FAÇADE TESTS ON FIRE PROPAGATION ALONG COMBUSTIBLE EXTERIOR WALL SYSTEMS

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ABSTRACT

With regard to fire protection for exterior walls of a building, only fire-resistant performance is considered, according to the current building standard law of Japan. In previous authors’ studies, a new test method for evaluation of fire propagation along combustible cladding was proposed using primarily test specimens of façade walls with exterior thermal insulation without vent layers. In this paper, newly made results of façade fire tests also with other specimens of combustible facades, such as sandwich panels, photovoltaic sheets, combustible coating materials, and exterior insulation with vent layer, are discussed.

Keywords: Combustible façade, Fire propagation, Fire test for facades, Ejected flame from opening, Vertical fire spread to upper floor.

1. INTRODUCTION

As per the concept of fire safety when there are combustible materials such as wooden facades, exterior insulation, sandwich panels and so forth are attached to the outside of exterior load-bearing walls of fire-resistant structure, currently in Japan, it is judged necessary not to damage the fire-resistant performance of only the load-bearing structure [1], and it is not exactly evaluated whether combustible materials are ignited and how flame will be propagated along the combustible facades. In case of exterior walls for reinforced concrete structures, it is considered possible to be attached with foamed plastics as insulating materials.

Regarding ignition of exterior materials and combustion of exterior facades, clear standards have not been specified in Japan, and information collection for actual fire
examples [2-3] and research [4-8] contributing to examination for test methods for performance evaluation have become urgent matters. The authors have so far proposed and implemented façade type fire experiments mainly using wet type exterior insulation test specimens, and have confirmed the possibility of evaluation of properties for fire propagation [9]. Meanwhile, the façade type fire experiment method, which the authors have proposed and implemented, has adopted a method to generate ejected flame from openings from the chamber in order to improve defects of medium scale façade tests (ISO 13785-1) (1) The difficulty to confirm the property of downward fire propagation, (2) Since the sand-burner is installed under the test specimen, it will be blocked up by droplets in case of foamed plastics installed within the façade specimen) [10]. In this paper, based on the said façade test methodology proposed by authors before, with some small changes added in heating intensity, we report the results of fire experiments performed not only with the wet type exterior insulation construction but also with other combustible facades (e.g. sandwich panels, photovoltaic sheets, ventilation layer construction method, resin coating/siding) as test specimens.

2. OUTLINE OF THE EXPERIMENTS

2.1 Purpose

To evaluate the fire properties of test specimens reproducing various types of combustible facades on the outside of the exterior load-bearing wall, presuming a scenario where an interior fire has occurred in a compartment and flame is ejected from an opening.

2.2 Test Method

As shown in Figure 1, after vertically installing the façade type test specimen (height 4,095mm × width 1,820mm), we coupled the opening of the test specimen (910mm square) with the combustion chamber (inner dimensions: height 4,095mm × width 1,350mm × depth 1,650mm), lit the burner inside the chamber (600mm square, installed at the center of the rear) to make it inject flames from the opening. As well as measuring the temperatures, we set the heating time at 20 minutes and installed thermocouples (top exterior surface of façade test specimen) on six points (500mm, 900mm, 1,500mm, 2000mm, 2,500mm and from the upper end of the opening), and measured incidence of heat flux by setting up heat flux meters at two positions 2 meters distant from the test specimen in the opposite direction. In addition, although we carried out a blank experiment (on clad ceramic fiber blanket (thickness: 25mm) on the outside of the calcium silicate plate in order to comprehend the conditions during heating in a situation where there were no combustible materials on the exterior side, prior to the experimental implementation for the combustible exterior test specimen, incident heat flux was measured by installing heat flux meters (on the same surface as the exterior top surface of the test specimen) in addition to the above mentioned. Installation positions
of thermocouples and heat flux meters are indicated by marks ●(①～⑥). In view of the actual building, for example, supposing the condition that floor height is 2600mm, the high-hip window is 1200mm (W) × 1000mm (H), the center to center distance between upper and lower windows is 2600mm, namely, ⑥, the distance between the upper end of lower window and lower end of upper window is 1600mm, that is, almost equivalent to ⑤.

