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Establishment of regression model for estimating shape parameters for vacuum-sealed glass panel using design of experiments

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ABSTRACT

Presently, the technique of edges sealing of vacuum glass panels is being utilized in a variety of industrial applications, such as in displays and home appliances. The sealing conditions of a vacuum glass panel strongly affect its key performance parameters, such as its insulation and strength. In the present study, edges of two glass panels were melted and sealed using a hydrogen mixed gas torch. The edges were sealed after appropriately setting process parameters that affected the shape of the sealed edges. Regression models were established for estimating the edge thickness, deflection, and maximum radius of the sealed part, which were considered as shape parameters. The effects of the process parameters on the shape parameters, as well as the interactions among the process parameters, were analyzed, and a polynomial regression model that considered these interactions was established. The feasibility of all the regression models was verified through analysis of variance.

1. Introduction

Vacuum glass is an adiabatic material that is used to improve insulation performance by sealing the edges of two vacuum glass panels and maintaining a vacuum condition in their inner side [1–7]. Edge sealing is a key process for maintaining the vacuum condition during the production of vacuum glass, and therefore, this process needs to be highly reliable.

Edge sealing is a process wherein two glass panels are sealed by applying frit on them. This process has been widely investigated in the past, and it is extensively used in various industrial applications, such as in displays and home appliances and in the construction field [8,9]. However, the application area of frit, which acts as a heat bridge in the insulated glass panel, is large, and this ultimately leads to impaired insulation performance.

In the present study, a hydrogen mixed gas torch was used for sealing the edges of two vacuum glass panels.

Process parameters that affect the shape of the sealed edges were set as independent variables, whereas the edge sealing thickness, deflection, and maximum radius of the sealed part (considered as shape parameters) were set as dependent variables.

In the vacuum glass, the edge sealing part is the part requiring air tightness to maintain vacuum, and there is no correlation between pressure and sealing thickness, according to vacuum pressure. and Deflection is caused by process parameters and gravity upon sealing, and has no correlation with vacuum pressure. The shape parameters are the manufactured physical value according to the process parameters.

An edge sealing experiment was performed based on a full factorial design, and the effects of the set process parameters on the shape parameters and the interactions among the process parameters were analyzed. The resultant analysis data was used to establish regression models for estimating the shape parameters, and the feasibility of the models was verified through analysis of variance (ANOVA).

2. Characteristics of edge seal

2.1. Experimental apparatus

A hydrogen mixed gas torch was used for sealing the glass edges. The experiment was performed inside an electric furnace to prevent breakage and deformation of the glass panels. Fig. 1 shows the schematic diagram of the electric furnace which houses the hydrogen mixed gas torch.

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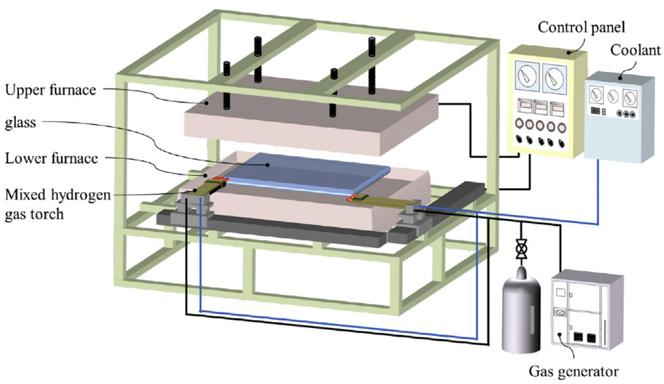

Fig. 1. Schematic diagram of furnace and hydrogen mixed gas torch.

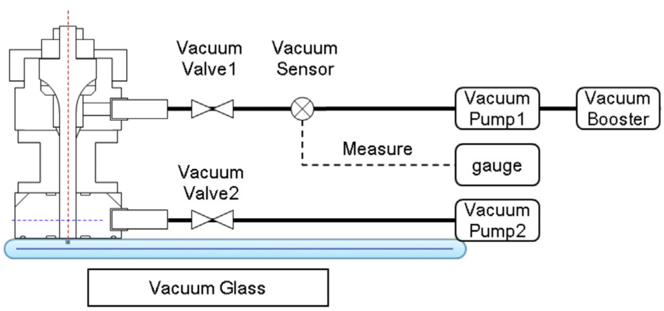

Fig. 2. Schematic diagram of the pump-out system.

