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Experimental study of fire barriers preventing vertical fire spread in ETISs

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Abstract. In recent years, the external thermal insulation system (ETIS) has been applied increasingly in a large amount of buildings for energy conservation purpose. However, the increase use of combustible insulation materials in the ETIS has raised serious fire safety problems. Fires involving this type of ETIS have caused severe damage and loss. In order to improve its fire safety, fire barriers were suggested to be installed.

This paper introduces fire experiments that have been done to study the effects of fire barriers on preventing vertical fire spread along the ETIS. The experiments were performed according to BS 8414-1:2002 "Fire performance of external cladding systems – Part 1: Test method for non-loadbearing external cladding systems applied to the face of the building". The test facility consists of a 9 m high wall. The fire sources were wood cribs with a fire size of 3 ± 0.5 MW. The insulation materials were expanded polystyrene foam (EPS). The fire barrier was a horizontal strip of rockwool with a width of 300 mm. Thermocouples were used to measure temperatures outside and inside the ETIS.

A series of experiments with different fire scenarios were done: no fire barrier, two fire barriers and three fire barriers at different heights. Test results were compared. The results show that the ETIS using EPS without fire barriers almost burned out, while the ETIS with fire barriers performed well in preventing fire spread. The temperatures above the fire barrier were much lower than those below the fire barrier, and most of the insulation materials above the top fire barrier stayed in place.

INTRODUCTION

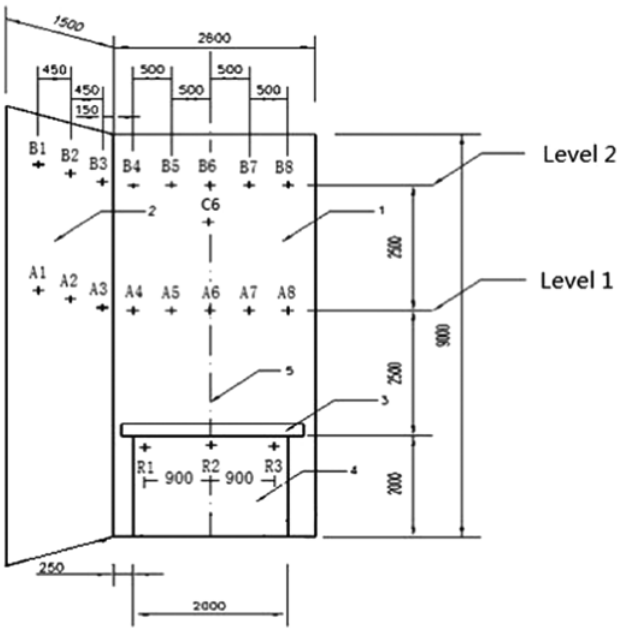
External thermal insulation systems have been widely used in buildings in order to meet the requirement of China law of building energy-saving. Insulation material is the main component of external thermal insulation system. The organic insulation materials have lower thermal conductivity, lighter weight, better water repellency, better weathering resistance and lower price than the inorganic insulation materials. Therefore, most external thermal insulation systems use organic insulation materials in China. However, the organic insulation material is combustible. Once it is ignited, the flame will spread along the insulation material on the external wall [1]. In China, several fire disasters involving combustible claddings occurred and have caused serious property damage and life loss in recent years [2–6]. The fire safety of exterior wall claddings has attracted not only public's eyes but also fire safety researchers' attention.

Fire barriers were suggested to be installed in ETISs by some researchers to prevent vertical fire spread along the ETISs. In order to study the effects of fire barriers used in ETISs, full-scale fire tests were performed with reference to British standard "BS 8414-1:2002 Fire performance of external cladding systems-Part 1: Test method for non-loadbearing external cladding systems applied to the face of the building" [7].

