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Safety Evaluation of Fire Resistant Extruded Panel for Partition Wall System

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Abstract

While the extruded cement panel has many advantages compared to drywall, it has limited applicability in buildings due to its low fire resistance. However, an extruded panel in which the fire resistance has been dramatically enhanced through the addition of a-hemihydrate gypsum is expected to become widely applied as a partition wall or interior material for buildings. To ensure its applicability, certain safety requirements for use, such as the leaning load by residents, the impact by indoor articles, and the fire, need to be taken into consideration. The purpose of this study is to review the impact load resistance, horizontal load resistance, and fire resistance as required safety properties for the partition wall and interior materials of the extruded panel that includes a-hemihydrate gypsum. The results of this study show that the impact load resistance of the extruded panel that includes a-hemihydrate gypsum achieves SD grade for industrial buildings, and the horizontal impact load resistance achieves HD grade for public buildings. In addition, it provides fire-resistance for approximately 7 minutes longer than the existing extruded cement panel. Based on this result, it is confirmed the extruded panel incorporating a-hemihydrate gypsum has adequate safety properties for use as partition wall or interior material.

Keywords: fire-resistant performance, horizontal load resistance, cement extruding panel, a-hemihydrate gypsum

1. Introduction

Strategies to ensure greater longevity of apartment buildings have recently been an issue in Korea as part of the country's efforts not only to reduce the construction waste generated by reconstruction projects but also to cope with the diverse lifestyles of residents. Building structures need to be separated into structural and non-structural parts. Structural parts provide structural durability, are fixed factors that cannot be easily changed, and generally have a long life. However, the changeability of non-structural parts is very important to respond to diverse demands, including the size and location of a residential space, not to mention to resolve the difference in service life between structural and non-structural parts[1].

Methods to build non-structural parts have been rapidly changing from wet construction to dry construction due to economic feasibility and construction duration. The extruded cement panel, one of the lightweight drywalls, provides high changeability compared to reinforced concrete walls or brick masonry bearing walls, allowing residents to change the interior space at their discretion; furthermore, the relatively reduced deadweight loss of the panels secures greater stability and reduces the construction duration. For these reasons, extruded cement panels have recently gained

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popularity in a wide range of applications. However, if they are exposed to fire, hydrates are generated, which triggers explosive spalling due to the internal vapor pressure caused by the vaporization of hydrates. For this reason, the extruded cement panel has limited application to partition walls or boundary walls between housing units in high-rise or large buildings, as safety is considered more significant in these building types.

Therefore, we have performed diverse studies to develop an extruded panel that causes no explosive spalling and satisfies performance requirements, including both strength and dimensional stability requirements, and finally developed one using a-hemihydrate gypsum, which was reported in a previous paper[2].

This paper examines horizontal load resistance, impact load resistance and fire resistance of the extruded panel with respect to the safety of residents when the extruded panel incorporating a-hemihydrate gypsum is applied to boundary walls or interior material.

2. Required safety performance of materials for the partition between housing units

2.1 Impact load resistance and horizontal load resistance

Drywalls have better constructability than brick masonry walls or concrete walls, but depending on the composition method they may not secure sufficient integrity of components compared to conventional wet construction methods, which is a disadvantage. For this reason, performance evaluation is required for the part.

Studies have been actively conducted in Korea to address such drawbacks of lightweight drywalls[3][4]. However, the studies have mostly focused on how to secure fire-resistance, fire insulation or sound insulation. There have been few studies conducted on horizontal load resistance or impact load resistance related to static or dynamic load that can be caused by residents or loaded objects. Since impact load resistance and horizontal load resistance are closely related to the safety of residents, they are important performance metrics for interior materials and materials for partitions between housing units. For this reason, it is necessary to study the performance of related materials[5][6][7]. KS F 2273 “Methods of Performance Test for Building Construction Panels” is the test criteria related to horizontal load resistance and impact load resistance[8]. But only the test method is defined in the test criteria: there are no grading criteria for the test results presented, and the test results must be interpreted relatively. However, the grading criteria are stipulated in the European criteria, BS 5234.

2.2 Fire resistance

Fire resistance of interior materials delays spreading of flames and blocks hazardous gas and smoke, and is one of the performance requirements. For this reason, in the event of a fire interior materials should offer one or more of the following: structural stability, thermal insulation and integrity. More specifically, the interior materials should be not be easily deformed, destroyed, separated, or cracked (structural stability), should block heat (thermal insulation determined by whether the temperature on the non-heating zone exceeds the required limit), and should block flames from reaching outside the space (integrity determined by whether there are any gaps through which fire spreads). In general, fire resistance performance is expressed as time, and the criteria for the fire resistance are stipulated in Public Notification No. 2005-122 “Structural Fire Resistance Requirements and Management Criteria.”

