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Fracture behavior of framing coated glass curtain walls under fire conditions

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ABSTRACT

Breaking glass and its subsequent fallout may markedly affect enclosure fire dynamics. However, little is known about the thermal fracture behavior of framing glass façades in different installation forms. Sixteen $600 \times 600 \times 6\ mm^3$ solar control coated glass panes, installed in exposed, semi-exposed and hidden frames, were heated by a $500 \times 500\ mm^2$ n-heptane pool fire to investigate the influence of frame constraints on glass breakage and fallout. Measurements were taken of the time to breakage occurrence, heat release rates, incident heat flux, central gas temperatures and glass surface temperatures. Measurements in relation to crack initiation and propagation as well as loss of integrity of the glazing assembly were also recorded. The experimental results show that all cracks initiated at the edge of covered sections and intersected rapidly, forming islands. The maximum temperature difference and heat flux that the glass can withstand are primarily in the range of 50–90 °C and 9–15 kW/m^2. Using the finite element method (FEM), the breakage mechanism is demonstrated, the predictions of which are in reasonably good agreement with the experimental results. Among four different installation forms, semi-exposed framing façades showed better fire resistance than exposed framing façades. Meanwhile, the fire resistance of hidden framing façades may depend on the fire location. It is intended that these results will provide practical guidelines for fire safety design.

1. Introduction

Glass curtain walls, due to their transparency, energy saving and architectural aesthetics, are increasingly used as building envelopes instead of concrete and steel [1]. However, as the weakest part of a building, glass is more prone to breakage when subjected to fire. The opening resulting from the breakage and fallout of glass panels may easily form a corridor through which fresh air can enter the compartment and promote fire spread, accelerating the fire development. This important issue was firstly highlighted by Emmons in 1986 [2]. Following his pioneering work, a large number of experimental [3–11] and theoretical [12–17] studies were conducted to investigate the mechanism of glass breakage. For example, Shields et al. [6,7,11] conducted some full scale experiments using ISO 9705 apparatus to explore the behavior of single and double glazing exposed to fire. Joshi et al. and Wang et al. [4,9], using Weibull distribution, analyzed the probability of glass breakage. Skelly et al. [3] found that the maximum temperature difference one glass pane could withstand between its center and its edge is 90 °C. Meanwhile, Keski-Rahkonen [17] theoretically determined the value to be 80 °C. From the prior works, a consensus has been reached that the thermal gradient between exposed and covered regions is the primary cause for glass breakage in fires. While almost all of the previous works have focused on the four-edge covered window glass panel, little is known about glass façades installed in different forms.

Through an onsite survey in four cities in China, it was found that glass curtain walls employed in engineering primarily can be classified into three types: point supported, frame supported and full glass curtain walls. Among the three types, frame supported curtain walls, in which the glass panel is fixed by a metal frame at its surrounding edges, is used most commonly. Fig. 1 shows the typical frame supported glass curtain walls employed in the four Chinese cities. It can be seen that there are four categories of façades, according to the installation forms: fully exposed, horizontal-hidden, vertical-hidden and fully hidden framing glass curtain walls. The envelope of one building was found to consist of several kinds of framing glass façades, which render the glass

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Fig. 1. The frame supported glass curtain walls, photographed in four cities in China. (a) Exposed frame, Suzhou; (b) Horizontal-hidden frame, Hefei; (c) Vertical-hidden frame, Huainan and (d) Hidden frame, Shenzhen.

system significantly more complicated and thus increase the potential fire risk.

Despite the existence of various installation forms, limited work has been conducted to study the effect of installation forms on the breaking behavior of frame supported curtain walls [18]; in particular, to the authors' knowledge semi-exposed and hidden framing façades have not previously been studied in depth. The thermal response of point supported glass curtain walls has been investigated in previous work of the authors [19,20]. It is anticipated that the fire response may also be significantly different when glass panels are supported in the various frames shown in Fig. 1 [21]. These designs may introduce fire problems and fail to comply with the national fire safety codes. Therefore, it is necessary to study the various glass façade systems and deepen understanding of their breaking mechanisms and conditions.

In the present study, a total of 16 full scale experiments, including four different fixing forms, were conducted to explore the thermal breakage of frame supported glass curtain walls. To satisfy the experimental requirements, a glass frame and relevant apparatus were carefully designed. Several critical parameters, such as the time of breakage occurrence, crack initiation and propagation, heat release rate (HRR), incident heat flux (HF), central gas temperature, glass surface temperatures and loss of integrity of the glazing assembly, were recorded. What is more, according to the thermal loading measured in experiments, a finite element software developed by the research group [22,23] was used to predict the stress distribution, breakage time, crack initiation and propagation. The experimental and numerical results are compared and discussed in depth.

2. Experimental setup and numerical principal

2.1. Experimental description

According to the conducted onsite survey, for framing façades each glass pane is supported vertically only by its surrounding frame, meaning that any adjacent glass panes or steel structures have almost no impact on it. Hence, in this work, a single glass pane fixed in a frame was selected as the research focus. To more closely resemble real life situations, a well-designed frame made of stainless steel, which could withstand temperatures of 1200 °C, was employed for glass support. As shown in Fig. 2(a), this frame has four edges that can be moved in two directions and if necessary each edge can also be removed from the main frame. In the thickness direction, the pane is clamped by several thin strips, and the clamping pressure is controlled by revolving these screws, as presented in Fig. 2(b). This design ensures the glass pane can be appropriately constrained in the *x*, *y* and *z* directions. Thus the installation forms or glass thickness can be changed depending on experimental need. Fig. 3 illustrates that, through adjustment, the designed frame can well satisfy the experimental requirements and fix glass panes in four different installation forms, including fully exposed (Case 1), horizontal-hidden (Case 2), vertical-hidden (Case 3) and fully hidden forms (Case 4).

In the experiments, the width of the covered region at the glass edge was 20 mm, and the frame offered no restraint to the glass since the maximum expansion, <1 mm, was less than the normal gap of several millimeters between the frame and the pane [17,24]. The different installation forms of framing façades are substantially the change of shading forms and, therefore, the designed frame can achieve the research objective. It should be noted that,