Analysis of the Precision of International Inter-laboratory Round Robin Test Results of a Sandwich Panel Assessed According to ISO 13784-1 Standard

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Abstract
Sandwich panels were tested according to the ISO 13784-1 standard by the Fire Insurers Laboratories of Korea and the Korea Institute of Construction Technology in Korea, the Royal Institute of Technology in Sweden, and the Commonwealth Scientific and Industrial Research Organization in Australia. The tested sandwich panels consisted of steel sheets, expanded polystyrene, and glass wool and were supplied by the Fire Insurers Laboratories of Korea. The heat release rate results were collated and compared, and the variation in the data distribution was analyzed statistically. The precision of the maximum heat release rate (HRR) and that of the THR determined according to ISO 13784-1 was ± 10.16 kW and ± 37.00 MJ, respectively, suggesting suitable consistency of HRR and THR values among the participating institutions. The inter-laboratory comparison for the assessment of the same product according to the ISO 13784-1 standard was found to be feasible despite variations in the laboratory facilities, specifically in terms of the extraction hoods and calorimeter HRR capacity.

Keywords: ISO 13784-1; round robin test; fire safety; sandwich panel; HRR

1. Background and Purpose
1.1 ISO 13784 Revision Project
The ISO 13784-1 standard specifies a test method for determining the reaction-to-fire of sandwich panel building systems, which are building component steel panels used in walls and roofs. This standard was first published in 2002 and subsequently updated in 2009 (ISO 13784-1, 2009). The ISO 13784-1 Revision (MKE, 2008) conducted by the Korean Government (led by the Korea Fire Protection Association (KFPA)'s Fire Insurers Laboratories of Korea (FILK)) in 2008 showed that the standard's descriptions pertaining to the methods for determining the heat release rate (HRR) value and, in particular, for validating the precision of a comparison of such values for a specific specimen at an inter-laboratory level were ambiguous. At the International Organization for Standardization (ISO)'s Technical Committee on Fire Safety (TC92) plenary meeting in Seoul in 2008, some suggestions were provided to resolve these ambiguities, and these were adopted by ISO TC92 in May 2009. Until last year, the outcomes of the ISO 13784-1 Revision Project were under Final Draft for International Standard (FDIS) review. As of Feb 2014, they have been successfully published as an international standard (ISO 13784-1, 2014). Tables 1. and 2. show details of the revision projects and a historical schedule of the ISO 13784-1 round robin test (RRT) until the presentation of test results at ISO TC92 in 2011.

Table 1. ISO 13784-1 Revision Project

| ISO Project Name | Revision of ISO 13784-1 |
|------------------|-------------------------|
| ISO Project ID   | Project 53738           |
| ISO Project Leader | Park Kye-Won/FILK of South Korea |
| ISO Project Convener | Patrick van Hees/Sweden |
| Relevant Authority in Korea | Korean Agency for Technology and Standards (KATS) under the Ministry of Knowledge Economy |
1.2 Establishing the ISO 13784-1 RRT
Along with the ISO 13784-1 Revision Project, an RRT project was organized and approved by ISO TC92 in April 2010 to verify the effectiveness of the ISO 13784-1 test methods. Originally six global research institutions from four nations-Korea, Australia, Sweden, and Japan-participated in this project, where two institutions from Japan have joined to make the comparison with ISO TS 17431 (model box test method). Finally, four global research institutions from three nations except Japan’s submitted the RRT results to the project leader.

Table 2. Time Schedule for ISO 13784-1 RRT

| Date/Meeting                      | Event Description                                              |
|----------------------------------|-----------------------------------------------------------------|
| May 2009 ISO TC92 Secretariat    | Proposed ISO 13784-1 Revision Project Approved                  |
| April 2010 ISO TC92 Meeting in Berlin | ISO 13784-1 RRT Plan Approved 6 Institutions from 4 Participating Nations participate |
| April 2011 ISO TC92 Meeting in Paris | Preliminary Findings from RRT Reported                           |
| November 2011 ISO TC92 Meeting in Brussels | Final Results from RRT Reported                                 |

This RRT project was led by KFPA’s FILK. The FILK distributed common test protocols and test specimens, and all the institutions performed and completed RRTs under FILK’s supervision over the period from 2010 to the second half of 2011.