2.3 Test Apparatus

With respect to the façade type test specimen (height 4,095 × width 1,820mm), first of all, its frame is composed of light-gauge steels and its whole exterior surface side (heated surface side) cladded with a calcium silicate plate. In the case of the combustible exterior wall test specimen, a test specimen was used in accordance with an ordinary construction method in actual buildings.

3. HEATED CONDITION RECEIVED ON THE EXTERIOR WALL SURFACE

In order to measure the temperature and the amount of heat received when heated with no combustible materials on the exterior wall side, a blank test was performed. Making burner heating intensities within the combustion chamber, 300kW, 400kW, 500kW, 600kW, 700 kW (in all cases, heat at a stroke from the initial condition of 0 kW), we made the heating time for the blank test 10 minutes. Meanwhile, the value of the heating intensity mentioned here refers to a calculation value (nominal value) on the assumption that propane gas was completely combusted, and in more accurate description, each heating-intensity situation corresponds to the prescribed flow rate {192, 256, 320, 384, 448 [L/min]} of propane gas respectively at constant value for each test.
3.1 Façade Surface Temperature

Table 1 indicates the result of the average values compiled (for 5 minutes after 5 to 10 minutes from the initiation of tests in respect to each case), in addition to which Figures 3 and 4 show examples of aging variations. Meanwhile T1−T6 correspond to the places indicated in Figure 2, and in regard to the upper end of the opening, it indicates the temperature result measured at places where flame was ejected (on the same center line as Fig. 2).

| Heating intensity | Upper end of opening | T1  | T2  | T3  | T4  | T5  | T6  |
|-------------------|----------------------|-----|-----|-----|-----|-----|-----|
| 300 kW            | 559                  | 342 | 301 | 209 | 178 | 131 | 134 |
| 400 kW            | 644                  | 375 | 335 | 235 | 200 | 148 | 150 |
| 500 kW            | 727                  | 424 | 381 | 270 | 225 | 163 | 167 |
| 600 kW -1         | 793                  | 461 | 406 | 295 | 244 | 180 | 180 |
| 600 kW -2         | 795                  | 434 | 374 | 280 | 221 | 189 | 166 |
| 700 kW            | 836                  | 462 | 407 | 302 | 247 | 184 | 182 |

As shown in Table 1, in all heating intensities, the measured temperatures show a decreasing trend along with increases in heights at measuring points. Meanwhile, in regard to T5 and T6, although a big difference cannot be observed as a whole due to maintaining almost invariable heights, T6 to some extent had higher temperatures at some points. This is estimated to indicate high values because the sensor of T6 was installed above the test specimen and air current sometimes wrapped around the backside of the test specimen due to the impact of winds and so on. If a comparison is made at each measuring position, an increase in the measuring temperatures can be observed as the heating temperature increases.
3.2 Incident Heat Flux on the Facade Surface

Table 2 indicates the results compiling the average values (for 5 minutes for 5–10 minutes after the initiation of experiment in each case) with regard to the incident heat flux on the exterior wall surface, while Figures 5 and 6 show examples of aging variations. In regard to HF1-HF6, these correspond to points ①–⑥ shown in Figure 2, and in respect to the opposite surface, it comes to the measured result of the heat flux meter installed on the opposite surface 2m off the façade test specimen (the height: 500 mm over the upper end of the opening). Further, in respect to ④ in all intensities and ⑤ at 700kW heating, there is no description due to a problem with the measurement.

| Heating intensity | HF1 | HF2 | HF3 | HF5 | HF6 | Opposite face |
|-------------------|-----|-----|-----|-----|-----|---------------|
| 300 kW            | 9   | 9   | 6   | 4   | 4   | 1             |
| 400 kW            | 11  | 11  | 7   | 4   | 4   | 2             |
| 500 kW            | 11  | 13  | 8   | 5   | 5   | 3             |
| 600 kW -1         | 12  | 14  | 8   | 6   | 5   | 4             |
| 600 kW -2         | 14  | 11  | 5   | 3   | 4   | 5             |
| 700 kW            | 12  | 14  | 8   | –   | 5   | 5             |

