Intermediate-Scale Free-Standing Box Tests for Fire Performance of Sandwich Panels

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ABSTRACT

With regard to reaction-to-fire tests for building materials in Japan, ISO 5660-1 (small-scale test cone calorimeter) is de facto the only method for evaluation, according to the current building standard law of Japan [1], which actually also designates ISO/TS 17431 (intermediate-scale test) as an alternative not being implemented very often, however, by the industry. It is noted that it is impossible to predict the fire performance of sandwich panels when they are actually used in real buildings only from small scale tests such as ISO 5660-1. This is not a deficiency regarding the ISO 5660-1 as a test method but it is difficult to use the small scale results on a horizontal surface (100 mm by 100 mm) in order to predict the fire performance of sandwich panels in real applications. The reason is that in actual building fires, both ceilings and walls made of sandwich panels are heated from various directions and weak points are the joints and seals which can never be evaluated with a small-scale test. Therefore, in this study, the authors firstly modified ISO/TS 17431 model box test with free-standing specimens, referring to ISO 13784-1, and different types of sandwich panels were chosen to be the specimens, and the results are discussed comparing with ISO 5660-1 results.

Keywords: Sandwich panel, intermediate-scale box test, free-standing, reaction-to-fire, ISO/TS 17431.

1. INTRODUCTION

The working group ISO/TC92/SC1/WG7, introduced the test ISO 13784-1 was for the proper evaluation of reaction-to-fire performance of sandwich panels originally proposed by SP research institute of Sweden [2-3] with the first international standard distributed in 2002. Thereafter, inter-laboratory tests were performed with several participating countries, and a second edition was successfully agreed and distributed in 2014 [4]. Briefly summarizing, ISO 13784-1 basically follows the principles of ISO 9705 (Room/Corner test for surface products) with respect to specimen configuration, internal size of...
compartment and burner heating, the biggest difference being that specimens constitute one compartment by themselves in ISO 13784-1, instead of them being attached inside on the permanently-installed compartment in ISO 9705. The merits of ISO 13784-1 are the following:

1. The inner size compartment is always the same, whereas it can be significantly decreased having thick panels in 9705.
2. The panel joints are precisely constructed in the same manner as in the actual buildings and
3. The fire behavior of such joints and panels can be easily observed during tests while it is impossible with 9705.

In a parallel development in Japan, ISO/TS 17431(Intermediate-scale Model Box Test) (W:840, D:1,680, H: 840mm) was proposed to ISO as an alternative or screening test for 9705(Full-scale Room/Corner test) by Hasemi et al. [5], in that both produce good correlation regarding the time of occurrence of flashover (Figure 1). In ISO/TS 17431, combustible specimens forming the box wrapped by steel sheets are firstly inserted into the permanently-existing noncombustible slightly-larger box, and then burner is placed at the inner box (made of specimens) corner attached to the two wall panels. This means that TS 17431 can be recognized as smaller-sized version of 9705. Note that in this configuration, it is practically impossible to observe the fire behavior of joints and edges of panels as they are covered by noncombustible larger box, and only flames emerging out from the opening can be observed only after the occurrence of flashover, which is almost the same situation as in 9705.

The present authors modified ISO/TS17431 so that specimen panels constitute a box (W:840, D:1,680, H: 840mm) without steel sheets wrapping the box or inserted in a larger-sized permanent non-combustible box. Hereafter, this test method is called as “free-standing box test” in this paper (Figure 2), with expectation that good correlation would be found with ISO 13784-1 in the future detailed analysis. Firstly relative thin-type of PE-cored sandwich panels (core: 3mm, surface aluminum panel: 0.5mm × 2 [thickness]), called “composite panels”, were tested with both the standard ISO/TS17431 and the free-standing box tests for comparison. [6]. The comparison was relatively successful with this material but it was decided that it is necessary to test other kinds of sandwich panels especially for the valid evaluation of fire performance of sandwich panels’ using the free-standing box test. Therefore in this paper, the authors prepared sandwich panels specimens having the following core materials XPS, PUR, PIR, PF, and PE. We note that all these products except for the PUR-cored specimen are ranked as the best “non-combustible material” by ISO 5660-1 based on Japanese criteria for an application of 50kW/m² for 20 minutes which can be described by the following limits: Peak HRR < 200kW, and THR<8MJ.
2. DESCRIPTION OF THE EXPERIMENTS

