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Research on fire endurance of tempered glass based on infrared imaging technology

LI Mingxuan*, LU Guojian, HU Zhongri, MEI Xiujuan, LI Le,WANG Liping

Sichuan Fire Research Institute of MPS, Chengdu, 610039, China

Abstract

The tempered glass is widely used in the buildings because of its good transparence and fire endurance under the protection of the sprinkler.The fire backdraft may occur under the good ventilation condition after the tempered glasses fall apart in fire, which can endanger the human evacuation and fire rescue. By the testing of the surface temperature of the tempered glass exposed to the building fire, the critical temperature of the glass fracture can be acquired and the basis for the prediction and prevention of the fracture of the tempered glass then can be provided, which is useful for the performance-based design of the fire safety. The infrared imaging equipment is firstly used in China for the research on the fire endurance of the tempered glass.

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Keywords: tempered glass; fire endurance; infrared imaging technology; critical temperature

1. Introduction

With the emergence of diversity of new architectural styles, new materials, and large volume buildings, the visual translucency and continuity are required in more and more buildings. So the traditional fire compartment, such as firewalls and fire-resistant rolling shutters are unable to meet such requirements, and more and more tempered glass are used in the doors, windows and fire compartment. The poor ventilation condition in the combustion chamber and the lack of oxygen may cause the extinguishing or smoldering of fire, however the good ventilation condition caused by the fractured glass may form the fire backdraft, which can endanger the fire fighters and occupants in the building. During the performance-based design of fire safety, the time and possibility of the

* Corresponding author. Tel.: +0-086-028-875-11960; fax: +0-086-028-875-11960.
E-mail address: robustlee@sohu.com

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glass fracture will greatly influence the smoke spread. Many researches on glass fracture have been done at home and abroad, but the fire fuel are almost the oil , the fire load is also low, and the glasses used in the test are almost in small size, which do not comply with the real building fire conditions. Thus, a mathematical algorithm for glass breakage prediction in the FDS is needed [1], and the full-scale test with the tempered glass is used to analyze the fire endurance of the tempered glass.

Many tests of the fire endurance of the tempered glass with the sprinkler protection have been conducted in China [2,3], in which the integrity of the tempered glass can maintain for a long time. However, the tests for the fire endurance of the tempered glass without the protection of the sprinkler have seldom been done, and the efficiency of the protection of the sprinkler for the tempered glass needs to be further validated.

2. Experimental setup

The testing room with the size of 10 m(L)× 10 m(W)× 5 m(H) for the full-scale test of the fire endurance of the tempered glass is located at the large-space testing building in Dujiangyan City. The two walls of the testing room are constructed of concrete block of 20cm thickness, the other two walls are formed by the tempered glass assembly with the aluminum columns, which is shown in Fig. 1. The facade A is composed of 5 aluminum columns and 4 tempered glass panes with the size of 2.5m(L)×5m(W)×0.012m(T). The facade B is composed of 6 aluminum frames and 5 tempered glass panes with the size of 2m(L)×5m(W)×0.012m(T). Each of the tempered glasses of facade B is protected by the window sprinklers installed at top of the tempered glass, and the activation temperature of the sprinkler is 68 ℃.The space between the tempered glass and the frame is filled with the fire sealant. The tests for the fire endurance of the tempered glass with or without the protection of the window sprinkler are analyzed respectively. And the mechanical ventilation system with the ventilation volume of $60m^3/m^2.h$ is used in the combustion chamber, which complies with China's codes for building fire protection. The fresh air can be supplied into the combustion chamber through the door.

At the center of the combustion chamber and near each of the tempered glass, the thermocouples are positioned at the height of 1.8 m, 3.5 m and 4.8 m from the ground separately, so the temperature of the gas, the tempered glass and the glass edges can be measured, which is shown in Fig. 2. Two infrared (IR) cameras are positioned 11 m away from the front of facade A, so the temperature distribution on both sides of the tempered glass can be recorded. For the better application, the highest Heat Release Rate(HRR) satisfies the requirements for the ordinary places, such as shopping mall, etc. with the reference to "*Technical Specification for Building Smoke Control*"[1]. The maximum fire load of the shopping mall with sprinkler protection can reach 4MW, while the fire load of public hall without any sprinkler protection can reach 8 MW. The fire sources are wood cribs, which have been calibrated by the cone calorimeter according to ISO9705 and SBI before the test [2].

Fig. 1. Testing room.

Fig. 2. Tempered glass of Façade A.