1.3 Purpose of Technical Research on ISO 13784-1’s RRT
Four global research institutions-the FILK and Korea Institute of Construction Technology (KICT) in Korea, the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia, and the Royal Institute of Technology (SP) in Sweden-participated in the RRT. All participating institutions of the RRT successfully performed an ISO 13784-1 evaluation of the same sandwich panel material (described in Section 2.2) assembled in the form of a free-standing room according to ISO 13784-1. This paper presents a statistical analysis of the results obtained from the ISO 13784-1 RRT.

2. ISO 13784-1 RRT Test Methodology and Specimen Construction
2.1 Relevance of ISO 13784-1 Method in RRT
This RRT was conducted in accordance with ISO 13784-1:2002 and the proposed method for deriving HRRs (method for precisely measuring flow velocity ratio, k, factor). The ISO 13784-1 tests examine the fire combustion performance (HRR and smoke production rate) of small sandwich panel room assemblies that are directly exposed to a flame for 20 min. in the corner of a room. If flashover (EN 14390, 2007) occurs during the tests, the test is stopped and the combustion performance prior to cessation is measured. This RRT was mainly aimed at measuring the HRRs such as equation (1), checking outliers from the HRR results, and obtaining a confidence interval for the distribution of the results.

\[
\phi_s = \frac{q_{hs}q_{h,0} \chi_s^2 R}{\chi_0 (1 + 1) - \chi_0} \frac{q_{hs}}{q_{h,0}} \phi_b
\]

where,
\[
\phi_s: \text{specimen HRR [kW]}
\]
\[
\phi_b: \text{burner HRR [kW]}
\]
\[
q_{hs}: 25^\circ C, \text{combustion rate of specimen, [}17.2 \times 10^4 \text{ kJ} \cdot \text{m}^{-3}\text{]}
\]
\[
q_{h,0}: 25^\circ C, \text{combustion rate of propane [}16.8 \times 10^4 \text{ kJ} \cdot \text{m}^{-3}\text{]}
\]
\[
q_{o,298}: 25^\circ C, \text{gas flow in exhaust ducts, calculated under atmospheric Pressure [m}^3 \cdot \text{s}^{-1}\text{]}
\]
\[
\alpha: \text{expansion coefficient [when the specimen was burned, } \alpha=1.105]\]
\[
\chi_s^2: \text{mole fraction of oxygen including water vapor in the air}
\]
\[
r : \text{oxygen consumption index}
\]

2.2 Summary of Test Procedure
Before testing the sandwich panel free-standing room assembly according to ISO 13784-1, the heat release output of the fire source or burner used was calibrated as described in this standard. Some key requirements of this procedure are described below and in Table 3.

(1) Burner calibration: During the calibration run, the exhaust capacity of the extraction hood was kept at a minimum of 3.5 m³/s. During the calibration (and during the actual test of the sandwich panel room assembly), an HRR baseline was obtained by recording data for a period of at least 2 min. before the burner or its ignition source was activated.

(2) Testing of sandwich panel room assembly: The burner is adjusted to the required output level within 10 s of activation of the ignition source. The burner heat output (see Table 3) is maintained at 100 kW for the first 10 min and 300 kW for another 10 min. If flashover occurs, the test is stopped.

2.3 Description of Sandwich Panel Specimen and Panel Assembly in Room Used in RRT According to ISO 13784-1
The sandwich panels used consist of a 50mm-thick double-layered core (expanded polystyrene (EPS) + glass wool) with a 0.5mm-thick steel plate on either side of the core forming the sandwich skins. As shown in Fig.1., the sandwich panels measure 2.4m x 3.6m x 2.4m in size and were assembled as a rectangular free-standing room assembly with an opening on the front face. Though ISO 13784-1 specifies the width of the...
panel as 1.2m, 1m-wide panels were used for ease of mass-production in Korea. The assembly consisted of four panels for the right and left walls, three panels for the back wall, four panels for the ceiling, and three panels for the front (with a 0.8m wide and 2.0m long opening).

