Self-standing Compartment Fire Tests on Sandwich Panels

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ABSTRACT

Evaluation of the fire performance of building materials is being conducted in Japan in accordance with ISO 5660-1. There is concern that sandwich panels containing combustible cores can pass certain classification criteria based on this small scale test even though they could be ignited and burn in actual fires including flashover. Within ISO/TC92/SC1, the ISO 13784-1 test addresses the evaluation of self-standing sandwich panels, but it is difficult to be routinely performed. This study proposes an intermediate-scale self-standing box test that a) has the same configuration as the ISO/TS17431 box test and b) compares this new proposed test with the ISO 13784-1 test both conducted for the first time in Japan in this program. A correlation between these two test methods (the new box test and ISO 13784-1) is also presented.

Keywords: Sandwich Panel, ISO 13784-1, ISO 9705, ISO/TS 17431, Model Box Test, Flashover.

1 INTRODUCTION

A sandwich panel consists of a core of organic insulation material having both surfaces clad in incombustible thin steel sheets. This panel exhibits good insulation characteristics and excellent hygienic performance; moreover, the panel is simple to construct and has been widely used in refrigeration, cold-storage, cold-temperature warehouses, clean rooms, and building facades. However, the risk of burning of the insulation adds to fire safety concerns. There is also a concern that the steel outer sheets would fall off hindering fire-fighting efforts[1-3]. Currently, evaluation and certification of the fire performance of sandwich panels is being conducted in Japan in accordance with ISO 5660-1 cone calorimeter small-scale test. Although the ISO5660-1 Cone Calorimeter test is adequate to evaluate surface combustion characteristics, the evaluation of joints treatment and load bearing capabilities for sandwich panels is not possible. It has been observed that certified sandwich panels materials based on the Cone Test, can burn in a quite vigorous manner in practical full scale installations[4-5].

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Standard ISO reaction-to-fire tests include

1. The ISO 9705 full scale room corner test and the ISO/TS17431 medium scale model box test correlations of flashover time are developed between the two tests.[6]

2. A specialized so called self-standing test (having no substrate) ISO13784·1 established and used in Europe, Australia, and Korea[7-12]. To date, no instance of the use of this test has been reported in Japan.

According to ISO the ISO13784·1 test is to be used for self standing sandwich panels (having no substrate) whereas only those sandwich panels directly adhered to a substrate wall could be evaluated by the ISO 9705 test. We note that in actual domestic Japanese construction there is space between a wall substrate and sandwich panels: therefore, based on the ISO’s position, the panels should be evaluated by ISO13784·1.

Finally we note that there are other approval tests in USA such as the parallel wall test in ANSI/FM Approvals 4910 and the corner test in FM Approvals 4880 that can be applied to evaluate the reaction-to-fire performance of sandwich wall panels.

In this study, we discuss the application and correlation of room tests such as the ISO 13784·1 and a new herewith proposed intermediate-scale self-standing box test. In Japan, ISO13784·1 is not suitable for widespread use as a normal evaluation test owing to the scale of the room and the cost. Comparison of the flashover occurrence in the present self standing test with the existing model box test (ISO/TS17431), was done by the present authors[13-14]. The present paper compares the new self-standing type model box with the ISO13784·1 self standing tests to evaluate correlations between the two regarding also joints and load bearing behavior. This paper reports the results of those evaluations.

2 EXPERIMENTAL

In the performance of this study the authors carried out four types of tests, namely ISO9705, ISO13784·1, which are full-scale tests, ISO/TS17431 and a self-standing model-box test, which are intermediate scale tests (approximately one-third). Photos of the test specimens are shown in Figures 1-4. The experimental methods used were in compliance with ISO. Visual observations as well as measurements were made of heat release rate, total heat released, fluctuations of temperature, ejected flame. The size of the rooms were as follows: full-scale·2.4 m (width) × 3.6 m (depth) × 2.4 m (height), door opening 0.80 m (width) × 2.0 m (height): medium-scale·0.84 m (width) × 1.68 m (depth) × 0.84 m (height), door opening 0.30 m (width) × 0.67 m (height). Also, internal size of box used for ISO/TS 17431 was 1.1 m (width) × 1.8 m (depth) × 1.0 m (height). In the cases of ISO13784·1, ISO/TS17431, and the self-standing model box test, the internal size of a room/box is exactly the specified size of the space, while in the case of ISO 9705, since the specimen is installed into a test compartment with specified dimensions the internal
dimension of the space is decreased by the thickness of the specimen. The reduction of the internal dimensions due to the thicknesses of specimens is one of the drawbacks of ISO9705.

