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Fracture behavior of a four-point fixed glass curtain wall under fire conditions

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ABSTRACT

The cracking and subsequent fallout of glazing could significantly affect compartment fire dynamics by creating a new opening for air to enter. Twenty-four $1200 \times 1200 \times 6\ mm^3$ soda-lime glass panes in eight different fixing forms were heated by a $500 \times 500\ mm^2$ N-heptane pool fire to investigate the influence of fixing conditions on glass breakage and fallout. The time of crack initiation, behavior of crack propagation, heat release rates, central gas temperatures, glass surface temperatures and loss of integrity of the glazing assembly were investigated. The relationship between fixing form and crack behavior is discussed, based on the experimental results. The results show that all the cracks initiated at the supporting point and intersected rapidly, causing glass fallout. Mechanical stress caused by supporting pins and thermal stress caused by glass temperature difference (ranging from 48 °C to 159 °C) are the causes of breaking for this kind of curtain wall. It is concluded that various fixing locations have a significant effect on glass breaking. Among the eight cases, the glass panes whose supporting points were located at 10 cm (Case 1) or 5 cm (Case 8) from the edges performed best: these support locations are recommended in practical engineering because of the good fire resistance and structural beauty of such panes.

1. Introduction

Glass curtain walls, because of their transparency and for aesthetic considerations, are becoming a very popular building surface material alternative to cement and steel, especially in high-rise buildings. However, as the weakest part of a structure, such curtain walls may easily break when exposed to large fires. The sudden venting resulting from fallout of glass panes may then provide a corridor for fresh air to enter the compartment, and an outlet for fire spread, accelerating fire development. The importance of research into glass thermal breaking was first proposed by Emmons in 1986 [1]. Several theoretical analysis and simulations were subsequently conducted to explore the breakage mechanism [2–9]. These studies revealed that the thermal stress induced by temperature difference is the cause of window glass breaking. This theory has repeatedly been verified by experiment [10–19]. Skelly et al. [10] established the temperature difference in a fire between the center of a glass panel and the edge was 90 °C. Chow et al. [11,12] investigated fire smoke effect on glass cracking, and analyzed the thermal stress. Pagni and Behr [13,14] analyzed failure strength, using Weibull distribution with data from numerous experiments. Shields et al. [15–17] conducted a series of experiments to study the thermal performance of single and double glazing assemblies. Xie and Wang [18,19] also examined the effect of thicknesses and temperatures variance on glass breaking in ISO 9705 and MTS 810. The experimental results suggest that the main cause for a single pane of glass exposed to a radiant heat source to fall out is the thermal gradient between the shaded and exposed regions of the glass.

However, the prior research discussed above only explored small-sized window glass with surrounding edges covered by an opaque frame or gasket. Until recently, very little research has been conducted to investigate point-supported glass curtain walls, which are generally supported by four points and widely used as the outside walls of high buildings or separation walls inside buildings. Due to its flexibility, lightness and structural beauty, this kind of glass facade has already been extensively employed in city landmark construction. Despite its wide application, its fire resistance and breakage mechanism is not yet well understood, however. If subjected to fire, the entire glass pane would be exposed to

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strong radiation, and the resulting breaking process would be very different from that of edge-covered glass.

Therefore, it is necessary to investigate the influencing factors of breakage and fallout for four-point fixed glass curtain walls, and deepen our understanding of their breaking conditions and principles. Harada [20] and Wang [21,22] investigated the breaking behavior of edge-covered window glass panes under different constraining conditions. It is anticipated that some differences may exist between the breakage behaviors of four-point supported and edge-covered glass panes, and the different fixing locations might also affect the thermal performance of point-supported glass curtain walls. This is effectively the motivation for the present study.

Twenty-four experiments, including eight different fixing forms, were conducted to explore the effect of fixing conditions on glass breakage and fallout. The breaking time, crack propagation, heat release rates, central gas temperatures, glass surface temperatures and loss of integrity of the glazing assembly were recorded for further discussion and comparison.

2. Experimental

As shown in Fig. 1, point-supported glazing is generally fixed by a stainless metal claw, which has four or six points to bear the weight of the glazing. Hence, each glass pane is supported vertically at only a few points. In this work, the most common glass panes, which are supported by four points, were selected as the research focus. Eight fixing forms of glass panes were designed and directly heated by a pool fire. To avoid accidental errors, each form was tested three times. The eight cases are presented in Fig. 2(b). It should be noted that this figure only shows the location change of upper left point. When this point changes, the locations of other three points also change, so that the four fixing points are always kept in centrosymmetry.

