Evaluation on Combustion Characteristics of Finishing Materials for Exterior Walls

Oh-Sang, Kweon¹, Heung-Youl, Kim¹ and Seung-Cho, Yang²

1. Fire Research Institute, Korea Institute of Civil Engineering and Building Technology, Hwaseong-si KS009, Republic of Korea

2. Architectural Engineering, Hannam University, Daejeon KS015, Republic of Korea

Abstract: Existing fire test methods rely on measurement of the energy released rate to identify the combustion properties of a material. However, they are inadequate when assessing combustion characteristics of a composite material characterized by vertical flame spread and different inside/outside combustion behaviors. In addition, major factors that affect the flame spread outside the building include the combustion characteristics of materials used as well as air flow around a skyscraper. However, since it is highly difficult to analyze and forecast the air flow from a fire engineering viewpoint, an investigation of the flame spread characteristics of exterior walls of a building depends primarily on the combustion characteristics of materials. Hence, this study examined, using ISO 13785-2 testing method, the temperature changes and vertical flame spread behaviors of one of the finishing materials for exterior walls—(generic & fire-resistant) aluminium panels by a real-scale combustion experiment. According to the results of real-scale experiment, the maximum heat temperature of 987.7 °C was recorded seven minutes after the fire test was initiated while the fire-resistant aluminium panels showed the maximum heat temperature of 850.2 °C after exposed for approximately 12 min. The vertical flame spread properties put more emphasis on the time required to reach the maximum temperature rather than its magnitude and there was a five minutes difference between the materials.

Key words: Finishing material, exterior wall, real (full)-scale fire test, vertical flame spread, combustible.

1. Introduction

The vast majority of fires follow a pattern of distinct stages, although the time scales, rates and magnitudes vary widely. Fire initiation includes ignition and the development of a self-sustaining combustion reaction. These are many possible sources of ignition both deliberate and accidental. The ignition source is commonly very small and has low energy, but if it affects combustible materials, it is often sufficient to start a fire.

To minimize the fire-related hazards to people and property, the building design incorporates fire growth and spread, smoke control measures and evacuation safety designs. However, the previous combustion spread prevention designs mainly target the prevention of the flame spread between the existing flame and floors, showing shortcomings to describe the flame

spread characteristics of a finishing material. For example, fire inside a building can be restricted during the early stages of a fire with the help of the fire protection system including sprinkler and fire detectors however, the non-presence of such system often leads to the rapid spread of a fire because of delayed detection of the fire in the very early stage.

In addition, existing small-scale combustion test methods are used to measure the heat release rate, similarly to a medium-scale test method, rather than to examine the prevention performance against the fire spread. On the contrary, exterior finishing materials are more likely to accelerate the vertical spread of fire if the flame is ignited, rather than contributing to the severity of a fire by the heat release.

The severity of the flame spread outside the building will vary depending on the combustion characteristics of materials and air flow around a high-rise building. However, due to difficulties in forecasting the air flow from a fire engineering perspective, an evaluation on

Corresponding author: Seung-Cho, Yang, M.Sc., research field: fire performance design. E-mail: ysj@kict.re.kr.

the flame spread traits of exterior walls has no choice but to rely on the combustion characteristics of a material.

Evaluation on the combustion properties of a building material involves the measurement of the heat release rate using ISO 5660-1 test method. However, exterior finishing materials are more susceptible to the flame spread rather than the heat released when a material is consumed, thereby making it difficult to predict the exact fire risks. In addition, ASTM E84 test method that can predict the flame spread is overly restricted to the fire spread characteristics of a horizontal material, thus the method is considered to be inadequate for the testing of combustion characteristics of a composite material. To resolve such issues, development of real-scale combustion test methods is thus underway and this study was undertaken to evaluate the fire performance of finishing materials for exterior walls of a building by a full-scale combustion experiment based on the ISO 13785-2 method suggested by the ISO (International Organization for Standardization).

2. Real-Scale Experiment of an Exterior Wall Finishing Material

The use of building materials, depending on the degree of vulnerability of a building to a fire, is restricted to suppress flame spread from an ignition source, thereby preventing a rapid fire establishment. Such limited application of a building material is based on: (1) the results of fire tests undertaken to predict the combustion characteristics of building materials; and (2) classification of the degrees of combustibility based on the test results.

Therefore, although evaluation of the accurate combustion characteristics of a material is the most crucial element however, current diverse building materials make it difficult to assess the combustion characteristics of each material using the existing fire test methods. In particular, exterior wall finishing materials require an analysis on the combustion

properties of composite materials that have different inner and outer combustion features as well as on the characteristics of the vertical flame spread by the exterior flame that is originated in a compartment of the building. Accordingly, various real-scale fire test methods that are different from the existing test methods are being suggested.