TEST MODEL SET-UP

Test facility

The test wall is 9.5 m in height and in the shape of L, the angle is 90°. The main wall is 2.8 m wide and the wing is 1.8 m wide. A combustion chamber with the opening as 2 m high and 2 m wide is



1——main test wall, 2——wing, 3——beam, 4——combustion chamber,
5——centre line of combustion chamber opening,
A1～A8——thermocouples at level 1, B1～B8——thermocouples at level 2,
C6 ——thermocouples at 4m above the combustion chamber,
R1～R3——thermocouples in combustion chamber

Figure 1. Schematic diagram of the test facility and location of thermocouples.

positioned at the base of the main test wall. The internal dimensions of the combustion chamber are 2 m wide, 1 m deep and 2.3 m high. Figure 1 gives the schematic diagram of the test wall. A wood crib with 1.5 m (long)× 1 m(wide) × 1 m (high) was used as heat source. The crib released a total heat output of 4500 MJ over 30 min at a peak rate of (3 ± 0.5) MW.

Thermocouples

The temperature inside and outside the ETISs were measured by Type K thermocouples. The locations of the thermocouples are showed in Figure 1. Two thermocouples were set at one measuring point except R1~R3. One was used for external temperature of the ETISs, the other was used for internal temperature of the ETISs. The external thermocouples were positioned 50 mm in front of the surface of the ETISs. The internal thermocouples were positioned at the mid-depth of each combustible layer.

TEST PROGRAM

A series of experiments were performed with ETISs installed without fire barrier, two fire barriers and three fire barriers. The insulation material of the ETISs was flame-retardant EPS with the thickness of 7 0mm. The limiting oxygen index (LOI) of the EPS was 35.5%. A (4 ± 1)mm thick plaster layer with glass fiber mesh was positioned on the outer surface of the insulation material. The fire barrier was

Table 1. Text cases.

NO.	Insulation material	Width of EPS	Thickness of plaster layer	
GL01	EPS LOI=35.5%	70 mm	(4 ± 1)mm	Fire barrier No fire barrier
GL02				Two fire barriers, positioned: 1) top edge of the combustion chamber 2) 4.6m above the combustion chamber
GL03				Three fire barriers, positioned: 1) top edge of the combustion chamber 2) 2.3 m above the combustion chamber 3) 4.6 m above the combustion chamber

a horizontal strip of rockwool with a width of 300 mm. When two fire barriers were installed in the ETIS, one was installed at the top edge of the combustion chamber, and the other was at 4.6 m above the combustion chamber. A fire barrier installed at 2.3 m above the combustion chamber was added for three fire barriers case. Table 1 shows the test cases.

The ambient temperature at the start of the tests was within the range 10 ∼ 25 °C. The air velocity in any direction is less than 2 m/s at the start of the tests. The data acquisition and audio visual records were commenced at least 5 min prior to ignition of the fuel source. During the test, the times of significant events such as the change of flaming conditions and any change in the mechanical behavior of the ETIS were recorded. The nominal duration of the test was 30 min. However, if the fire was too large to control, the test can be terminated early. When the test was ended, the test facility should be cooled naturally and then examining the damage of the ETIS.

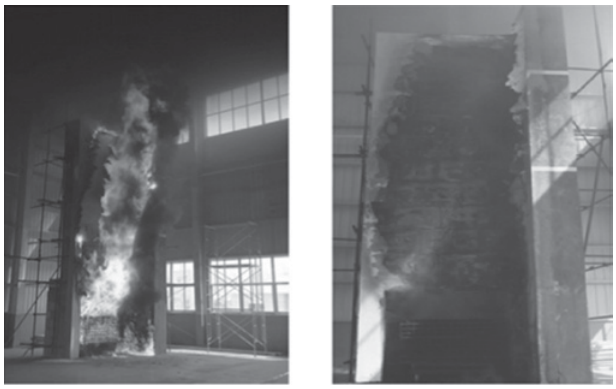
RESULTS AND DISCUSSION

Test phenomena

Figure 2 shows the photos of the test without fire barrier. Almost all the insulation materials on the main wall and the wing were on fire 18 min after the ignition of the wood crib. The extent of flame spreads over the surface of the ETIS both vertically and horizontally. And many dripping insulation materials were burning continuous on the ground. After the test, the insulation materials were almost burned out.

