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Study of point-supported glass breakage behavior with varying point-covered areas under thermal loading

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ABSTRACT

Point-supported glazing assemblies are widely used in modern buildings for aesthetic elegance, as well as for economic reasons. However, the formation of vents caused by glass breakage could aggravate ventilation controlled compartment fires. The point-covered area generally varies and may constitute potential fire hazards. Accordingly, it is necessary to investigate the fire performance and breakage mechanisms in various point-covered areas. In this study, a total of 12 tests, including three various point-covered area glazing, were heated by a 200 × 200 mm^2 pool fire. The breakage time, glass surface and air temperatures, incident heat fiux, and crack initiation and final fall out ratio were obtained. The critical conditions for the three aforementioned various point-covered area glazing were determined. The reference breakage times, t_r, which were calculated by assigning a failure probability of 0.1 to the two-parameter Weibull distribution were 119, 140, and 166 s. It was established that a relatively small point-covered area glazing can survive longer; the smaller the point-covered area was, the larger the final fallout ratio of glazing assemblies will be. Numerical simulations were performed to investigate the stress distribution on the glass pane, with breakage times well predicted. Accordingly, these results have implications on the fire resistance design for point-supported glazing assemblies.

1. Introduction

In recent years, with the rapid development of glass production technology, various types of functional glass have been developed, further increasing their applications in the building industry sector. Glass curtain walls have become essential parts of building functionalization and diversification [1]. Thus, instead of four-edge covered glass facades, point-supported glass curtain walls are increasingly being employed in high-rise building envelopes for their aesthetic and flexible characteristics [2,3]. Although glass is not a type of combustible material under a fire environment, as it is a relatively fragile material compared with concrete or steel, it may easily crack and even fall out when subjected to fire, which would unavoidably detrimentally influence building structure stability and integrity [4,5]. Newly formed vents, which would supply more oxygen from the outside fresh air, could increase the growth of ventilation controlled enclosure fire and have a crucial contribution to the interactive-external tridimensional fire development. The extensive employ of point-supported installation of glass façades would inevitably introduce with it, not only aesthetics, but also risks associated with fire. Accordingly, it is essential to explore its specific fire performance.

In the 1st International Symposium on Fire Safety Science, Emmons highlighted that “glass breakage is an important fire structure problem” [6]. Thereby, Keski-Rahkonen [7,8], established a classic physical model to analyze its fracture mechanism when subjected to uneven thermal loads. Through an analytical method, it was determined that the covered edges were the most prone to cracking. Skelly et al., Pagni et al., and, Shield et al. [9-12], performed a series of experiments to validate a previous theoretical model and concluded that the critical temperature difference among edge-covered glazing was approximately 90 °C. Manzello [13] and Klassen et al. [14,15], investigated the fire performance of large-scale glazing under a real fire. Chow et al. [16] conducted fire tests concerning the heat transfer and smoke movement in a model box on part of a glass system with two panels. Recently, Debuyser et al. [17] heated monolithic and laminated glazing with a special focus on the heat transfer and developed a 1D heat transfer model to determine the evolution of the temperature profile as a result of a given incident heat flux. BREAK1 [18] and EASY [19] were developed to predict the cracking time. Through previous studies, several consensuses have been reached, such as the following: although various types of glass, installation forms, and external heat sources have remarkable influence on the fire performance of glazing, the major cause

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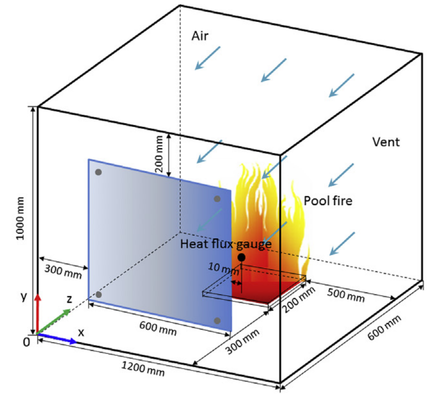
Fig. 1. Point-supported glass curtain wall, USTC campus, Hefei.