The position of the thermocouples for temperature measurement is illustrated in Figure 5 in plan view. C1-C3 indicate the ceiling surface, W1-10 are wall installations. The thermocouples are glued on the wall about halfway up the height of the wall. Although the room dimensions vary between the actual-scale test and the intermediate-scale test, the ratios relative to the absolute value of dimensions (for example, if it is a quarter, the dimension becomes a quarter of the whole width) are the same shown in Figure 5.

The heat source is propane gas supplied to a burner installed on the left-hand side corner, heating the specimen at 100kW (from 0-10 min) and 300kW (from 10 min-20 min) for ISO13784-1, 40kW (0-20 min) for ISO/TS17431 and 40kW (0-20 min) for the self-standing box test. For the ISO9705, the gas burner was installed in the back corner of the right-hand side. For ISO13784-1, ISO/TS17431, and ISO9705, the installation sites were configured in accordance with ISO standards. The heating rate was determined by the oxygen consumption method, namely by measuring the oxygen concentration in the exhaust air duct during the experiment.
3 TEST SPECIMENS

The size and configuration of the specimens are shown in Table 1.

Table 1 Overview of Specimens.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Core material*</th>
<th>Surface material</th>
<th>Configuration</th>
<th>Classification by ISO 5660-1 as used in Japan</th>
<th>Performed Test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Self-standing</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ISO 13784-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>ISO 9705</td>
</tr>
<tr>
<td>A</td>
<td>XPS (30 mm)</td>
<td>Galvanized steel sheet** (0.35 mm)</td>
<td>Ceilings and Walls</td>
<td>Non-combustible</td>
<td>1</td>
</tr>
<tr>
<td>B</td>
<td>PUR (50 mm)</td>
<td>Hot-dip zinc-coated steel sheets (0.4 mm)</td>
<td>Ceilings and Walls</td>
<td>Below rank</td>
<td>1</td>
</tr>
<tr>
<td>C</td>
<td>PIR (50 mm)</td>
<td></td>
<td></td>
<td>Non-combustible</td>
<td>1</td>
</tr>
<tr>
<td>D</td>
<td>PF (50 mm)</td>
<td>Galvanized steel sheet** (0.35 mm)</td>
<td>Ceilings and Walls</td>
<td>Non-combustible</td>
<td>1</td>
</tr>
<tr>
<td>E***</td>
<td>PE (3 mm)</td>
<td>Aluminum sheet (0.5 mm)</td>
<td>Ceilings Only*****</td>
<td>Non-combustible</td>
<td>1</td>
</tr>
<tr>
<td>F***</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>


*** The difference between E and F is the edge of each panel. E: edge of PE core is wrapped by aluminum sheet. F: edge is not wrapped and is exposed to air.

**** ATH is Aluminum Tri-Hydroxide, Al(OH)_3.

***** Walls of E and F are made of calcium silicate boards (ISO13784-1) and gypsum boards (box test), which is classified as non-combustible. This means that E and F specimens cover only ceilings, which is also permitted in ISO 13784-1.
In both the large-scale and intermediate-scale the specimens contain the same products and use the same construction technique; only the dimensions are different. Of Specimens A-F, all the specimens except for B are classified as non-combustible material by the small-scale cone calorimeter test which is not adequate to characterize the large scale fire behavior as discussed in the introduction.

Regarding specimens B-D, the thickness of the core materials is standardized at 50 mm, whereas core materials and surface materials, masonry joint treatments between panels, and clamping of ceiling and wall are different. Finally, specimens E/F, whose core material thickness is 3 mm, are used in ceilings only as allowed by ISO 13784-1; wall structures are composed of non-combustible materials (calcium silicate board for full-scale, gypsum board for intermediate scale). Joint treatments and clamping in the specimens are exactly in accordance with the practical construction methods, the details of which will be described below.

XPS (extruded polystyrene), which is a core material of Specimen A, has excellent water resistance and does not warp. In addition, it is a foam insulation easy to machine. The construction of Specimen A is a sandwich of XPS core material between galvanized sheets of thickness 0.35 mm. The panels are joined using a slip joint, in which the core material of a panel on one side is bare, and the surface material of another panel is extended to connect to both adjacent panels by covering the bare core material. Peripheral trim for the ceilings and walls was composed of galvanized steel sheets.