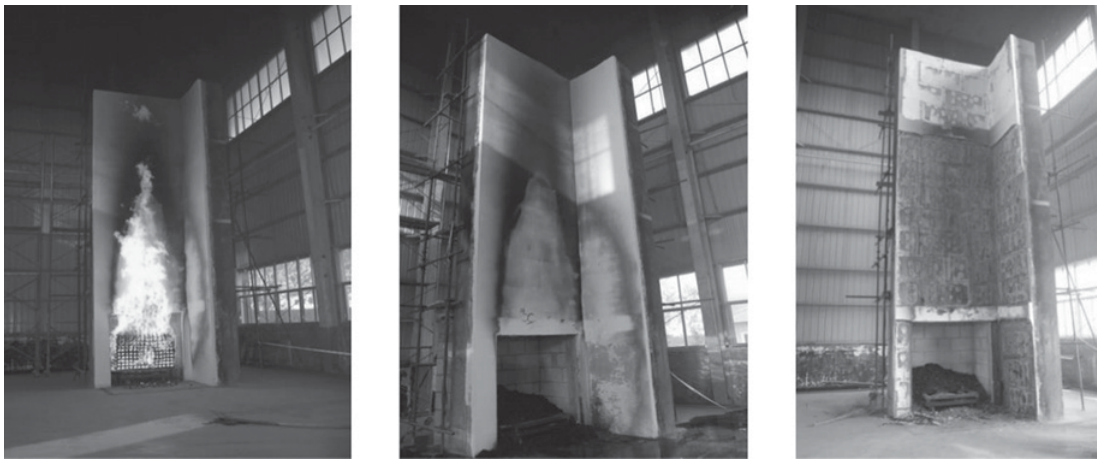
Figure 3 shows the photos of the test with 2 fire barriers. The surface of the ETIS was raised obviously during the test. The extent of flame was close to the top of the test wall. Flaming droplets did not appear during the test. There was almost no damage on the surface of the ETIS after the test, except some cracks above the bottom fire barrier on the main wall. These means the insulation materials contacted with the flame during the test. After removed the plaster layer, we could see that the insulation materials below the top fire barrier were burned out. However, the insulation materials above the top fire barrier were remained a lot and just became thinner.

Figure 4 shows the photos of the test with 3 fire barriers. The test phenomena were almost same as the test with 2 fire barriers. Flaming droplets also did not appear during the test and only some cracks were on the surface of the ETIS. The extent of flame was just above the top fire barrier. After removing the plaster layer, we found that almost all the insulation materials above the top fire barrier were still in place. The insulation materials between the top fire barrier and the middle fire barrier were melted a lot. The insulation materials below the middle fire barrier were almost burned out.



(a) during test *(b) after test (plaster layer removed)*

Figure 2. Pictures of the ETIS with EPS and no fire barrier installed.



(a) during test *(b) after test (plaster layer unremoved)* *(c) after test (plaster layer removed)*

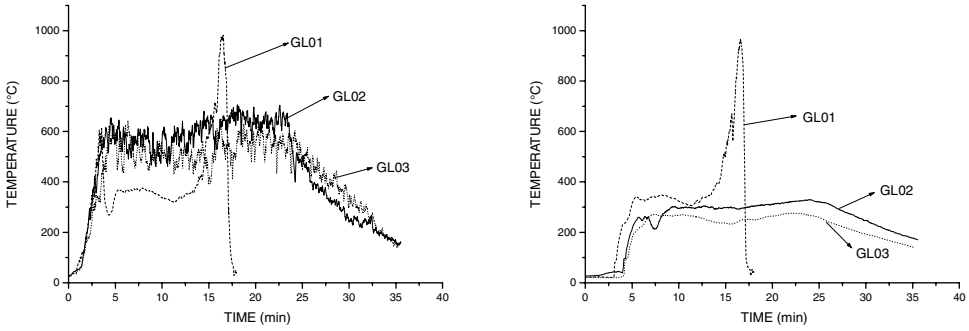
Figure 3. Pictures of the ETIS with EPS and two fire barriers installed.