3. Summary of ISO 13784-1 RRT HRR Results

As mentioned above, four institutions tested the sandwich panel specimens provided by FILK for 20 min according to ISO 13784-1. Among common qualitative observations, flashover did not occur. Ten minutes after burner ignition, the flame went up along the wall panels adjacent to the burner, and the flame spread along the ceiling extended toward the front of the room ~50 cm from the room opening. Fig.2. shows test photos at each location in the RRT. Fig.3. shows an overlay of the plotted curves for the HRR vs. time for each laboratory assessment conducted in the RRT.

Table 3. Burner Heat Outputs During Burner Calibration and Testing of Sandwich Panel Room Assembly According to ISO 13784-1

| Tests                     | Time (min.) | Heat Output (kW) | Remarks |
|---------------------------|-------------|------------------|---------|
| Burner Calibration        | 0–2         | 0                |         |
|                           | 0–2         | 0                | The calibration test is performed 1 m below the center of the hood. The change from one HRR level to another for each stage should be achieved within 20 s. Each burner heat output is controlled within ± 5% of the set value. |
|                           | 2–7         | 100              |         |
|                           | 7–12        | 300              |         |
|                           | 12–17       | 100              |         |
|                           | 17–19       | 0                |         |
| Sandwich Panel Room Assembly Test | 0–2 | 0 | Each burner heat output should be controlled within ± 5% of the set value. If flashover occurs, the test is stopped. |
|                           | 2–12        | 100              |         |
|                           | 12–22       | 300              |         |
|                           | 22–32       | 0                |         |

Table 4. THR and HRR Measured by the Four Institutions and FIGRA

|                              | A    | B    | C    | D    |
|------------------------------|------|------|------|------|
| THR (MJ) (0–20 min.)         | 259  | 233  | 244  | 279  |
| Max HRR (0–2 min.)           | 113.6| 111.7| 137.6| 140.7|
| Elapsed Time (s)             | 117  | 114  | 106  | 120  |
| Max HRR (0–10 min.)          | 114.5| 119.8| 144.7| 140.7|
| Elapsed Time(s)              | 121  | 261  | 366  | 120  |
| Max HRR (0–12 min.)          | 394.3| 340.2| 386.5| 349.6|
| Elapsed Time(s)              | 716  | 711  | 720  | 710  |
| Max HRR (0–20 min.)          | 418.6| 425.0| 415.8| 430.0|
| Elapsed Time(s)              | 790  | 810  | 886  | 795  |
| FIGRA (kW/s)                 | 0.150 | 0.154 | 0.131 | 0.164 |

The maximum HRR, a major evaluation parameter, measured in A, B, C, and D was 418.6, 425.0, 415.8, and 430.0 kW, respectively. These values are converted into FIGRA (FIre Growth RAte; maximum HRR divided by the elapsed time (s)) (EN 14390, 2007) values of 0.150, 0.154, 0.131, and 0.164 kW/s (see Table 4.).
4. Precision Analysis

Because only four institutions participated in the statistical analysis, the RRT results' analysis was referred to in the method in chapter 7.2 of ISO TR 9705, which explains the ISO RRT analysis (ISO TR 9705-2). Furthermore, for checking the equal distribution, outlier, and confidence interval of the results, the precision analysis described in ISO 9725-2, which is generally used for RRT precision analysis, was adopted (ISO 9725-2, 1994).

4.1 Grubbs's Test

The HRRs obtained by the four institutions during the RRT were subjected to Grubbs's test, a statistical method for homogeneity indication, as described in ISO 9725-2 (ISO 9725-2, 1994). The results determined were $G_{\text{min.}} = 1.025$ and $G_{\text{max.}} = 1.197$, which were lower than the critical value of $G = 1.481$ (n = 4, p<0.05), validating the homogeneity of the RRT evaluation results. The distribution of the RRT HRR results indicated that there was no outlier (see Table 5.). Therefore, to detect an outlier, Dixon's Q test was additionally performed.

4.2 Dixon's Q Test

To detect an outlier using Dixon's Q test (see Table 6.), the RRT HRR data are sequenced (n = 4) as follows:

When determining an outlier for the maximum value of 430.0 kW in equation (2),

$$Q_{\text{exp max}} = \frac{x_n - x_{n-1}}{x_n - x_1} = \frac{(430-425)}{(430-415.8)} = 0.350$$

When determining an outlier for the mode of 415.8 kW in equation (3),

$$Q_{\text{exp min}} = \frac{x_2 - x_1}{x_n - x_1} = \frac{(415.8-415.6)}{(430-415.8)} = 0.197$$

At 95% confidence level, the critical value for n = 4 was $Q_{\text{crit}} = 0.829$.