Although PUR (polyurethane), which is the core material for Specimen B, has excellent insulation properties, it is very flammable. Specimen B is constructed of a sandwich of PUR core material between painted hot-dipped-zinc steel sheet (thickness: 0.4 mm). The joint between panels is caulked with silicon caulking applied a male-female fitted joint. This type of joint is considered relatively strong for fire safety. The peripheral trim for the ceiling and wall, though composed of aluminum that was anticipated to be more susceptible to fire damage in comparison to steel, was adopted for the current test because it is frequently used in construction.

PIR (polyisocyanurate), which is the core material of Specimen C, having enhanced fire retardant properties compared to the polyurethane used in specimen B, is expected to perform well both as fire retardant and as insulation. All conditions other than core material (such as joint treatment, peripheral trim, etc.) are exactly the same as Specimen B.

PF (Phenol Foam), which is a core material of Specimen D, has both good fire retardant and insulation qualities, widely used as insulation for housing and other types of construction. Specimen D is a sandwich of the PF core material between galvanized steel sheets (thickness of 0.35 mm). The panels are joined by a spline joint, a method in which both sides of adjacent panels are notched to take fire retardant dowels, and since applicable examples of sandwich panels using these core materials are plentiful, we adopted this method. The ceiling and peripheral trim, was composed of galvanized steel sheets.
While the core material for specimens E and F is PE (polyethylene) which has been made fire-retardant by the addition of aluminum hydroxide (ATH), specimens E/F are thin resin composite sheets sandwiched between thin aluminum sheets (thickness of 0.5 mm). As previously mentioned, Specimens E/F are used for the ceiling only. With respect to the end part of ceiling panels (3 sheets as shown in Figure 5) of specimen E, the aluminum outer material is wrapped around the non-combustible PE core material by the box folding method. On the other hand, the surface material is not tucked down in F, such that the end part of the core material is exposed. Specimen E was projected to have good fire-prevention properties, but the condition of F is much used in actual construction, so authors tested both specimens in the experiments.

4 EXPERIMENTAL RESULTS

4.1 Outline

The results of ISO13784-1 are shown in Table 2 and Figure 6: maximum heat release rate, total heat released, initiation time of each condition (fire ejection from joints to the outside of specimens, ejected flame from opening, flashover), while the results of heat release rate of the self-standing box tests are shown in Table 3 and Figure 7. The time history of temperatures of Specimens A and C are indicated in Figure 8, 9, 10, 11. The results for ejected flame from joints etc. to the outside of the specimen and ejected flame from an opening were obtained by visual observation. Although there are several different definitions with regard to flashover, for the convenience of comparison, we defined it as “Heat release rate of 1000kW/10 seconds or more in ISO9705 and 13784-1,” and in a medium scale test, in reference to the evaluation standard for the ISO/TS17431 model box test in Japan, it was defined as a point in time when “heat release rate increased by 140kW or more in 10 seconds.” A thermocouple was attached by means of a heat-resistant adhesive, but the bond failed due to the increase in temperature and deformation of the specimen. Because the thermocouple separated from the point of measurement, the results show some cases in which the temperatures dropped abruptly, for instance in Figure 11. The temperature data in this case is shown for reference regarding the temperature increase in the specimen compartment.
### Table 2 Summary of test results on ISO 13784-1.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Core</th>
<th>Peak HRR</th>
<th>THR*</th>
<th>Occurrence time (min)</th>
<th>Fire penetration from joint of panels</th>
<th>Flame ejected from opening</th>
<th>Flash over</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>value (kW)</td>
<td>time (min)</td>
<td>value (MJ)</td>
<td>time (min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>XPS</td>
<td>3,712**</td>
<td>13</td>
<td>482</td>
<td>13</td>
<td>5</td>
<td>·</td>
</tr>
<tr>
<td>B</td>
<td>PUR</td>
<td>5,597</td>
<td>3.1</td>
<td>1,061</td>
<td>8</td>
<td>3.3</td>
<td>3.6</td>
</tr>
<tr>
<td>C</td>
<td>PIR</td>
<td>3,018</td>
<td>12.3</td>
<td>1,086</td>
<td>17.5</td>
<td>4.6</td>
<td>6.8</td>
</tr>
<tr>
<td>D</td>
<td>PF</td>
<td>1,826</td>
<td>13.5</td>
<td>420</td>
<td>15</td>
<td>-</td>
<td>8.3</td>
</tr>
<tr>
<td>E***</td>
<td>PE with ATH</td>
<td>370</td>
<td>12.2</td>
<td>217</td>
<td>20</td>
<td>5</td>
<td>·</td>
</tr>
<tr>
<td>F***</td>
<td>PE with ATH</td>
<td>360</td>
<td>11.2</td>
<td>223</td>
<td>20</td>
<td>6.8</td>
<td>·</td>
</tr>
</tbody>
</table>