As illustrated in Table 2, the tendency of the incident heat flux to decrease can be observed in parallel with increasing heights of measuring points in all heating intensities. Since the heights of HF5 and HF6 are about the same, although a large difference could not be observed in general, HF6 had higher values in some cases. This is estimated to indicate high values because the sensor of HF6 was installed above the test specimen and the air current sometimes clung around the back of the test specimen due to the impact of winds and so on. If comparison is made at each measuring position, an increase in measuring temperatures is observed as the heating temperature increases. These trends are similar to the temperatures in the preceding clause. Furthermore, with respect to the incident of heat flux on the opposite surface 2m off the façade test specimen (the height: 500 mm over the upper end of the opening), an increase in measured values along with heating intensity in the combustion chamber has conspicuously appeared.
4. FIRE PERFORMANCE OF COMBUSTIBLE FAÇADE TEST SPECIMENS

To perform fire tests with combustible façade specimens, authors set the test time at 20 minutes and the target value of heating intensity in the combustion chamber at 600[kW], that is to say, we set the flow rate of propane gas at 384[L/min]. Although there are various views in regard to setting the heating intensity, we decided to carry out this experiment at the above intensity based on the continuous formation of stable ejected flame from the opening in the blank test, the desire not to make a continuous flame reach the upper end of the test specimen, and the fact that the set value of 300[kW] in previously published data appeared to be rather weak [9].

4.1 Category of the Combustible Façade Specimens

The details of combustible façade specimens are described in Table 3.

Table 3 Combustible exterior test specimen

| No. | Classification | Details | Vertical joint |
|-----|----------------|---------|----------------|
| ①  | Exterior thermal insulation (Dry type) (Vent layer: 20mm) | Phenol foam (50mm), Surface: Galvalume steel plate | None |
| ②  | XPS (50mm), Surface: Galvalume steel plate | | |
| ③  | Sandwich panel (50mm) | Core: isocyanurate foam (49mm), Surface: coated steel plate (0.5mm) for both sides Opening frame: ceramic boards | Present |
| ④  | Core: polyurethane foam (49mm), Surface: coated steel plate (0.5mm) for both sides Opening frame: steel sheets | | |
| ⑤  | Resin painting | Water resistant exterior finish paint, on calcium silicate boards. (Coated thickness: 2~3mm) | None |
| ⑥  | Exterior thermal insulation (wet type) (Edge: Aluminum frame) | EPS (50mm), SBR system polymer cement mortar (Thickness: 4mm), reinforcing net (2 layers), Edge: Aluminum frame, Finishing material: fire-retardant | Present |
| ⑦  | Resin siding boards | Made of Vinyl chloride resin. | Present |
| ⑧  | Sandwich panel (4mm) | Core: Fire-retardant polyethylene (3mm), Surface: coated aluminum (0.5mm) for both sides | Present |
| ⑨  | Photovoltaic sheet + Sandwich panel ⑧ | Base material is SWP (Same as ⑧) Photovoltaic sheet (1.3mm) on the surface | Present |
| ⑩  | Exterior thermal insulation (wet type) (Edge: back-wrapping) | EPS (50mm), Acrylic resin mortar (2mm), Reinforcing net (single layer), Edge: Back-wrapping, finishing material: combustible. | Present |

Each test specimen has a common size (height 4,095 × width 1,820), and was constructed outside of the calcium silicate boards as base sheets. For reference, test specimen ② was prepared in a shape scaled down from the vent layer based upon the actual
construction cross section of the TVCC building in Beijing, which suffered a massive façade fire on February 9, 2009. We selected test specimen ② as the one with the largest calorific value among the paint finishes used in actual buildings. Test specimen ② has already acquired some certificates on fire safety for facades effective in several western countries. With regard to vertical joint within a façade specimen, though it is not very realistic to allocate a joint at the upper center part of the window opening in an actual building, authors decided to basically use a vertical joint on the center line in order to clarify the impact of the joint, simulating the most dangerous situation. And exceptional specimens without vertical joints are test specimens (③/④), where there is an extremely low possibility of attaching a joint in actual buildings, and also test specimen (⑤), where not adding a joint would represent a more dangerous situation from the fire safety viewpoint.

