. For edge corner part deflection values, the effects of process parameters were analyzed through an analysis of variance and a regression analysis. Mathematical equations were derived for the relationship between the edge corner part deflection and process parameters.

2. Process Parameters and Deflection of Edge Corner Sealing Part

2. 1 Section of Process Parameters

Basic tests were conducted to compare the deflection of edge parts. The edge sealing device seals edges using a torch that emits hydrogen mixed gas at ambient temperature in the furnace. The experimental setup is shown in Fig. 1, and the functions of each devices are presented in Table 1. The process parameters influencing edge sealing were found to be the gas flow rate, feed rate of the torch, and distance between the torch and glass. As shown in Fig. 2(a), edge part deflection is larger for higher gas flow rates. From Fig. 2(b), we can see that edge part melting may not occur under higher feed rates and longer distances between the torch and glass. Thus, the process parameters of this study are as shown in Fig. 3. The range of glass sealing conditions, derived from basic tests, is given in Fig. 4.

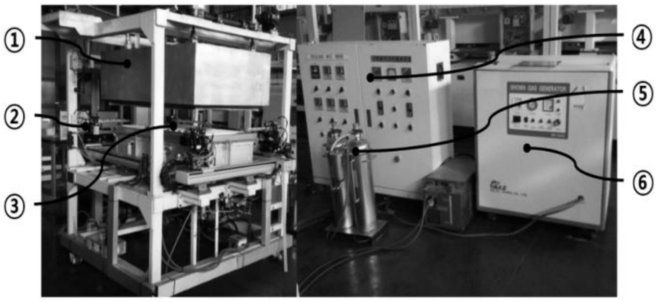
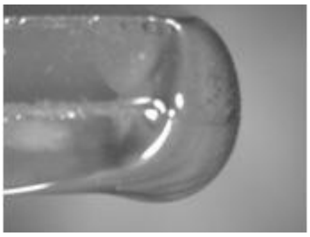
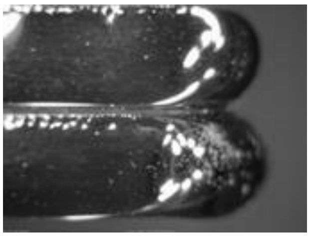


Fig. 1. Experimental setup



a) over melting condition



(b) deficient melting condition

Fig. 2. Abnormal shapes according to the process variables

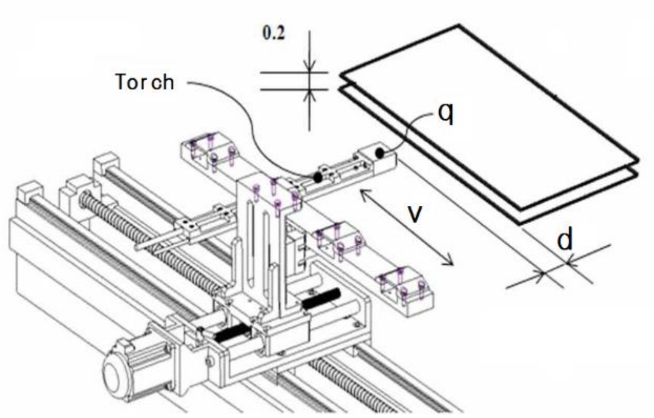
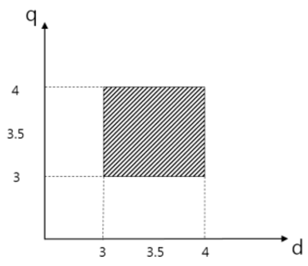
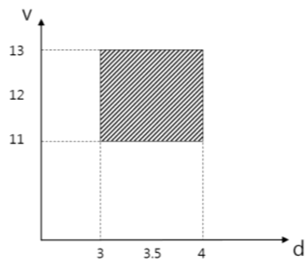


Fig. 3. Glass sealing set of process variables



(a)



(b)

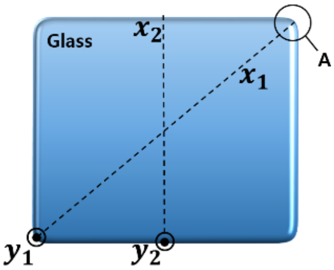
Fig. 4. Range of process variables

TABLE. 1. The function of the equipments

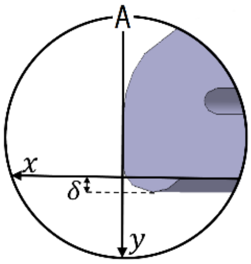
No	Name	Function
1	Furnace	Pre heating for glass
2	Torch transfer	Torch moving
3	Torch	Glass edge sealing
4	Control panel	Supplying of the hydrogen mixed gas
5	Coolant	Temperature control furnace
6	Gas generator	Cooling for gas torch