* The THR (total heat released) for each test specimen should not be compared because they have different test times. They are shown for reference.

** The Specimen A test was terminated for the safety of the technicians before HRR reached its peak value. Therefore, the value described in the table is not the peak value but the value when the test was terminated, which is shown for reference and should not be compared with other specimens. For Specimens B-D, HRR had reached peak values (as shown in Figure 6), even though those tests were terminated 20 minutes earlier. Consequently, it is possible to compare those results as peak values.

*** For Specimens E and F, only the ceilings were composed of the test specimen; the walls were made of calcium silicate boards. This is because it is impossible in an actual building to construct a compartment where both ceilings and walls are made of those materials. Also, it is popular to have ceilings made of those materials while the walls are made of other non-combustible materials.
Figure 6  Heat release rate in ISO 13784-1.

Table 3  Summary of test results on self-standing box test.

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Core</th>
<th>Peak HRR</th>
<th>THR</th>
<th>Occurrence time (min)</th>
<th>Fire penetration from joint of panels</th>
<th>Flame spouted from opening</th>
<th>Flash over</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>value (kW)</td>
<td>time (min)</td>
<td>value (MJ)</td>
<td>time (min)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>XPS</td>
<td>112</td>
<td>5.1</td>
<td>79</td>
<td>20</td>
<td>2.7</td>
<td>-</td>
</tr>
<tr>
<td>B</td>
<td>PUR</td>
<td>539</td>
<td>4.8</td>
<td>221</td>
<td>20</td>
<td>9.1</td>
<td>2.3</td>
</tr>
<tr>
<td>C</td>
<td>PIR</td>
<td>244</td>
<td>7.3</td>
<td>161</td>
<td>20</td>
<td>6.5</td>
<td>3.2</td>
</tr>
<tr>
<td>D</td>
<td>PF</td>
<td>190</td>
<td>5.4</td>
<td>95</td>
<td>20</td>
<td>8.0</td>
<td>2.6</td>
</tr>
<tr>
<td>E*</td>
<td>PE with ATH</td>
<td>71</td>
<td>9.5</td>
<td>48</td>
<td>20</td>
<td>10.3</td>
<td>-</td>
</tr>
<tr>
<td>F*</td>
<td>PE with ATH</td>
<td>137</td>
<td>12.1</td>
<td>83</td>
<td>20</td>
<td>6.4</td>
<td>9.1</td>
</tr>
</tbody>
</table>

* For specimens E and F, only the ceilings were composed of the test material; the walls were made of gypsum boards. This is because it is impossible in an actual building to construct a compartment where both ceilings and walls are made of those materials. Also, it is popular to have ceilings made of those materials, while the walls are made of other non-combustible materials.
The self-standing box test was conducted over a time period of 20 minutes for all test specimens, while in the ISO13784-1 test, the test was forcibly terminated for safety reasons by suspending burner heating. The burner heating time was described in the line of measurement times in Table 2. Although heating of Specimens B/C/D was finished in less than 20 minutes, since it finished after exceeding the peak heat release rate, the value of the peak heat release rate is meaningful for comparison purposes. In the case of Specimen A, the test was terminated while the heat release rate was still rising, and the value in the peak heat release rate column in Table 2 is just a reference value, but not the peak value.

### 4.2 Comparison between Iso13784-1 and Self-Standing Box Test (Specimens A -D, Where Both Ceiling and Wall are Composed of Sandwich Panels)

The condition of the joints between the sandwich panels, in both the full-scale and intermediate-scale tests, were monitored to confirm flame ejection and instillation. We describe the details of each test below.