2.1 Test Specimens

Overview of information on test specimens is described in Table 1.

| Product | Core material* | Surface material | Configuration | Classification by ISO 5660-1 as used in Japan | Performed Test |
|---------|----------------|------------------|---------------|--------------------------------------------|----------------|
| A       | XPS (30mm)     | Galvanized steel sheet** (0.35mm) | Ceilings and Walls | Non-combustible | 1 0 |
| B       | PUR (50mm)     | Hot-dip zinc-coated steel sheets (0.4mm) | Ceilings and Walls | Below rank | 1 0 |
| C       | PIR (50mm)     | Galvanized steel sheet** (0.35mm) | Ceilings and Walls | Non-combustible | 1 1 |
| D       | PF (50mm)      | Galvanized steel sheet** (0.35mm) | Ceilings and Walls | Non-combustible | 1 0 |
| E***    | PE (3mm) with ATH**** | Aluminum sheet (0.5mm) | Ceilings***** | Non-combustible | 1 0 |
| F***    |                |                  |               |                                            | 1 0 |

* XPS: Extruded polystyrene foam, PUR: Polyurethane foam, PIR: Polyisocyanurate foam, PF: Phenolic foam, PE: Polyethylene.
** Galvanized steel sheet means aluminum-zinc alloy-coated steel sheet.
*** Difference between E and F is edge of each panel. E: edge of PE core is wrapped by aluminum sheet. F: edge is not wrapped and exposed to air.
**** ATH stands for Aluminum Tri-Hydroxide, Al(OH)_3.
***** Walls of E and F are made of gypsum boards, which is classified as non-combustible rank. This means that E and F specimens are constituted only by ceilings, which is also permitted in ISO 13784-1.

As shown in Table 1, only free-standing box tests were performed for the specimens except for Product C. And only for Product C, ISO/TS 17431 (Model Box Test) was also performed for comparison.

2.2 Test Method

Firstly regarding the test procedure for ISO/TS17431 on Product C, authors basically followed both ISO document and usual procedure used at testing organization in Japan.

- Internal box size made of specimen: W:840, D:1,680, H: 840 mm, (Total surface area: 5m²).
- Propane burner: 170 × 170 × H:145 mm, HRR: 40 kW. (Placed at left back corner.)
- Time: 20 min.

The deviation from usual method in Japan is only test duration time, which is usually up to 10 min as TS17431 is permitted only to the quasi-non-combustible material (second best) and not to non-combustible (best rank). Internal size of box constituted by specimen panels is always the same with all products, as it is internal size (840×1,680×840...
mm) that is designated in the ISO document, which is different from ISO 9705 in that internal size is dependent on the specimen thickness. But because of this, with TS 17431 specimen thickness is restricted only up to 50mm as thicker specimens than 50mm cannot be practically inserted into the permanently-installed larger model box. This is also the demerit of TS/17431 together with invisibility during the test, and with free-standing box test this problem is solved as there is no limitation against external size of specimen box.

With respect to free-standing box tests for all products (A to F), authors followed the same way as above, and sole difference from TS/17431 was the lack of larger-sized model-box which contains the smaller box constituted by specimen panels. Still pictures for TS17431 and free-standing box test are shown in Figures 1 and 2 respectively both with product C. With TS 17431 flame emerges only from opening of model box, while with free-standing box test flames are observed from all parts of the box made of specimen panels.

![Figure 1 ISO/TS 17431 (Model box test)](image1)

![Figure 2 Free-standing box test](image2)

3. EXPERIMENTAL RESULTS

3.1 Overview

Overall, most of the specimens burned to some extent with intermediate-scale free-standing box tests in this study even with “non-combustible” classification made by ISO 5660-1 with domestic use in Japan, except for product B which is below any rank. It can be said that these results reveal the limitation of classification based only on the current domestic usage of con-calorimeter, and that intermediate-scale free-standing box tests might be closer to actual fire behavior of those tested products and could be one option for alternative test methods in the future. Below, details of each test results will be discussed.

