Vacuum 149 (2018) 262–269

Contents lists available at ScienceDirect

Vacuum

journal homepage: www.elsevier.com/locate/vacuum

Using a hydrogen gas torch to seal edges of vacuum glazing panels and analysis of the related characteristic strength according to the sealed edge shapes

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A R T I C L E I N F O

Article history:
Received 20 November 2017
Accepted 3 January 2018
Available online 6 January 2018

Keywords:
Vacuum-sealed glass panel
Weibull distribution
Characteristic strengths
Sealed edge shapes
Hydrogen-mixed gas torch

A B S T R A C T

The edges of vacuum glazing panels sealed using a hydrogen-mixed gas torch are of various shapes, which affect the strength of vacuum glass. The characteristic strengths were analyzed according to the edge shapes. Specimens with different edge shapes were manufactured to study the characteristic strengths according to the edge shapes. Three shape parameters (thickness, radius, and deflection) were selected to numerically represent the edge shapes, and the cross-sections were measured accordingly. The four-point bending test was employed on the prepared specimens. Furthermore, the Weibull distribution, which is a statistical analysis method commonly used to study product failure and malfunctioning, was employed to analyze the experimental results. The strength and fracture distribution of the sealing shape were confirmed using the shape parameter and scale parameter of the Weibull distribution. In addition, the cross-sectional shape with the maximum strength was determined by taking into account the characteristic strength and safety factors proposed by major countries. Therefore, it can be applied to the production of vacuum glass by sealing the edge of the glass using the hydrogen-mixed gas torch in the cross-sectional shape satisfying the strength performance of the sealing parts.

1. Introduction

A vacuum glazing panel is a type of insulating material comprising two glass panes with a gap in between. The edges are sealed, and hence, a vacuum is created to effectively decrease energy loss [1].

Edge bonding is a very important process to maintain the inside of the glass in a vacuum; various studies have been carried out on this process. The formation of a contiguous indium/glass bond is essential for achieving a vacuum-tight seal. However, as indium oxidizes almost instantaneously when exposed to air, an inert atmosphere or vacuum is required for the full fabrication process [2].

Many studies on the edge-sealing process have been conducted. Edge sealing is one of the methods for manufacturing vacuum glazing panels. In this method, frit is applied over glass to seal two glass panes together [3,4]. This edge-sealing technology can be extensively used not only for display units, but also for home appliances and windows. However, the difference in the coefficients of expansion between glass and glass sealant creates problems [5].

This study used a hydrogen-mixed gas to seal edges and solve the shortcomings of frit usage. In this method, the hydrogen-mixed gas torch seals edges by fusing the glass edges together and letting them gradually cool down.

The cross-section areas assume different shapes, depending on reasons related to processing (e.g., process parameters) when a hydrogen-mixed gas torch is used to seal the glass edges. The shape of the sealing parts affects the strength of the vacuum glass panel.

Therefore, the edge joints were fabricated into various shapes, and the shapes were digitized. The fabricated specimens were subjected to a bending strength test, and their strength characteristics were analyzed according to the cross-sectional shape. We use the Weibull function to analyze the strength characteristics. The cross-sectional shape satisfying the strength of the fusion sealed

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https://doi.org/10.1016/j.vacuum.2018.01.005
0042-207X/

glass edge was determined by taking into consideration the safety factor and failure probability proposed by major countries.

2. Specimen manufacture

2.1. Sealing edges with a hydrogen-mixed gas torch

Two glass panels of 300 mm × 300 mm × 3 mm in size were placed together, such that their edges could be fused using a hydrogen-mixed gas torch. Fusion was performed to study the strengths according to the different edge shapes. The study results obtained by Kim [6] were used as a reference for the edge-sealing process parameters. The edges were sealed according to three standards, by considering the three process parameters that affect the shape of the sealed edges. The three process parameters were set at three levels, taking into account the gas flow rate of the hydrogen mixed gas stream, the feed rate of the torch, and the distance between the torch tip and the glass. A total of 47 test specimens were prepared for the cross-sectional shape measurement and the strength test analysis.

Specimens with 220 mm length and 50 mm width were cut using a waterjet [7–9] for the strength tests on the sealed glass edges. The specifications were based on the strength test standards for glass edges indicated in references, such as ISO-1288-3, ASTM C-1581, and ASTM C-1161. Fig. 1 shows a conceptual diagram of the specimen with edges sealed together and cut to the size required for the strength test.

2.2. Measurement of the cross-sectional shapes

A digital microscope was used to observe the cross-sections for the measurement of the cross-sectional shapes of the edges. The cross-sections were numerically represented here by selecting the thickness (T), radius (R), and deflection (δ) as the shape parameters representing the cross-sectional characteristics (Fig. 2 (a)). Fig. 2 (b) shows the cross-section of an edge sealed using a hydrogen-mixed gas torch [10].