While Specimen A flashed over in ISO13784-1, there was no flashover in the self-standing box test. This discrepancy was not observed in Specimens B -D. Meanwhile, in both the ISO13784-1 test and the self-standing box test, though smoke generation and flame ejection were observed, flame was not ejected from the openings in either test. In ISO13784-1, while only the ceiling (C1-C3) increased its temperature about
3 minutes after inception while subjected to 100kW, the temperature of W6 increased (Figure 8) in 8 minutes. At the 5-minute point, since a joint adjacent to W6 was burnt through, we considered the temperature increase to have been caused by the flame reaching to the core material from the joint opening. The temperature of the whole wall increased sharply within 10 minutes after increasing the heat to 300 kW, and a small amount of molten core material was left on the floor. Based on this result, because the core material which remained on the wall was touched by the flame without melting or flashover, the molten material is considered to have come from a region which was seen to be burnt. In the self-standing box test, although the joint burned through in 2.7 minutes, instillation was observed from the masonry joints in 5 minutes, and there was no flashover. The heating time data illustrated in Figure 7 shows that there is a 5-minute period where the heat intensity remains below 100kW, quite low in comparison to the other test specimens, leading us to believe that there is little or no occurrence of combustion. Judging from the lack of combustion, despite the joints being burned through, we believe that the core material had already become molten before burning through. The difference in situation between ISO13784-1 and the self-standing box test can be considered as follows: The former's heating intensity occurs in two stages, and local heating during the 100kW heating period reached to the ceiling, and during the latter 300kW heating period, the intensified heating condition “crawled” horizontally along the ceiling to cause the in-compartment temperature to rise. On the other hand, the self-standing box test’s heating is constant at 40kW right from the start of the test, and results in a situation of uniform heating where the in-compartment temperature rises right after inception. In cases where core XPS becomes molten at high temperatures, although combustion does not occur due to the melting, which is advantageous from the view of fire prevention, this condition does not occur in ISO13784-1, a full-scale test. With respect to Specimen A, due to the aforementioned reason, while an intensive combustion characteristic is observed in the full-scale test, extremely moderate combustion is observed in the intermediate scale, and it is difficult to determine correlations between the two test methods.
Figure 8  Temperature results of specimen A in ISO 13784-1.  
(See Figure 5 for installation positions of thermocouples.)

Figure 9  Temperature results of specimen A in self-standing box test.  
(See Figure 5 for installation positions of thermocouples.)
Specimen B reached flashover around 3 minutes after the test-start both in ISO13784-1 and the self-standing box test. There was ejected flame from the opening: flame ejection from the joint to the outside, and intensive combustion and the fall of surface materials from ceiling were confirmed. After the test, the core material was completely carbonized. Core material PUR generates inflammable gases by pyrolysis and is considered to generate intense combustion. Both full-scale and intermediate-scale tests generate a peak heat release rate at around 5 minutes, which was the maximum value among all the specimens. With regard to the specimens using thermosetting core materials, correlation of the results was observed in both tests.

Specimen C is a material that uses a core material PIF, which is in simple expression flame-retardant treated PUR. The flame-retardant’s effect was clearly observed in both the full-scale and intermediate-scale tests. In ISO13784-1, fire penetration from the broken joint occurred in 4.6 minutes, and flame ejection from the opening was confirmed after 6.8 minutes. Intense combustion and deformation of the specimens was observed during the last 10 minutes of 300kW heating intensity. From the temperature data in ISO13784-1, the ceiling and wall increased in temperature in sequence from measuring points around the periphery of burner, and the temperature increased further after 10 minutes (Figure 10). The core material was burnt and mostly carbonized, and it remained in a partly sound state. In the self-standing box test, since the temperature in the specimen increased rapidly, some thermocouples came unfastened from the measurement points (Figure 11). Flame ejection was confirmed in 3.2 minutes. Joints were burnt through in 6.5 minutes, and the core material was mostly carbonized, similar to ISO13784-1.

![Figure 10](attachment:temperature_results.png)
Specimen D generated an ejected flame from the opening at 8.3 minutes in the ISO13784-1 test, and smoke from joints was observed, but flame ejection did not occur at the joints. In the self-standing box test, flame ejection from the opening occurred in 2.6 minutes and fire ejection from the joints was observed in 8 minutes. Both core materials were mostly carbonized after the test. Peak heat release rates are in order of B/C/D in sequence from the highest value. With respect to the sandwich-panel specimens containing thermostetting core materials, in both full-scale and intermediate-scale tests, correlations can be observed to a certain extent between both test methods. In specimens B, C, and D, the visual observation after the fire tests showed that the burned area was also in order of B/C/D in sequence from the highest value, and this coincides with the order of total heat released in the intermediate-scale tests.