3.2 Result of Product A (Core Material: XPS (30mm))

Intermediate-scale free-standing box test was performed with product A. As shown in Figure 3, from test start to three minutes only HRR contribution of burner output (40 kW) was observed, while at three minutes flame emerged out of box roof at the left rear side (where burner is located) and spread horizontally to the front side, that is expressed
as HRR peak around five minutes. After five minutes combustion peak was passed but still maintained till the end of test at twenty minutes. Roughly saying, flame propagated from left-rear to right-front along the box roof top, from three minutes to twenty minutes. This HRR result could be categorized as “flame-retardant” level (the third best, or the very last level among the classification), when referring to the domestic usage of ISO/TS 17431 which is not free-standing but contained by model-box, just for reference. On the other hand, the same material with thicker XPS (50 mm) was categorized as “non-combustible” (the best rank) with domestic usage of ISO 5660-1. It will be necessary to perform intermediate-scale test with 50 mm thickness in the meantime, but even this result shows the difference between the test methods.

![Figure 3 Heat Release Rate of Product A (core material: XPS(30mm)) with intermediate-scale free-standing box test.](image)

### 3.3 Result of Product B (Core Material: PUR (50mm))

Intermediate-scale free-standing box test was performed with product B. As shown in *Figure 4*, from test start to two minutes only HRR contribution of burner output (40 kW) was observed, while at two minutes black smoke started to be emitted from box opening up to three and a half minutes, which corresponds to the first peak in *Figure 4*. After three and a half minutes, box specimen flashed over with huge flame ejected from box opening, which corresponds to the second peak at five minutes as in *Figure 4*. After the second and biggest peak at five minutes, burning became moderate, but still burning maintained especially at the box roof top, which corresponds to the flat line from nine to thirteen minutes as in *Figure 4*. At least with this specimen of product B, the classification results based on cone-calorimeter and intermediate-scale free-standing box test are identical, which is below any classified rank.
3.4 Result of Product C (Core Material: PIR (50mm))

Both intermediate-scale free-standing box test and ISO/TS17431 (intimate-scale box test, containing the specimen box inside) were performed with product C. Heat release result of the former is shown at Figure 5, while the latter at Figure 6.

Firstly with intermediate-scale free-standing box test, as shown in Figure 5, at two and a half minutes black smoke started to emit from box up to four minutes, which corresponds to first peak in Figure 5. After four minutes, flame emerged from the box opening and reached flash-over, which corresponds to the second peak at seven minutes in Figure 5. After the second peak at seven minutes, burning became moderate, but flame kept on emerging especially at the box roof-top as well as through the wall panel joints, and also from the box opening, which corresponds to the gradual decline from seven minutes to twenty minutes in Figure 5. This HRR result could be categorized below classification level, when referring to the domestic usage of ISO/TS 17431 which is not free-standing but contained by model-box, just for reference. On the other hand this specimen of product C is classified to be “non-combustible”, the best rank with cone-calorimeter, which reveals the big difference of results between small-scale and intermediate-scale tests.

Secondly with ISO/TS17431 (intimate-scale box test, containing the specimen box inside), as shown in Figure 6, at two minutes black smoke began to emit from the box opening, and gradually not only smoke but also flame emerged from the opening and reached flash-over, which corresponds to the peak at six minutes in Figure 6. With this ISO/TS17431, only opening could be observed due to the configuration in which the model box contains specimen box inside, and other parts such as panel joints at roof and walls were not observed. This HRR results was also categorized below classification level, when referring to the domestic usage of ISO/TS 17431. And further,
when comparing the two methods of intermediate-scale free-standing box test and ISO/TS17431, the former had higher peak heat release rate, together with more intensive burning behavior overall. This result coincides with the former full-scale test study [2], where they compare ISO 9705 and ISO 13784-1 (free-standing), in that free-standing configuration had shown more intensive burning and higher HRR values. The merit of free-standing configuration for sandwich panel test specimens, whether it may be intermediate or full scale, is that real end-use situation is applied to the joints and edges of panels and fire behavior is observed visually, while only smoke and flame can be observed with ISO 9705 and ISO/TS 17431.