4.2 Surface Temperature of Exterior Wall Surface

In this experiment, the temperatures on the exterior top surface of each test specimen during the test were measured and chronological changes are shown in Figures 7–16. We compiled results of average temperatures of blank tests and the highest temperatures of each test specimen as shown in Table 4.

| No. | Classification                                      | T1  | T2  | T3  | T4  | T5  | T6  |
|-----|-----------------------------------------------------|-----|-----|-----|-----|-----|-----|
| -   | Blank testing                                       | 447 | 390 | 287 | 232 | 184 | 173 |
| ①  | Dry exterior insulation with vent (phenol)          | 439 | 378 | 322 | 260 | 225 | 211 |
| ②  | Dry exterior insulation with vent (XPS)             | 483 | 432 | 369 | 320 | 264 | 240 |
| ③  | Sandwich panels (isocyanurate foam)                 | 536 | 373 | 304 | 246 | 203 | 181 |
| ④  | Sandwich panels (polyurethane foam)                | 488 | 403 | 306 | 230 | 196 | 179 |
| ⑤  | Resin painting                                      | 571 | 408 | 326 | 263 | 219 | 192 |
| ⑥  | Wet exterior insulation (Edge : Aluminum frame)     | 438 | 357 | 297 | 243 | 197 | 176 |
| ⑦  | Resin siding boards                                 | 519 | 459 | 360 | 293 | 243 | 200 |
| ⑧  | Sandwich panels (Fire-retardant polyethylene)       | 513 | 392 | 290 | 239 | 188 | 179 |
| ⑨  | Photovoltaic sheet + Sandwich panel ⑤               | 807 | 730 | 585 | 414 | 299 | 250 |
| ⑩  | Wet exterior insulation (Edge : back-wrapping)      | 645 | 469 | 369 | 289 | 225 | 198 |

* The values of blank test are average of the averages during a stable period of both blank tests (two times), while the values of combustible specimens (①～⑩) are maximum.

In respect to the blank average, average values have resulted in exceeding general timber flash points in T1–T3. Moreover, in a multitude of combustible test specimens, while the maximum values of temperatures exceed the blank average value, in test specimens ①, ③, ④ and so on, in particular, the temperatures (T1・2) measured vertically at the lower parts have fallen under the blank average, and it was numerically indicated that these test specimens were relatively sluggish in combustion properties. At the same
time, test specimens ②, ⑤ and so forth have generally shown high values at heights in vertical directions, and intensive combustion was numerically indicated. Further, in regard to test specimen ⑩, while comparatively high temperatures were measured at lower positions (T4–6), they have rapidly decreased at high positions (T4–6): intensive combustion occurred only in the vicinity of the ejected flame from the opening and it is indicated that spreading fire does not occur limitlessly. With regard to test specimens (①, ⑦, ⑧, etc.), which do not indicate the peaks in chronological changes, it indicated the combustion was slow.

Figure 7 Façade surface temperature (Specimen 1)

Figure 8 Façade surface temperature (Specimen 2)

Figure 9 Façade surface temperature (Specimen 3)

Figure 10 Façade surface temperature (Specimen 4)

Figure 11 Façade surface temperature (Specimen 5)

Figure 12 Façade surface temperature (Specimen 6)
4.3 Time-Temperature Area (TTA)

Although maximal value is a significant measurement result with regard to the façade surface temperature, it is not necessarily the most appropriate index when evaluating the total damage generating properties due to the façade test specimens. In this regard, authors calculated time-temperature areas (min. °C), which are integral values with the horizontal axis in chronological change graphs (Figure 7–16) and illustrated them in Figures 17 to 22.

![Figure 13 Façade surface temperature (Specimen 7)](image13)

![Figure 14 Façade surface temperature (Specimen 8)](image14)

![Figure 15 Façade surface temperature (Specimen 9)](image15)

![Figure 16 Façade surface temperature (Specimen 10)](image16)

![Figure 17 Time-temp. areas of façade specimens (unit:min·°C) (T1)](image17)