4.3 **Comparison between Iso137814-1 and Self-Standing Box Test (Specimens E and F Using Sandwich Panels for Ceiling Only)**

The Specimen E/F sandwich panels were used for the ceiling only, because of the use of other non-combustible materials for the walls (calcium silicate boards for full-scale; gypsum boards for intermediate-scale) the amount of burnable material contained in the specimens is lower in comparison to the other specimens and the heat release rate is low. While E is wrapped up in a core material (polyethylene given fire-retardant treatment with aluminum hydroxide) at the end of the specimen, in the F specimen the surface material is not folded over the core, leaving the core material exposed at the end. Effects
from the core material being covered by surface material are expected up to the melting point of aluminum, and Specimen E was predicted to be relatively safer because of this. However, in the ISO13784-1 test, in full-scale, both E and F were burned through by flame touching the ceiling right above the burner positioned at the corner, and from that point on, there was no lateral fire propagation along the ceiling, and the heat release rate showed almost the same results (Table 2, Figure 6).

Meanwhile, in the intermediate-scale self-standing box test, heating intensity is strong against the compartment scale, since lateral fire propagation occurred, revealing the difference between the end treatments of Specimens E/F with respect to burning characteristics (Table 3, Figure 7). E where the end was folded back, was effective: burning was slow and the peak heat release rate was 71kW. Burning was more intensive in F, where the end of core material is bare, than in E. The peak heat-release rate reached 137kW, nearly twice as high as in E, a level slightly less than the standard value of 140kW used in Japan.

In terms of judging the difference in fire safety between Specimens E and F, though the results of the self-standing box test were clearer, the result in which the difference has not emerged in ISO13784-1 of a full-scale also is important, relevant to these specimens, the self-standing box test has resulted in being capable of expressing it to be positioned in a little bit rough screening for ISO13784-1.

4.4 Comparison between “Self-Standing Test” and “Test Where Specimen Installed Inside Rig” (Specimen C)

For Specimen C only (core material: isocyanurate), all four categories of experiments were performed: ISO13784-1 (self-standing room test in full scale), ISO9705 (a full-scale room corner test), self-standing box test in intermediate scale, and ISO/TS17431 (model box test in intermediate scale). Chronological changes in heat release rate are illustrated in Figure 12 and Figure 13. When implementing ISO 9705, since the test was terminated for safety reasons before the peak heat release rate was reached, the measurement result up to the 12 min. 30 sec. is shown in (Figure 12).
Figure 12  Heat release rate of specimen C in ISO 13784-1 and ISO 9705.

Figure 13  Heat release rate of specimen C in self-standing box test and ISO/TS 17431.
In the full-scale, self-standing-type room test (ISO13784-1), a marked increase in the heat release rate started at around 9 minutes during the 100kW heating in the first half, exceeding the standard value of 1,000kW in less than 10 minutes. The combustion accelerated after increasing the heating intensity by more than 300kW, and it began to reduce after reaching the maximum value of 3,018kW in 12 minutes, 20 seconds. In the traditional room corner test (ISO9705), heat release and specimen combustion were not measured, other than the value of the burner heating, during the 10 minutes of the first half of the 100kW heating; the inception of salient combustion of the specimen can be seen from Figure 12 after the heating intensity was increased to 300kW from after 10 minutes on. If the ISO9705 had not been terminated (discontinuation of burner heating and watering), though it is presumed the combustion would have continued, in general, if compared with the result of ISO1378-4, the combustion rate is lower. This result conforms to the results from the SP Technical Research Institute of Sweden[8].

The intermediate-scale test, the self-standing box test and ISO/TS17431 (traditional model box test) achieved a standard value of 140kW in 3 minutes, 40 seconds, and 3 minutes, 54 seconds respectively; the initial states were nearly identical. Subsequently, the self-standing box reached a maximum value of 244kW in 7 minutes, 16 seconds and the traditional-model box began to calm down after arriving at the peak value of 184kW. Although both tests are similar in the time required to achieve the peak heat release rate and the rough combustion scenario, the value of peak heat release rate is larger in the self-standing type, and it became a relatively intensive combustion. From this viewpoint, the relationship between the two tests is almost the same as that in a full-scale test.