To make the experiment more closely resemble real life situations, the glass was carefully installed 30 cm from the floor by four screws into a frame, as shown in Fig. 3. The glass edges were polished, and four circular holes with diameter of 12 mm were drilled into each corner. Twenty-four float glass panes with the same dimensions ($1200 \times 1200 \times 6\ mm^3$) were chosen to mimic the size commonly used in buildings. During the tests, the glass panes were placed 0.5 m away from n-heptane pool fires in a $500 \times 500\ mm^2$ square pan, as shown in Fig. 4. Through preliminary tests, this distance was proved to be appropriate for generating cracks in glass.

The measuring system primarily consisted of thermocouples (K-type sheet and bare thermocouples), a mass loss balance with a range of 40 kg and a standard video camera with a framing rate of 25 frame/s. The sheet thermocouples were attached to the glass panes to detect the surface temperature via their high heat-conducting sheets, which is made of aluminum alloy with a high heat conductivity of 226 W/m·K. As shown in Fig. 5(a), the dimension of sheets is approximately $2.5 \times 1.5\ cm^2$, thus it can increase the contact areas between detected objects and a temperature-sensing element. Moreover, the surface of the sheet is light reflective, which can reduce the effect of radiation from the fire, rendering the results more accurate. Ten sheet thermocouples, numbered from TC01 to TC10, were used to detect the temperature variance of both glass sides, as shown in Fig. 5(b and c). A bare thermocouple with a diameter of 1 mm (TC11) was placed 5 mm away from the center of the exposed face to record the air temperature variance. Because of direct radiation heating on these thermocouples, uncertainties in temperature measurement are estimated to be 5%. In addition, a balance was used to measure the mass variance of burning fuel, to explore the relationship between the glass breaking and fire development. A camera was set to record the breaking process and fallout behavior.

3. Results and discussion

The results obtained from the 24 experiments are presented below. Some important parameters, in terms of initial crack time, glass surface temperature, cracking behavior, central gas temperature, heat release rates and loss of integrity of the glazing assembly, are analyzed and discussed in the following sections.

3.1. Time of first crack

The time of breaking is a significant parameter, which determines fire development, but because of great randomness in the cracking of glass, this parameter is still extremely difficult to predict by theoretical or numerical analysis. Experimental investigations are a comparatively direct and practical method of studying this phenomenon. Unlike edge-covered glass, point-supported glass curtain walls easily fall out once breaking occurs, due to their large size and fixing form. The experimental results show that 21 of these samples fell out directly. Three samples first cracked without any loss of glazing, and then the majority of the glazing fell out. Therefore, the breaking time includes the time of crack initiation and fallout for each glass pane.

The first fallout time is listed in Table 1. It may be seen that the values for the three tests in each case are similar, but the differences between cases are comparatively great. When the supported point position changes from Location 1 to Location 3 in the horizontal direction (shown in Fig. 2(b)), the average time of fallout decreases. The time for Case 4 is also greater than Case 5. Results for Cases 6 and 7 are similar. When the supported point

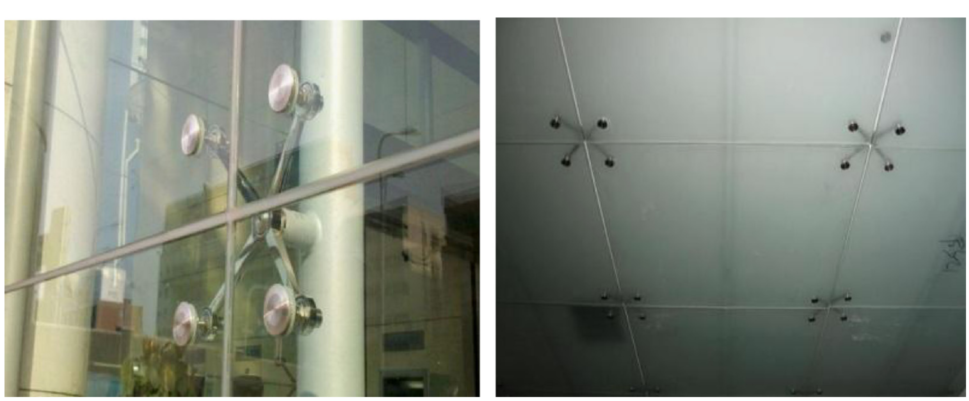

Fig. 1. Point-supported glass curtain wall.