NFPA 285 suggests a test method for determining the fire propagation characteristics of exterior non-load-bearing wall assemblies and panels used as components of curtain wall assemblies and panels used as components of curtain wall assemblies, constructed using combustible materials. BS 8414-1 suggests a test method for determining the combustion characteristic of exterior non-load-bearing wall finishing materials and exterior wall systems. In addition, ASTM E 119, NFPA 251, CAN/ULC-S101-07 suggest a test method for determining the combustion characteristic, but these methods are inadequate to analyze combustion characteristic of exterior finishing materials because it is impossible to supply a heat source directly on finishing materials.

Fig. 1 describes the full-scale fire test method of the ISO 13785-2. This ISO test method involves direct exposure of an exterior composite material's surface to a fire plume emerging from an opening in a combustion chamber. The test method consists of a combustion chamber and a test specimen containing an internal corner with a re-entrant angle of 90° . The size of a primary test specimen is $4.0 \times 3.0 \text{ m}^2$ (Height $\times$ width), while that of a secondary test specimen shall be $4.0 \times 1.2 \text{ m}^2$ (Height $\times$ width) and the total test duration was 25 min.

Fig. 2 shows the propane gas flow rate in a burner in the combustion chamber. The flow rate consists of three stages—a five-minute gradual build-up to the maximum gas flow rate of 120 g/s, followed by a 15-minute period at a steady fuel supply rate (i.e., 120 g/s) and a five-minute cool down period.

As shown in Table 1, the full-scale combustion

Fig. 1 ISO 13785-2 large scale fire tester.

Fig. 2 The propane gas flow rate used in this study.

Table 1 ISO 13785-2 large scale fire test.

Test material specimen	Main wall: 3.0 (W) × 4.0 (H) m Side wall: 1.2 (W) × 4.0 (H) m
Opening	2.0 (W) × 1.2 (H) m
Heat source	Propane burner: Max. 120 g/s
Type of specimen	General aluminium composite panel Retardant aluminium composite panel
Test time	25 min
Measurement	Temperature

experiment of an exterior wall finishing material was undertaken using an aluminium composite panel and the temperature changes were measured. The aluminium composite panels used for the experiment were a generic aluminium composite panel that is composed of a 3 mm polyethylene core sandwiched between two 0.5 mm aluminium skins and a fire-resistant aluminium composite panel which consists of a 3 mm mineral wool, instead of polyethylene to secure combustibility, sandwiched between two sheets of 0.5 mm aluminium.

The flame temperature was measured at T_1 , T_2 and T_3 above the opening during the test period as shown in Fig. 3 and the temperature variations by the flame spread on the test specimen were also measured at T_4 - T_7 in the top of the specimen. In addition, the heating intensity of 800 °C above the portal (i.e., T_1 - T_3) was maintained during the second phase where the propane gas flow rate is maximized.

3. Results of the Full-Scale Combustion Experiment of an Exterior Wall Finishing Material

Fig. 3 presents the results of the full-scale fire test undertaken using aluminium composite panels. The fire was set at the lower end of a generic aluminium composite panel by the flame in the opening in the 1st stage and rapid vertical flame spread was observed in the initial stage of the test after about 3 min. In the 2nd phase (5 min after the experiment was carried out) when the propane gas flow was maximum, the flame was spread to the top of the test specimen and the flame intensity started to decrease when combustible materials were completely consumed by the upward fire spread (9 min after the test was initiated). These observations provide valuable information that the exterior wall finishing materials are more vulnerable to the vertical fire spread than the horizontal fire spread. In addition, considering the height (4 m) of the test specimen, it is believed that the vertical fire spread will travel much quicker in reality, namely, in an actual building.

Fig. 3 Fire behavior of ISO 13785-2.

With regards to the fire-resistant aluminium composite panel, the rapid upward fire growth was not observed until the second stage of the propane gas flow rate was reached. The combustion reaction was initiated by the flame in the portal during the 2nd stage, resulting in the establishment of the vertical fire

spread. Although the flame travelled vertically to the top of the test specimen prior to the termination of the experiment, a delay in the growth of the fire intensity was observed, as expected, in the fire-resistant aluminium composite panel in comparison to the generic aluminium composite panel. Unlike the generic aluminium composite panel test specimen that showed a rapid growth of the vertical fire spread in the beginning of the 2nd stage, gradual increases in fire growth and flame spread were observed in the fire-resistant aluminium composite panel test specimen.

Fig. 5 illustrates the temperature readings during the test period at three points above the window opening ($T1-T3$) and four points at the top of the test specimen ($T4-T7$).