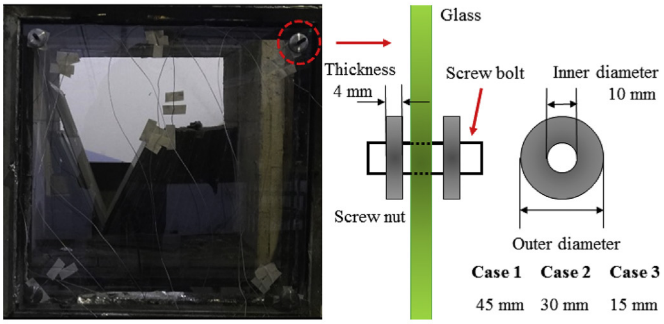
of glass rupture is the excessive tensile stress caused by inhomogeneous temperature distributions resulting from the presence of shaded areas, including the location of heat source relative to the glazing.

Nevertheless, previous studies concerning the fire performance of point-supported glass façade, which are typically supported by four points and extensively used as external façades of core wall structured buildings or partition walls, as shown in Fig. 1, were limited. Recently, Wang et al. [2,20], conducted experiments and numerical simulations concerning the fire response of point-supported glazing. In relation to the investigation of the influence of various point-covered areas, a geometric factor was introduced as a function of covered width, as proposed by Pagni et al. and Joshi et al. [21,22], to investigate the edge-covered width effect. Tofilo et al. [23] conducted an investigation to theoretically determine the influence of various covered widths on thermal stress by establishing an approximate solution for a long strip of glass pane. Chen et al. [24] conducted experiments concerning different shaded widths, ranging from 10 to 50 mm under radiant heat. It was established that various shaded widths of glass panes have a vital influence on breakage behavior, whereas previous studies discussed above, solely concentrated on the framed edge-covered glass façades, which were generally covered by a nontransparent frame or gasket. To the best of our knowledge, there is no open literature concerning the influence of varying point-covered areas on point-supported glazing assemblies. In engineering practice, the supporting point-covered area typically varies, which may introduce a potential fire hazard. Thus, it is insufficient with respect to practical guidance and national fire codes on the fire performance of various point-supported areas. In consideration of the increasing adoption of point-supported glazing with different point-covered areas in modern buildings, it is essential to investigate the thermal breakage behavior and underlying heat transfer mechanism, which could enhance our comprehension of the breakage process and criteria.

2. Experimental setup



(a) Test apparatus.



(b) Point-supported frame.

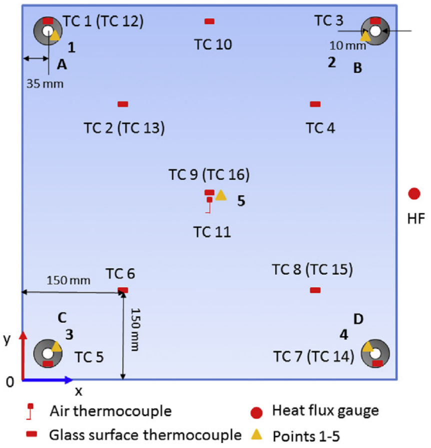


Fig. 2. The schematic of the experimental setup.

As shown in Fig. 2(a), the test equipment primarily consisted of four sections: heat source, cabinet for glass installation, temperature and incident heat flux measurement system, and mass-loss balance system. The cabinet had a vent in front of the glass installation, which could support combustion in a compartment space. The edge-polished float glass pane was mounted on a frame with four screws. To investigate the influence of different supporting point-covered areas, three different sizes of screw nuts, as illustrated in Fig. 2(b), made of 304 stainless steel with a heat conductivity of 16.2 W/(m·K) at 373 K, and with the same inner diameter and thickness, were adopted. The inner diameter and thickness were 10 and 4 mm, respectively, and were not changed in the course of the experiments. The outer diameters were 15, 30, and 45 mm. In order to make the experiment comparable to a real fire environment, four 10-mm diameter circular holes were drilled in each corner at a distance of 35 mm from the edge of the glazing. The glazing was located 300 mm above the ground and 300 mm away from the n-heptane pool fire in a $200 \times 200\text{-mm}^2$ pan, which was determined by a pre-experiment. Twelve $600 \times 600 \times 6\text{-mm}^3$ float glasses made of identical materials by the same local manufacturer were selected. As shown in Fig. 2(c), the glass surface temperatures were determined by 15 1-mm diameter K-type sheathed thermocouples (TCi), which were attached to the glass panes with high-temperature adhesive. The thermocouples were numbered TC1–TC10 (attached to the fire side surface), TC12–TC16, and TC1–TC10 (attached to the ambient side surface). In addition, a sheathed thermocouple, numbered TC 11, was set 5 mm in front of the glass to measure the air temperature. It should be noted that TC01, 03, 05, 07, 12, and 14 were attached to the point-covered areas to measure temperature variations in the experiments.