According to the report[8] from the SP Technical Research Institute of Sweden, which proposed that ISO13784-1 is more suitable than ISO9705 from the standpoint of evaluation for sandwich specimens, they have largely reported the behavior of joints between the panels to be important in view of fire safety observed from outside; by defining the internal dimensions of specimens, comparison between more-varied specimens is possible; on the other hand, in ISO9705, internal dimensions of specimens vary according to the thickness of each specimen, and when comparing with the same specimens, since ISO13784-1 has been shown to have a tendency toward more intense burning, it is posited as a more severe test. Also in this study, in addition to confirming the same trend as mentioned before in the full-scale test in Specimen C (core material isocyanurate), the self-standing box test indicates a little more intense combustion than ISO/TS17431, it can be said that the same trend has been confirmed in the intermediate-scale test. At the same time, since it is the result of only one specimen, generalizations cannot be made, and further testing of other, varied specimens is necessary.
5 DISCUSSION

Based on the results of section 4, with regard to ISO13784·1 and the self-standing box test, our conclusions are as follows:

1. When using sandwich panels whose core material becomes molten or flows away, as in Specimen A, while intensive combustion occurs due to the ignition of the core materials prior to melting in ISO13784·1, it was understood in the self-standing box test that it was difficult for combustion to occur because core materials became molten before ignition. In this regard, due to the increasing trend in the heat release rate, the occurrence of flashover is considered to be unrelated between the two test methods.

2. In Specimens B/C/D, when the core material of the sandwich panel remains, or is carbonized by heat and combustion, since the self-standing box test has a relatively large heating intensity considering the specimen size, the occurrence of flashover and peak heat release rate is more rapid than ISO 13784·1. But with respect to the occurrence of FO and the comparison with intensity of combustion between the different specimens, there were few differences between the two test methods.

3. To predict the heat release rate of ISO13784·1 from the result of the self-standing box test of B/C/D, where correlations were seen in the current test, is rather difficult. However, to predict the occurrence of flashover and time in ISO13784·1 from the peak heat release rate of the self-standing box test seems feasible, based on the results of (B-D). Specifically, when the peak heat release rate of the self-standing box test is 140kW or less, flashover does not occur in ISO13784·1. When the peak heat release rate of the self-standing box test is 140kW or more and under 200kW, flashover time of ISO13784·1 is 10-20 minutes; when the peak heat release rate of the self-standing box test is 200kW or more, flashover time of ISO13784·1 is under 10 minutes. Though it is a limited number of specimens this relation can be made in reference to aforementioned tests except for Specimen A.

4. Furthermore, with respect to the thin-type of specimens, E and F, the self-standing box test distinguished between different joints in the ceiling panels, where ISO 13784·1 tests showed practically no difference in the results. In this regard, for the thin-type of specimens, the self-standing box test could function as an effective screening test for ISO 13784·1.
6 CONCLUSION

The knowledge obtained by this study can be summarized as follows:

(1) When the core materials of a sandwich panel do not melt, or are carbonized by heat and combustion, there are correlations between ISO13784-1 and the self-standing box test to some extent. Relations are observed between the peak heat release rate in the self-standing box test and the time to occurrence of flashover in ISO 13784-1.

(2) In the case of a specimen using a sandwich panel whose core material is melted due to the heat it is subjected to in the test, no correlation is seen in the occurrence of flashover when the self-standing box tests follows the current test methodology, including the heat intensity and burner position.

7 FUTURE WORK

These conclusions are obtained from the test results in the scale and heating intensity using the current test size, and as seen in the variation in the trends in temperature increase, achieving an accurate correlation between ISO13784-1 and the self-standing box test is difficult with the heating method currently used especially for core melting materials. In this regard, the possibility of achieving correlation between core-material melting may be achieved by decreasing the heating rate in the self-standing box test and increasing it in a stepwise manner. Also, improving the position of burner at the corner of the box might result in a better correlation between the tests. Since the number of test specimens is limited this time, and testing is not necessarily applied to all the test specimens using core materials, it is necessary to carry out additional experiments with different joint treatments, peripheral trim, etc.

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