Because both $Q_{\text{exp max.}}$ and $Q_{\text{exp min.}}$ are smaller than $Q_{\text{crit}}$, the null hypothesis (there was no significant difference between the seemingly abnormal data and other data) of the Q-test was adopted, and the maximum value and mode were not recognized as an outlier. For extreme values, it was ascertained that there was no outlier in the RRT results. Table 6. summarizes the results of Dixon's Q test.

Table 6. Dixon's Q Test for Outliers

| Q_{\text{exp max.}} (95% C.L, n = 4) | 0.350 | Q_{\text{exp min.}} (95% C.L, n = 4) | 0.243 |
| Q_{\text{exp max.}} (HRR_{\text{max.}} = 430.0) | 0.197 | Q_{\text{exp min.}} (THR_{\text{max.}} = 279.35) | 0.427 |

Outlier

| if $Q_{\text{exp}} > Q_{\text{crit}}$ | No outlier | if $Q_{\text{exp}} > Q_{\text{crit}}$ | No outlier |

4.3 Confidence Interval

The mean of the RRT HRR (M) was 422.35. The determined standard deviation (S) was 6.390, $S_{\text{mean}} = S/\sqrt{n}$ was 3.190, and for a degree of freedom (df) of 0.3, at 95% confidence level (significance level 0.05), the t value ($t_{\text{crit}}$) was 3.182 and final confidence interval was calculated as $S_{\text{mean}} \cdot t_{\text{crit}} = \pm 10.16$.

Table 7. Precision of RRT Measurements with 95% Confidence Level

| Mean of HRR | 422.35 | Mean of THR | 254 |
| Standard Deviation | 6.390 | Standard Deviation | 20 |
| $df$ (n = 4) | 3 | $df$ (n = 4) | 3 |
| Confidence Level | 95% (p<0.05) | Confidence Level | 95% (p<0.05) |
| t Distribution Value | 3.182 | t Distribution Value | 3.182 |

95% Confidence Interval $\pm 10.16$ 95% Confidence Interval $\pm 37.00$
Therefore, the precision error range of the four institutions' maximum HRRs from this RRT can be expressed as (422.35 ± 10.16) kW (95% confidence interval). Table 7 summarizes the confidence interval parameters determined.

Furthermore, the correlation analysis of the HRR curve over time showed that they are very closely correlated (at least \( R^2 = 0.948 \) for each institution), as shown in Table 9, ensuring the statistical significance of these RRT results.

### 5. Conclusion and Discussion

This study intended to show the processes followed by international institutions for RRT and how to obtain precise results from the same. The following conclusions were derived from this study:

1. Based on the results collated from the four institutions participating in this RRT, the precision of the maximum HRR and that of the THR determined according to ISO 13784-1 was ± 10.16 kW and ± 37.00 MJ, respectively. Therefore, a suitable consistency of HRR and THR values was achieved among the institutions that participated in the RRT.

2. Given a precise test method and the calibration procedure specified in ISO 13784-1 as a prerequisite for each sandwich panel small room fire test, it was determined that the inter-laboratory comparison for the assessment of the same product according to the ISO 13784-1 standard was feasible despite variations in the laboratory facilities, specifically in terms of the extraction hoods and calorimeter HRR capacity.

3. The ISO 13784-1 was revised in Feb 2014. This study has presented a significant RRT result supporting the use of this standard.

### Acknowledgement

Each RRT laboratory had specific extraction hood capabilities for capturing and measuring the heat and smoke and large-scale calorimeters with various specifications (Table 8); A had a 4.5m x 7.6m rectangular hood (maximum HRR capacity of 3 MW); B, a 10m-wide circular hood (maximum HRR capacity of 10 MW); C, a 6m-wide circular hood (maximum HRR capacity of 5 MW); and D, a square hood 5m on a side (maximum HRR capacity of 5 MW). To mitigate the differences between the effects of the various calorimeter hood styles described, a precise calibration process was performed in each laboratory to ensure that the specified HRRs (5 min. at 100 kW and 5 min. at 300 kW) were attained.

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