3. Data analysis

3.1. Fire scenario I

For the wood crib fire test of 4 MW, Fig. 3 shows the temperature rise of the tempered glass of façade A at 10

minutes after the ignition, in which the temperature is about 100 ℃ at 3 m height, and about 40 ℃ at 1m height. Fig. 4 shows the temperature rise of the tempered glass of façade A at 20 minutes after the ignition, in which the temperature is about 180 ℃ at 3 m height, and about 80 ℃ at 1m height. The temperature difference between the upper part and the lower part is great because of the smoke stratification. The gas temperature of the upper part is higher than that of the lower part, because the fresh air comes in from the outside, and the convection between the different smoke layers causes the different temperature distribution on the tempered glass. Fig. 5 shows the time-dependent temperature of the tempered glass of façade A at 0.5 m、1.5 m、2.5 m and 3.5 m height during the test, and the temperature difference between the upper part and the lower part is not over than 100 ℃. Fig. 6 shows the temperature of the 4 points in the horizontal direction for façade A at 3 m height. It shows clearly that the temperature difference in the horizontal direction is not over than 20 ℃. It is shown in Fig. 3 and Fig. 4 that the surface temperature of the tempered glass exposed to the fire source is not obviously higher than that of the other part of the tempered glass [3], which demonstrates that the radiation is not the dominant factor for the temperature rise of the tempered glass. The integrity of the tempered glass maintains well during the test, and no glass fracture or collapse happens [4].

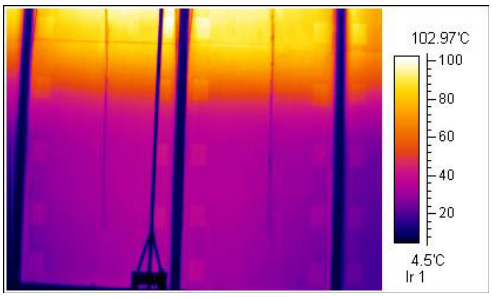

Fig. 3. Temperature distribution on glass 2 and glass 3 at 10 minutes.

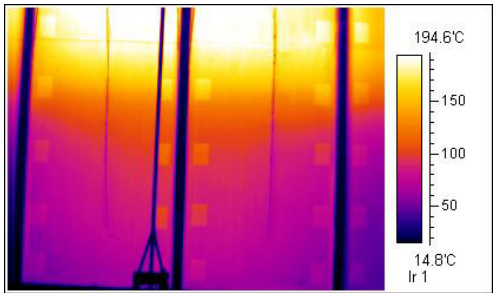

Fig. 4. Temperature distribution on glass 2 and glass3 at 20 minutes.

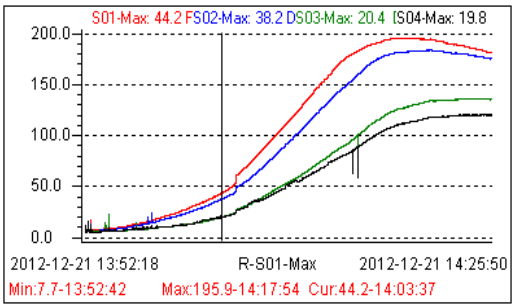

Fig. 5. Time-dependent temperature of glass 2 at 4 different heights.

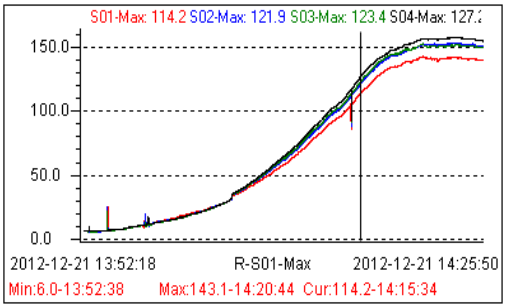

Fig. 6. Time-dependent temperature of 4 points of glass 2.

3.2. Fire scenario II

For the wood crib fire test of 8 MW, Fig. 7 shows that the left upper part of the tempered glass 2 breaks at 540 seconds after the ignition, when the highest temperature on the unexposed side is 300℃ and the highest temperature on the exposed side reach 700 ℃,which are recorded by the thermocouples. The right upper part of the tempered glass 3 breaks at 660 seconds after the ignition, when the highest temperature on the unexposed side reaches 335 ℃ and the highest temperature on the exposed side reaches 650 ℃, which are recorded by the thermocouples. Fig. 8 shows that the lower part of the tempered glass 2 breaks at 680 seconds after the ignition, when the fracture temperature of the upper part on the unexposed side is 350 ℃ and the lower part temperature is 100 ℃, while the highest temperature of the upper part on the exposed side reaches 620 ℃, and the lower part temperature is 150 ℃, which shows the great temperature difference between the exposed side and the unexposed side. Fig. 9 shows the

time-dependent temperature of the tempered glass 2 at 0.5 m, 1.5 m, 2.5 m and 3.5 m height, and the temperature difference between the upper part and the lower part is around 200 ℃. Fig. 10 shows the time-dependent temperature of the tempered glassof 4 points in the horizontal direction at the 3m height, which clearly shows that the temperature difference in the horizontal direction is narrow.