2. 2 Deflection by Edge Sealing Part

To compare, the deflection of the edge corner part and edge part cross-section, a schematic diagram of glass deflection was drawn. As shown in Fig. 5(a), $x_1$is the cutting direction of the edge corner part and $x_2$is the cutting direction of the edge part. $y_1 y_2$ represents the direction used in measuring deflection. Fig. 5(b)shows the deflection (δ)of edge corner parts.



(a)



(b)

Fig. 5. Measured point for deflection glass corner

3. Test Details and Procedures

3. 1 Configuration of Test Conditions

TABLE. 2. Variable conditions for glass edge sealing

Process Parameters	Level 1	Level2	Level 3
Flow rate of gas: $q(l/\text{min})$	12	13	14
Moving speed of torch$v$(mm/sec)	3	35	4
Distance between torch of glass: d(mm)	3	3. 5	4

3. 2 Edge Sealing Test

As shown in Table 3, the two sheets of glass were aligned for the nine test conditions, consisting of the aforementioned three levels. The glass was prepared on the inner setter of the furnace.

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 18 (2015) pp 39751-39754

TABLE. 3. Orthogonal array

No	q	v	d
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

4. Analysis of Results

4. 1 Measurement of Edge Cross-Section Deflection

To analyze the relationship between process parameters and edge corner part cross-section deflection, edge corner parts were sliced into cross-sections, as shown in Fig. 6. The deflection of cross-sections was measured via a digital microscope. The measured deflection values are presented in the graph of Fig. 7.

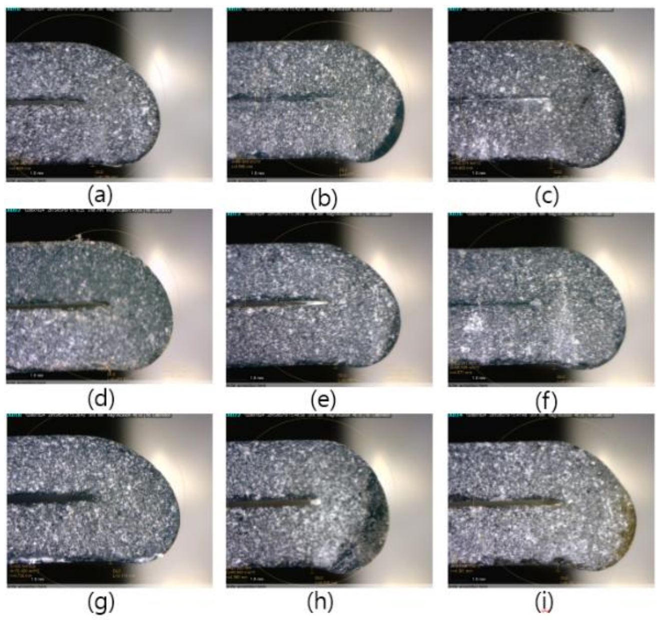


Fig 6. Section of glass edge corner point($\times$ 40)