Temperature in the tests

The external and internal temperature at C6 and B6 measuring point of the tests with and without fire barriers were showed in Figure 5 and Figure 6. To C6 measuring point (4 m above the combustion chamber, below the top fire barrier), the external temperature is 983.3 °C in test without fire barrier, 705.7 °C in test with two fire barriers and 648.4 °C in test with three fire barriers. The internal temperature is 965.4 °C in test without fire barrier, 330.6 °C in test with two fire barriers and 276.2 °C in test with three fire barriers. To B6 measuring point, the external temperature is 976.9 °C in test without fire barrier, 578.5° in test with two fire barriers and 581.3 °C in test with three fire barriers. The internal temperature is 968.6 °C in test without fire barrier, 275.3 °C in test with two fire barriers and 233.8 °C in test with three fire barriers.

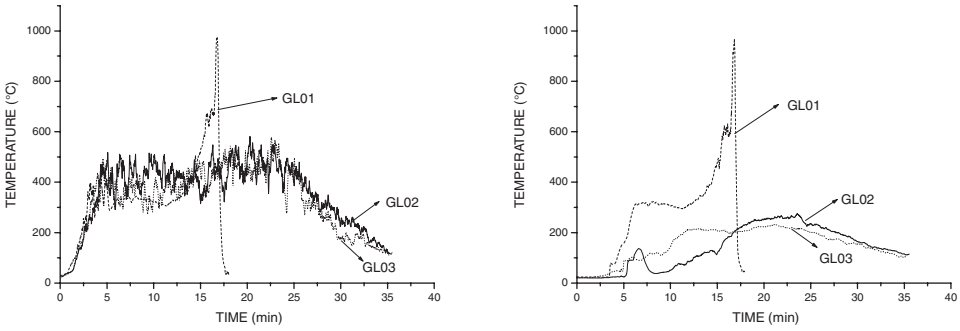
(a) during test *(b) after test (plaster layer unremoved)* *(c) after test (plaster layer removed)*

Figure 4. Pictures of the ETIS with EPS and three fire barriers installed.



(a) external temperature *(b) internal temperature*

Figure 5. Temperature at C6 measuring point.



(a) external temperature *(b) internal temperature*

Figure 6. Temperature at B6 measuring point.

From the temperature acquired in the tests, at C6 measuring point, the external temperature difference reached 300 °C and the internal temperature difference reached 600 °C between the test without fire barrier (GL01) and the tests with fire barriers (GL02 and GL03). And at B6 measuring point, the external temperature difference reached 400 °C and the internal temperature difference reached 700 °C between the test without fire barrier (GL01) and the tests with fire barriers (GL02 and GL03). This indicates that the fire barrier can improve the fire performance of the ETIS significantly. In addition, the external highest temperature at C6 and the external and internal highest temperature at B6 of the test with three fire barriers (GL03) were lower than those of the test with two fire barriers (GL02). This shows that the ETIS with three fire barriers has better fire resistance.

CONCLUSIONS

This study has focused on the effectiveness of fire barrier on preventing vertical fire spread in ETISs. A series tests were conducted with ETISs installed without fire barrier, two fire barriers and three fire barriers. The tests were performed according to BS 8414-1:2002 “Fire performance of external cladding systems–Part 1: Test method for non-loadbearing external cladding systems applied to the face of the building”. Following conclusions can be drawn from the experimental results: (1) Fire barrier with 300 mm wide can improve fire performance of the ETISs and prevent fire spread along the ETISs. (2) Increase the number of the fire barriers or decrease the spacing between the fire barriers can make the ETISs have better fire resistance.

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