A MATLAB program was used to measure the recorded cross-sections of the edges with the selected shape parameters. Two glass panes were fused together, and the xy coordinates were laid on top using the center point as the origin to numerically represent the shape parameters. The sealing thickness, deflection, and radius were calculated using the selected coordinates.

Fig. 2 (c) shows the coordinates along the edge boundary, using a MATLAB program. Table 1 lists the measured results of the cross-section. We measured the radius, thickness, and deflection of the 47 specimens.

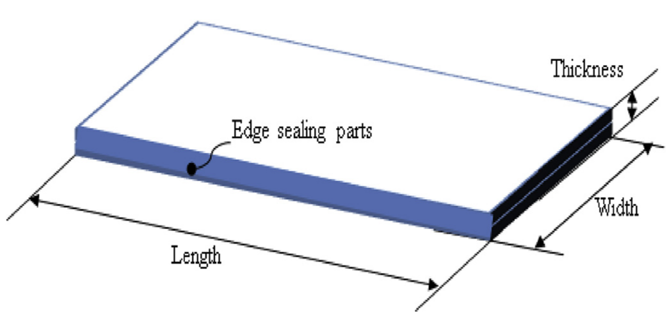

Fig. 1. Schematic diagram of the glass sheet for the four-point bending test.

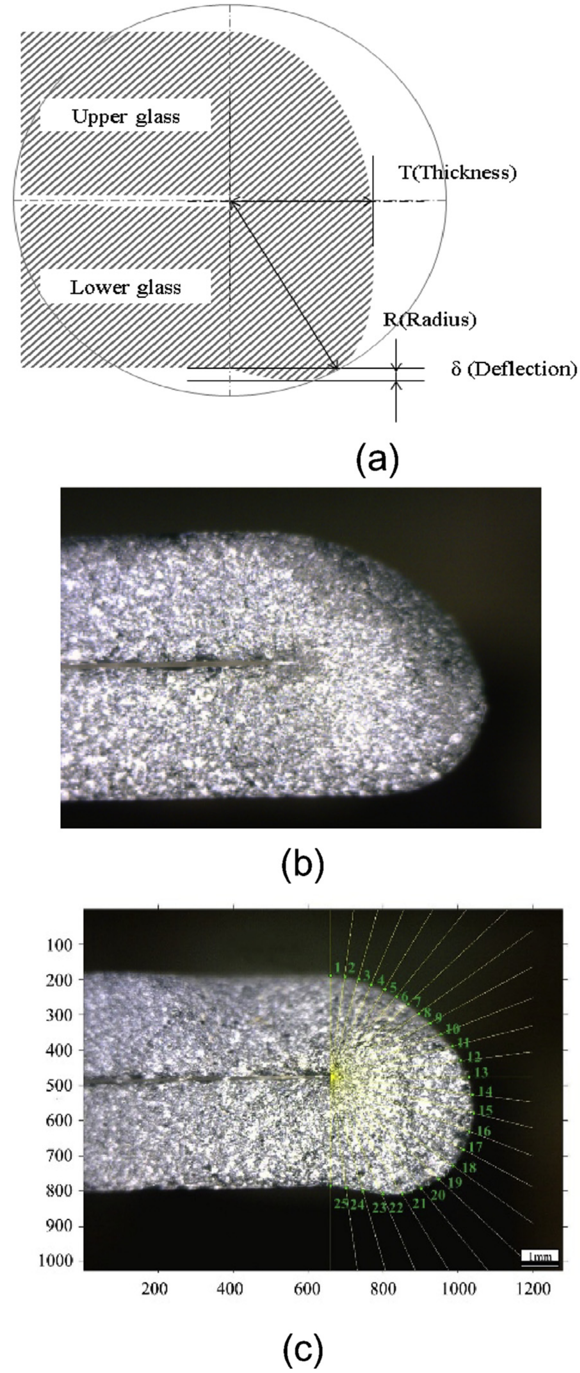

Fig. 2. Edge shape of the glass. (a) Shape parameters (not to scale); (b) cross-sectional shape; and (c) selecting the end point of the edge with MATLAB program.

3. Strength test

3.1. Four-point bending test

The four-point bending test was used to study the strength characteristics of the sealed edges. The simply supported beam span on the bottom was set to 200 mm based on the strength test standards in ISO-1288-3, ASTM C-1581, and ASTM C-1161. The loads were added at two points (100 mm apart) at the top of the beam. A universal hydraulic material testing machine (MTS810) with a crosshead speed of 2 mm/min was used for the tests [11–13]. Fig. 3