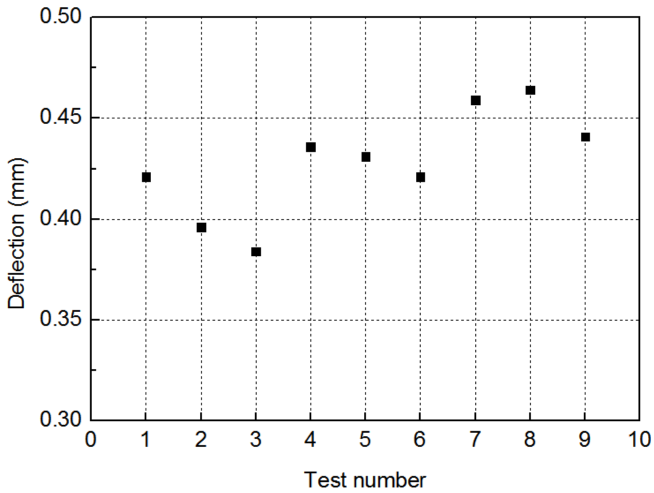


Fig 7. Measured deflection of specimen on Fig 6

4. 2 Analysis of the Edge Corner Part Deflection

The relationship between process parameters and edge corner part deflection was analyzed. Fig. 8presents the main effects of edge corner part deflection. The results of the main effect analysis showed that factors affecting edge corner part deflection, in decreasing order, were gas flow rate, distance between the torch and glass, and feed rate of the torch. A p-value of 0. 000 was obtained from an analysis of variance, indicating a very high significance, as shown in Table 4. $R^2$was 97. 5%, and the adjusted$R^2$of 95. 9% was used to examine the significance of the test results. The residual plot of Fig. 9 follows a normal distribution.

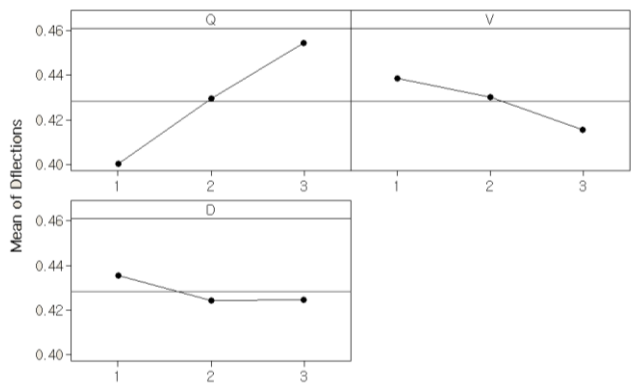


Fig 8. Main effects plots for deflection

TABLE. 4. Analysis of variance

Source	SS	MS	F	P
Regression	0. 005416	0. 001805	65. 84	0. 000
Error	0. 000141	0. 00028		
Total	0. 005557			
S=0. 00371937	$R^2 = 97.5\%$	$R^2(adj) = 95.9\%$		

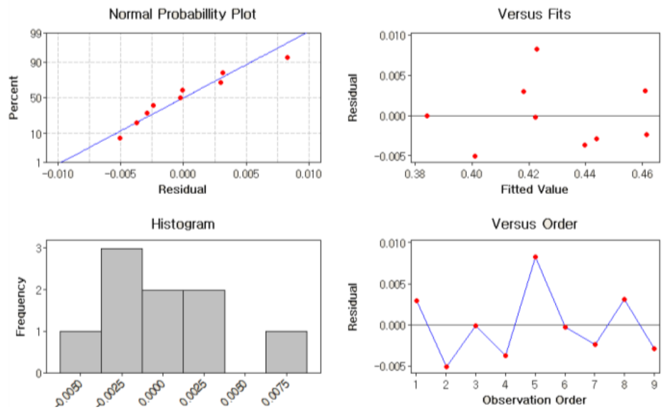


Fig 9. Residual plots for deflection

4. 3 Regression Equation

To estimate the deflection of sealed corner parts, a multiple regression model was introduced. The dependent variable was glass edge deflection, while the independent variables were the gas flowrate (q), feedrate of the torch (v), and distance between the torch and glass (d). The multiple regression model can be expressed as shown in equation (1).

$$\delta = a_0 + a_1 q + a_2 v + a_3 d \qquad (1)$$

Where,

δ ; Edge sealing cross-section deflection
q; Flow rate of hydrogen mixed gas $(12 \leq q \leq 14)$
v ; Feed rate of the torch $(3 \leq v \leq 4)$
d ; Distance between the torch and glass $(3 \leq d \leq 4)$

A multiple regression analysis was employed to measure deflection in Fig. 3. The coefficients of Equation (1) can be expressed by Equation (2) below.

$$\delta = 0.221 + 0.0272q - 0.0233v - 0.0107d \qquad (2)$$

5. Conclusion

This study analyzed the relationship between process parameters and deflection of edge corner parts in the edge sealing process. DOE was used in edge-sealing tests, and measurements were taken of deflection in corner part cross-sections. Through a multiple regression analysis, mathematical equations were derived for the relationship between edge cross-section deflection and key process parameters.

Acknowledgment

This work was supported by the Human Resources Development program(No. 20154030200940) of the Korea Institute of Energy Technology Evaluation and Planning(KETEP) grant funded by the Korea government Ministry of Trade, Industry and Energy

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