![Figure 18 Time-temp. areas of façade specimens (unit:min·°C) (T2)](image18)
Table 5  Time-temperature areas (TTA) of façade specimens (Unit : min•˚C)

| No. | Classification                                                                 | T1    | T2    | T3    | T4    | T5    | T6    |
|-----|--------------------------------------------------------------------------------|-------|-------|-------|-------|-------|-------|
| 1   | Blank testing                                                                   | 8,748 | 7,568 | 5,609 | 4,545 | 3,613 | 3,380 |
| 2   | Dry exterior insulation with vent(phenol)                                       | 7,213 | 6,438 | 5,380 | 4,428 | 3,822 | 3,536 |
| 3   | Dry exterior insulation with vent(XPS)                                          | 6,411 | 5,944 | 5,206 | 4,443 | 3,802 | 3,522 |
| 4   | Sandwich panels (isocyanurate foam)                                            | 8,068 | 5,924 | 4,770 | 3,995 | 3,335 | 2,951 |
| 5   | Sandwich panels(polyurethane foam)                                             | 8,599 | 6,991 | 5,247 | 3,944 | 3,435 | 3,151 |
| 6   | Resin painting                                                                   | 7,655 | 7,264 | 5,745 | 4,655 | 3,820 | 3,376 |
| 7   | Wet exterior insulation(Edge:Aluminum frame)                                   | 6,165 | 5,767 | 4,797 | 3,888 | 3,111 | 2,795 |
| 8   | Resin siding boards                                                             | 8,502 | 7,771 | 6,009 | 4,882 | 4,104 | 3,417 |
| 9   | Sandwich panels(Fire-retardant polyethylene)                                   | 7,921 | 6,488 | 4,683 | 3,888 | 3,046 | 2,907 |
| 10  | Photovoltaic sheet + Sandwich panel                                             | 9,351 | 7,857 | 5,801 | 4,635 | 3,713 | 3,314 |
| 11  | Wet exterior insulation(Edge:back-wrapping)                                     | 9,428 | 7,930 | 5,910 | 4,593 | 3,722 | 3,347 |

* In regard to ①~⑩, the actual measurement results of the integral values are described. In respect to the blank, the integral value of the actual measurement result for the initial two minutes was totaled by multiplying the average temperature for stable period with a duration of 18 minutes.
Regarding the blank average, T1–3 exceeded 5,200 [°C·min], which is tentatively calculated by multiplying the test time of 20 minutes by a presumable flash point of 260 °C for timber. In regard to the combustible façade specimens, those that exceeded the blank test value were specimens ⑩/⑩ in T1, specimens ⑩/⑩/⑩ in T2, specimens ⑩/⑩/⑩/⑩ in T3 and T4, specimens ⑩/⑩/⑩/⑩ in T5, and specimens ⑩/⑩/⑩ in T6. With regard to test specimens ⑨/⑩ (resin system paints)/⑦ (resin siding)/⑨ (SWP+ photovoltaic sheet)/⑩ (wet type exterior wall insulation), the possibility danger increases for an upper floor fire spreading through an opening, for example, in the upper floor over the room where the fire is in an actual exterior wall, as compared with the situation where there is no combustible materials on exterior walls, simulated by blank test in this research.

With reference to test specimens ⑩/⑩ (Vent layer exterior wall insulation), due to the top of the façade specimens finished with galvalume steel plates, although the time-temperature areas in T1–T4 did not exceed the blank test, in T5 (close to the upper end) and T6 (on the upper end), they resulted in exceeding the blank test affected by flames running through the ventilation layer. As a consequence, it was clarified that not only surface temperatures but also interior temperatures of the ventilation layer should be measured in order to obtain the information on high temperatures in the case of test specimens with vent layers.

4.4 Incident Heat Flux at the Upper End of Façade Specimen and on the Opposite Surface 2m Off the Specimen

During the fire test, incident heat flux is measured in two places, the upper end of test specimens and opposite faces 2 m off (height is over 500 mm from the upper end of the opening), and the average values of blank tests and maximal values of each test case are exhibited in Figures 23–24.