2.2. Validation test for leak free seal

This study carries out a pump-out experiment to check whether the melting-sealed glass' edge part can maintain vacuum state using a hydrogen mixed gas torch. Fig. 2 shows a schematic diagram of the pump-out system, and Fig. 3 shows measurement.

Concerning pump-out, the air within the glass was pumped-out with a hole on the upper part using a vacuum pump, and the vacuum pressure was measured. Fig. 4 shows the vacuum pressure within the glass panel by using a pump-out device and a vacuum sensor. This paper has checked the retention of a certain level of vacuum pressure, and has ascertained the vacuum glazing panel's application possibility.

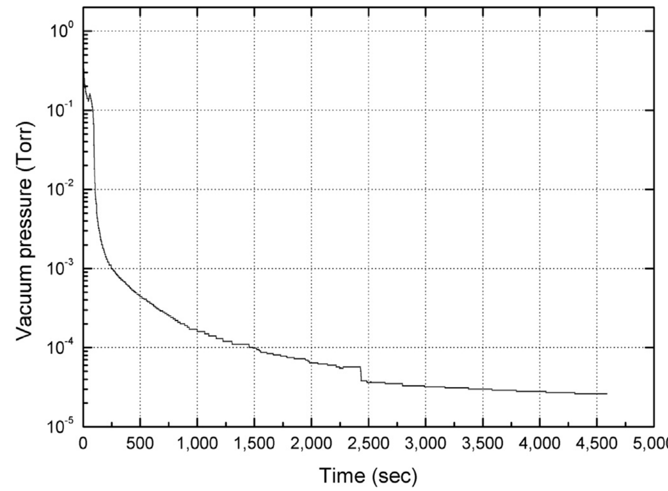

Fig. 4. Vacuum pressure of the edge sealed glass.

3. Setting of process parameters and shape parameters

3.1. Setting of process parameters

The following were the four process parameters affecting the shape of the sealed edges of the glass panels: the flow rate of the hydrogen mixed gas, the movement speed of the torch (hereafter, simply “torch movement speed”), distance between the torch and the glass panels, and the angle of the torch nozzle (hereafter, simply “torch nozzle angle”). Two values (i.e., levels) were taken for each process parameter. The process parameters presented in the paper of the Y. Kim [10] were three factors and three levels. In this paper, it set to four factors and two levels. The angle of the torch nozzle was added to the parameter. Fig. 5 shows a conceptual diagram of the edge sealing process, and Table 1 lists the process parameters and their levels for performing edge sealing.

3.2. Setting of parameters of edge shape

The various shapes of the sealed glass edges are shown in Fig. 6. First, the sealed parts were cut (see Section 3 for further details on this) in order to analyze the various shapes of the sealed edge. Then, the process parameters affecting the shape of the sealed edge were set. Further, three parameters were set as shape parameters: edge

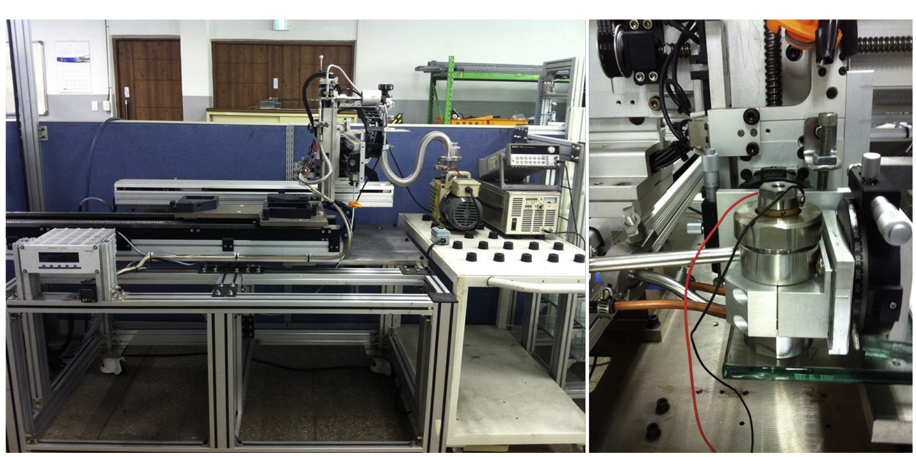

Fig. 3. Leak test of glass using the pump-out system.