![Figure 5](image1.png)  
*Figure 5  Heat Release Rate of Product C (core material: PIR (50mm)) with intermediate-scale free-standing box test.*

![Figure 6](image2.png)  
*Figure 6  Heat Release Rate of Product C (core material: PIR (50mm)) with ISO/TS17431 (intimidate-scale box test, containing the specimen box inside).*
3.5 Result of Product D (Core Material: PF (50mm))

Intermediate-scale free-standing box test was performed with product D. From one minute to two minutes, black smoke emitted from box opening, which corresponds to the moderate HRR increase in Figure 7. After two minutes, flame emerged from box opening and reached flash-over, which corresponds to the peak from four to six minutes in Figure 7. After six minutes burning became moderate, and in this case of product D, flames were not observed at box roof-top or wall panel joints after flashover finished, while they were observed with products A, B, and C. This HRR results was also categorized below classification level, when referring to the domestic usage of ISO/TS 17431 for reference. On the other hand this specimen of product D is classified to be “non-combustible”, the best rank with cone-calorimeter, which reveals the big difference of results between small-scale and intermediate-scale tests.

![Figure 7](image_url)  
*Figure 7 Heat Release Rate of Product D (core material: PF (50mm)) with intermediate-scale free-standing box test.*

3.6 Result of Products E and F (Core Material: PE with ATH (3mm))

In case of products E and F, only the roof of box was made of specimen (thin type of sandwich panel, core material: PE with ATH (3mm)), and walls of box were made of gypsum boards. This is because in actual building situations it is practically not realistic that both ceiling and walls are constituted by this type of sandwich panels, and usually either ceiling or walls is made of the specimen. And assuming the more intensive burning, authors decided to compose the ceiling (in other words, roof of box) with this product, and walls made of gypsum boards as they contribute only limited amount of heat release when fire tested. The difference between products E and F is the edge of panel used for the box roof. With product E, edge of PE core is wrapped by aluminum sheet extended from the panel surface, which means that PE core is not exposed. While with product F, panel edge is not wrapped and PE core is exposed to air. Two panels constituted the box-roof.
Intermediate-scale free-standing box tests were performed with products E and F. Heat release result of the former is shown at Figure 8, while the latter at Figure 9.

In case of product E, burning behavior was very moderate compared to other products in this study. Burner flame at left-rear inside box only penetrated the box roof, and that flame from the roof hole was observed, and no horizontal flame spread occurred. Also flame was not ejected from box opening, which is different from other specimens. This HRR results was also categorized as “non-combustible” (best level), when referring to the domestic usage of ISO/TS 17431 for reference. This is identical with the classification made by cone-calorimeter.

In case of product F, burning behavior was more intensive than product E, due to the panel edge where PE core is not wrapped by aluminum. In this case, first HRR peak was observed at nine minutes in Figure 9, when burner flame vertically penetrated though the box roof-top. After that, flame horizontally propagated from rear to front inside box along the ceiling, then flame emerged from the box opening, which corresponds with the second peak at twelve minutes in Figure 9. This result of product F shows the weakness of PE-core exposed panel edge, compared to the result of no horizontal flame spread along the ceiling in case of product E. This HRR results was also categorized as “quasi-non-combustible” (second best level), when referring to the domestic usage of ISO/TS 17431 for reference. This is different from cone-calorimeter result, which is “non-combustible” (best level). These results of products E and F show that it is possible to evaluate the effects of panel joints with intermediate-scale free-standing box tests, which is usually very difficult with cone-calorimeter.

![Figure 8](image_url)  
*Figure 8  Heat Release Rate of Product E (core material: PE with ATH(3mm)) with intermediate-scale free-standing box test.*
3.7 Discussion

Table 2 summarizes the test results, such as peak HRR and its occurrence time, as well as classification results based on test results.