In regard to the incident heat flux on the combustible specimens, it indicated considerably high values in comparison with the average of the blanks, except for test specimen ⑧ (sandwich panel: Nurate core material). In test specimens ⑩/⑩ (vent layer exterior wall insulation) and test specimen ⑨ (wet type exterior wall insulation), maximal values exceeding 100kW/m² were found. At the same time, in regard to incident heat flux of the opposite face (height: 500 mm from the upper end of the opening), although all test specimens hold bigger values than the average of the blanks, drastic changes cannot be observed, and in respect to the test specimens this time, the danger of fire spreading to the next building is considered not to substantially increase when using a combustible façade.
4.5 Heat Release Properties

With respect to the heat release rate (HRR) of each façade test, Figure 25 indicates both the blank test average value (the average of each average value of the two blank tests), and the maximal values of each combustible façade specimen. Both the heat release rate (HRR) and the total heat released (THR) illustrate the gross value including the contribution of burner combustion. Further, with reference to the blank test (average of stable period), propane gas is supplied aiming at a “nominal” heating intensity (600[kW]) during experiment, and as a result it was measured to be 534[kW] by oxygen consumption method. Next, in connection with the total heat released (THR) in the experiment, the blank test takes the value obtained by multiplying the average value in Figure 25 by 20 minutes and other combustible façade specimens indicate actual measurement values in Figure 26. Both values of the heat release rate (HRR) and the total heat released (THR) of all the combustible façade specimens exceeded the ones of the blank test, which indicate the burning of combustible materials in addition to the contributing factors of the fire source in the combustion chamber. But, there was not great difference among the façade specimens, only except for the high value in test specimen ② (created in reference to the TVCC building construction plans). Therefore, it can be assumed that heat release properties are not adequate enough to effectively evaluate the fire performance of combustible facades.
5. CONCLUSIONS

Based on the façade-type fire-propagation test proposed by authors in the previous study[9] primarily on façade specimens of exterior thermal insulation (wet type), in this research paper, façade fire tests were conducted on specimens of not only exterior thermal insulation (wet type without vent layer) but also of other various types of combustible facades such as sandwich panels, photovoltaic sheets, resin system painting materials/siding, and even exterior thermal insulation (dry type with vent layer) etc. in order to confirm fire propagation properties over facades when heated by ejected flame from an opening of combustion chamber. The temperatures at façade surface, time-temperature area (TTA), incident heat fluxes (the upper end and the facing surface of façade specimen), heat release rates (HRR) were measured and calculated for comparisons among the façade specimens. Although the maximal value of façade surface temperature is effective to some extent as an indicator to grasp the most intensive burning of façade specimens, time-temperature area (TTA) would be more appropriate to evaluate the total risk of fire propagation over the façade specimens caused by burning of combustible materials installed within exterior wall system. And when the value of TTA for a certain combustible façade specimen greatly exceeds the counterpart value for blank test (without combustibles), there is the possibility that the danger of fire propagation to upper floor is increased if such combustible façade is applied to an actual building. With respect to incident heat flux at the upper end of the façade specimen, the maximum values of combustible façade specimens widely exceeded an average value of the blank test (without combustibles). Whilst, in respect to incident heat flux on the facing surface two meters distant from façade specimen, only slight increase was observed with combustible façade specimens compared with blank test. At least with regard to the test results this time, an increase in the risk of fire-spread to an adjacent building is considered not to be very enormous by applying combustible façades. In regard to the amount of heat release, combustible façade specimens have increased as compared with blank testing, reflecting the combustion of inflammable materials applied within facades, but only slight difference was observed among the combustible façade specimens, therefore, it is not appropriate enough to clearly confirm the fire properties of actual façade test specimens or the increase in the risk of upper floor fire propagation, and in view of its purport, other indicators described earlier are thought to be more suitable. In order to properly evaluate the fire propagation over combustible façades, in addition to surface temperature, time-temperature area, incident heat flux during fire test, it would be more desired to make some visual investigation on damaged area of specimen after fire test, from the view point of total risk analysis on façade fire safety.

As for the future challenge, with regard to the façade specimens with vent layer, authors will try to measure the temperatures not only at the façade surface but also inside the vent layer, as it would be possible to occur the massive flame propagation within
the vent layer especially when there is much combustibles inside even if the façade surface itself is covered by non-combustible materials such as steel sheets. This paper has discussed the results of façade fire tests conducted in 2011, and furthermore in the upcoming paper, authors will try to compile and discuss also the façade tests in 2012 including the specimens with vent layer and wooden façades etc., and to propose fire safety criteria for façades based on test results.

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