Over 900 °C of temperature was measured across all the temperature measurement points except $T4$ in the generic aluminium composite panel. Since a window flame was set to produce and maintain more than

Fig. 4 ISO 13785-2 measurement point.

(a) General

(b) Retardant

Fig. 5 Results of temperature measurements.**Table 2** Results of max. temperature & time general retardant.

	General		Retardant	
	Max. temperature	Fire retardant	Max. temperature	Fire retardant
<i>T4</i>	186.5 °C	6 min 2 s	190.8 °C	14 min 27 s
<i>T5</i>	897.7 °C	6 min 46 s	307.2 °C	14 min 1 s
<i>T6</i>	955.2 °C	6 min 56 s	592.4 °C	11 min 57 s
<i>T7</i>	987.7 °C	6 min 56 s	850.2 °C	11 min 57 s

800 °C from the 2nd stage that allows the maximum propane gas flow rate, $T1$ - $T3$ do not essentially represent the vertical fire spread properties of a test specimen. Accordingly, the ability to prevent the vertical fire spread can be assessed by reading the temperature at $T4$ - $T7$. A significant temperature spike at $T5$ - $T7$ in the beginning of the 2nd stage (300 s after the experiment was carried out) but a gradual decrease by the consumption of combustible materials was observed. These results suggest that the generic aluminium composite panel does not have an ability to prevent the fire from combustion spread, resulting in a rapid vertical fire spread.

Regarding fire-resistant aluminium composite panel, more than 800 °C of mean temperature was recorded at the lower end of the panel and also temperature variations between the measurement points at the other end of the panel were obtained. Since the test specimen is L-shaped, $T6$ and $T7$ located in the corner exhibited relatively higher temperature. The combustion reaction started to gradually decrease after the initial increase of temperature in the 2nd stage—approximately 700 s after the experiment was carried out. Similar maximum temperature was also obtained from the fire-resistant aluminium composite panel, although it exhibited a gradual temperature increase compared to the generic aluminium composite panel.

Table 2 compares the maximum temperature and the time to reach the maximum temperature between the generic aluminium- and the fire-resistant aluminium composite panel obtained at the temperature measurement point in the top of the specimen, namely, $T5$ - $T7$ that practically represent the vertical spread of the flame.

A maximum temperature of 987.7 °C was recorded at $T7$ and the time obtained was approximately 7 min in the generic aluminium composite panel, while it took 12 min to reach the maximum temperature in all points with a maximum temperature of 850.2 °C at $T7$ in the fire-resistant aluminium composite panel.

4. Conclusions

Since the current fire testing methods that examine the combustion characteristics of a material through the rate of heat release are not appropriate to evaluate an exterior wall finishing material's properties including vertical flame spread and different in- and outside combustion features. Thus, this study was carried out to determine the combustion properties of exterior wall finishing materials using a full-scale fire test.

The real-scale test method includes a combustion chamber with an opening in the wall to produce a window flame by a propane gas burner, with a major test specimen (3 m wide by 4 m high) and a side test specimen (1.2 m wide by 4 m high) positioned perpendicularly.

The fire test using (generic/fire-resistant) aluminium composite materials was carried out for 25 min and the characteristics of vertical flame spread were determined through temperature measurements at the top of the specimen.

The generic aluminium composite panel was ignited by the exterior flame from the 1st stage of the propane gas flow volume and the flame started to spread vertically once the fire was ignited at 3 min after the test was initiated. The flame travelled to the top of the test specimen during the 2nd stage where the maximum propane gas flow (120 g/s) is supplied (5 min after ignition) and gradual decreases of the flame was observed when the materials were completely consumed by the vertical fire spread at 9 min after the test was initiated.

A rapid spread of vertical flame was not observed before the second stage of the propane gas flow volume in the fire-resistant aluminium composite panel. The combustion reaction was initiated by the exterior flame from the 2nd stage where the vertical flame spread was established.

The real-scale fire test results provided that the time to reach the maximum temperature was appropriate to assess the properties of vertical flame spread rather

than the maximum temperature, evidenced by the 5 min gap between the generic- and fire-resistant aluminium composite panels.

In spite of the disadvantage that the real-scale fire test is not able to measure the basic physical properties of a material, it can provide comprehensive combustion properties of a material used in a building. However, since current fire safety standards are defined by the basic physical properties evaluated by a small-scale experiment only, the performance classification of a material by a real-scale testing is not available. Therefore in line with existing fire safety standards, thorough evaluation on the combustion characteristics of finishing materials through a full-scale fire testing is required and it is also necessary to establish specific fire performance criteria that finishing materials are required to meet to restrict the use of inadequate materials based on the grades of fire risk. In the future, such issues are to be addressed and resolved by the improvement of relevant standards through a full-scale fire test targeting diverse finishing materials.

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