4. Results

Through the full-scaled fire tests of 4 MW and 8 MW, the integrity of the tempered glass used in the shopping malls and public buildings without any protection of window sprinkler is studied, the temperature distribution on the tempered glass is measured, the different temperatures of the glass fracture are recorded and the following results are included:

(1) The infrared camera(IR) can be used to record the surface temperature of the tempered glass during the whole test, so the thermocouple installation may be reduced, but the calibration with the thermocouple shall be carried out before the test.

(2) The temperature of the upper part of the tempered glass is higher than that of the lower part because of the smoke stratification [5], which shows that the convection has more influence on the temperature rise than the radiation. Because the tempered glass has no good heat conductivity, the strain caused by the temperature difference is the key factor leading to the glass breakage.

(3) The tempered glass maintains good integrity in the wood crib fire test of 4 MW, which demonstrates that the tempered glass used as the compartment item is reliable in the shopping mall under the sprinkler protection[6].

(4) The tempered glass does not maintain the integrity well in the wood crib fire testof 8MW without any sprinkler protection, and the temperature difference between the exposed side and the unexposed side when the tempered glass cracks, is about 300 ℃. So the tempered glass can be used as fire compartment item only when the reliable window sprinkler is used.

(5) The tempered glass of facade B maintains good integrity in the tests, which demonstrates the effectiveness of the sprinkler protection.

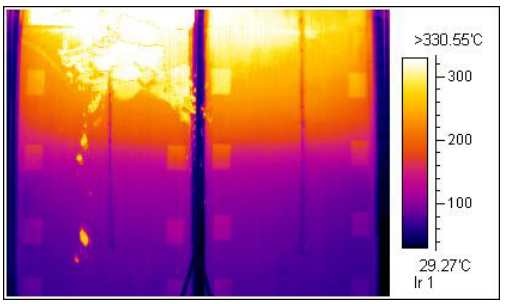

Fig. 7. Temperature distribution on glass 2 and glass 3 at 540 seconds.

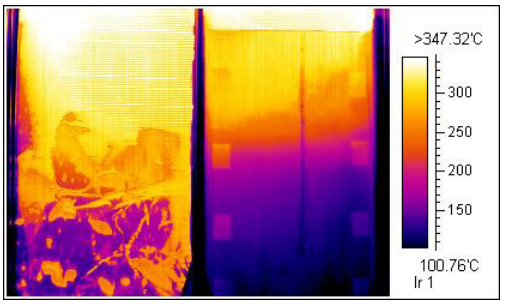

Fig. 8. Temperature distribution on glass 2 and glass 3 at 680 seconds.

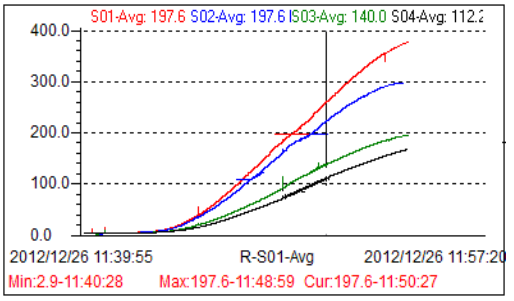

Fig. 9. Time-dependent temperature of glass 2 at 4 different heights.

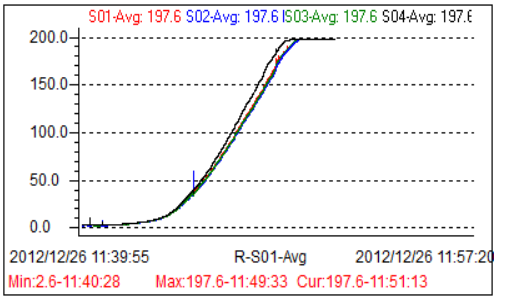

Fig. 10. Time-dependent temperature of 4 horizontal points on glass 2.

5. Conclusions and future works

The traditional fire compartment items such as fire wall, fire-resistant rolling shutter, etc. are not characterized with transparence, which can't meet the needs of the building designers and owners. The testing results show that the tempered glass can be used as the fire compartment item under the sprinkler protection. However, the relationship between the temperature difference and the thermal strain of the heated tempered glass should be studied in the future research to set up the mathematical model for the prediction of the tempered glass breakage in the building fire.

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