Table 2  Summary of Test Results (peak HRR and time-to-peak)

| Product | A          | B          | C          | D          | E          | F          |
|---------|------------|------------|------------|------------|------------|------------|
| Core material | XPS (30mm) | PUR (50mm) | PIR (50mm) | PF (50mm)  | PE (3mm) with ATH*** |
| Free-standing box test | 139 kW (5 min) | 544 kW (5 min) | 245 kW (7 min) | 236 kW (5 min) | 88 kW (9 min) | 169 kW (12 min) |
| Classification* | Flame-retardant | Not classified** | Not classified** | Not classified** | Non-combustible | Quasi-non-combustible |
| ISO/TS 17431 | – | – | 184 kW (6 min) | – | – | – |
| Classification* | – | – | Not classified** | – | – | – |
| Cone-calorimeter Classification* | Non-combustible | Not classified** | Non-combustible | Non-combustible | Non-combustible |

* Classification levels are non-combustible, quasi-non-combustible, and flame-retardant, from the very best to the third best.
** "Not-classified" in the table means that it is below flame-retardant level.
*** ATH stands for Aluminum Tri-Hydroxide, Al(OH)₃.

As Table 2 shows, free-standing box tests tend to have more severe classification results than cone-calorimeter, only except for product E. This is because with intermediate-scale specimens realizing the end-use panel joints, fire behavior is more severe and more realistic than small-scale test specimen only heated by the cone-
heater from above. Also, difference of joints was properly evaluated by free-standing box test, such as Products E and F. In case of product E, where core-edge is wrapped by aluminum, the result was very moderate burning, resulting in the classification of non-combustible. On the other hand in case of product F, where core-edge is not wrapped, burning was more intensive, resulting in the classification of Quasi-non-combustible. When compared to ISO/TS 17431 in case of product C, free-standing box test showed more intensive burning and higher peak HRR, which is identical with the relationship between ISO 9705 and ISO 13784-1 in case of full-scale tests [2].

4. CONCLUSIONS

Intermediate-scale free-standing box tests were performed for six different types of sandwich panel products. As described in “3.6 Discussion”, they tend to have more severe results than cone-calorimeter, as end-use situation of panel joints are realized with box test specimens, which cannot be evaluated by cone-calorimeter. As for the test specimens of the same core material with different panel joints, these intermediate-scale free-standing box tests turned out to make reasonable and different results.

When compared to ISO/TS 17431, free-standing box test showed more intensive burning and higher peak HRR, which is identical with the relationship between ISO 9705 and ISO 13784-1 (free-standing) in case of full-scale tests [2]. Also, with intermediate-scale free-standing box tests, mounting and joints techniques can exactly follow the actual end-use situation, while it is not always possible with ISO/TS 17431 as specimen box is inserted into the model box. Furthermore, fire behavior of edges and panel joints can be observed visually with intermediate-scale free-standing box tests, while only smoke and flame emerging from the opening could be observed with ISO/TS 17431.

Based on the results above, it could be said that intermediate-scale free-standing box tests will be one of the best solutions for properly evaluating the actual fire performance of sandwich panel products. In order to consolidate the data background, authors will try to perform full-scale tests in the near future for clarifying the correlation between the intermediate and full-scale fire tests.

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REFERENCES

1. The Building Center of Japan: The Building Standard Law of Japan, May 2009.
2. P. Johansson and P. van Hees: Development of a Test Procedure for Sandwich Panels using ISO 9705 Philosophy, SP Report, SP Swedish National Testing and Research Institute, 2000: 26
3. J. Axelsson and P. van Hees: New data for sandwich panels on the correlation between the SBI test method and the room corner reference scenario, Fire and Materials, pp. 53-59, 2005: 29
4. ISO13784-1:2014, Reaction to fire test for sandwich panel building systems -- Part 1: Small room test.
5. Y. Hasemi, M. Yoshida, Y. Tanaike, etc.: “Fire-safety Evaluation of Interior Linings by Revised Model Box Test,” AIJ Journal of Technology and Design, No. 9, 1999 (in Japanese).
6. Masamichi Tamura, Hideki Yoshioka, Yuhei Nishio, Masashi Yoshida, Takafumi Noguchi, Manabu Kanematsu, Tatsuo Ando, Tomohiro Naruse, Yoshihiro Hase, and Yutaka Tanaike: Model Box Tests on Aluminum Composite Panels for Interior Finish, Summaries of Technical Papers of Annual Meeting, Architectural Institute of Japan, September 2014 (in Japanese).