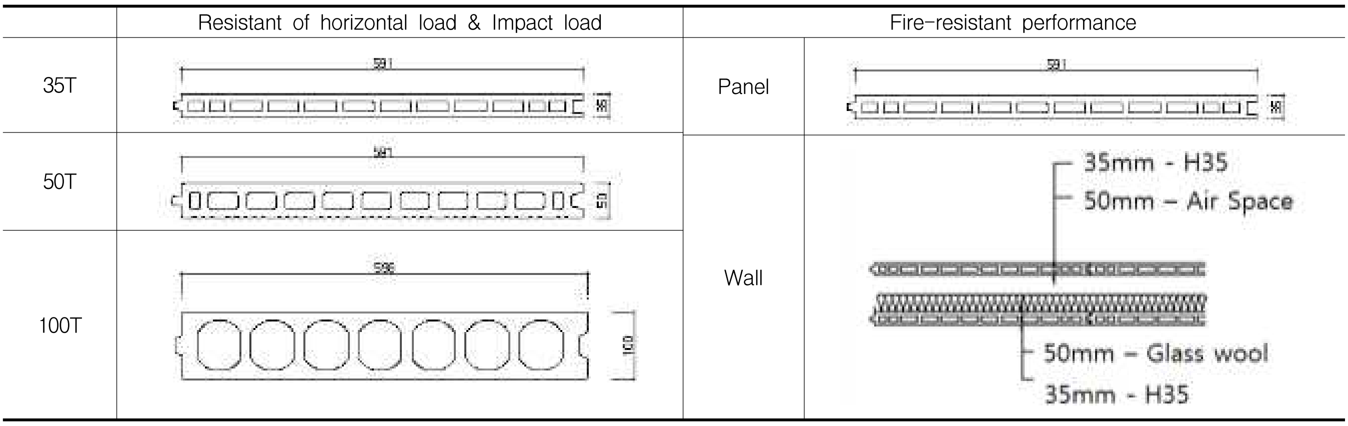


Figure 1. Sections of panel and wall modules in this test

3. Experiment plan and method

3.1 Experiment plan

This research aims to understand horizontal load resistance, impact load resistance and fire resistance of the extruded panel incorporating a-hemihydrate gypsum. As indicated in Table 1, horizontal load resistance, impact load resistance, and fire resistance were evaluated by panel type and shape based on KS and BS (British Standard).

For the horizontal load resistance and impact load resistance, 35mm, 50mm, and 100mm-thick panels with air layer were tested in compliance with KS F 2221 Impact Test Method of Impact for Building Boards. Since there are no rating criteria stipulated in KS, the results were evaluated based on the rating criteria stipulated in BS 5234 Part 2 "Partitions (Including Matching Linings)"[10].

In terms of fire resistance, the 35mm-thick panel was tested using a small furnace that could be heated according to the standard heating curve as stipulated in KS F 2257-1 "Methods of Fire Resistance Test for Building Construction - General Requirements"[11], and compared with the 35mm-thick panel that did not include a-hemihydrate gypsum (Base).

Table 1. Design of experiments

Factors		Test items	Test method
Type of panel	Type of module	Test items	Test method
35T, 50T, 100T	·Panel	·Horizontal load resistance ·Impact load resistance	·BS 5234 ·KS F 2221
35T	·Panel ·Wall	·Fire-resistant performance	·KS F 2257-1
Control	·Panel ·Wall	·Fire-resistant performance	·KS F 2257-1

3.2 Test method

3.2.1 Horizontal load resistance

The tester used in the horizontal load resistance performance test is shown in Figures 2 and 3. The tester consists of a frame on which a panel with a size of 1200mmx2400mm is fixed, the LVDT Stand with which deformation of the panel is measured, and an actuator with the highest load capacity of 200kgf. As illustrated in Figure 1, the panels are 35mm, 50mm or 100mm thick and have an air layer. Each of the panels was manufactured to be 1200mmx2400mm, and fixed to the tester for the horizontal load resistance. Then, three LVDTs were installed at intervals of 300mm based on the center on the other direction of load, and loads of 50kgf and 100kgf were placed horizontally using the actuator. When loads of 50kgf and 100kgf were placed, the maximum deformation was measured, and the residual deformation was measured 5 minutes after the load was eliminated.

The flexural test method for assembling walls is stipulated in KS, but there are no rating criteria for the test results. In BS 5234 Partitions (including matching linings): Part 2, the stiffness test method is stipulated by considering the flexural capacity of the wall affected by the reclining of a human against the wall or climbing on a ladder put against the wall. To perform a simulation of the situation, the static load is placed horizontally at a certain height, at which the maximum displacement and residual displacement are measured, respectively. The grade is divided into four categories as shown in Table 2: LD(Light Duty), MD(Medium Duty), HD(Heavy Duty) and SD(Severe Duty). More specifically, LD(Light Duty) is for areas of a housing unit that people use with their attention paid and have a low risk of having an accident or being overstrained; MD(Medium Duty) is for areas of offices that people use with their attention paid but have a slightly higher possibility of having an accident or being overstrained; HD(Heavy Duty) is for public places or industrial settings; and SD(Severe Duty) is for heavy industrial settings.

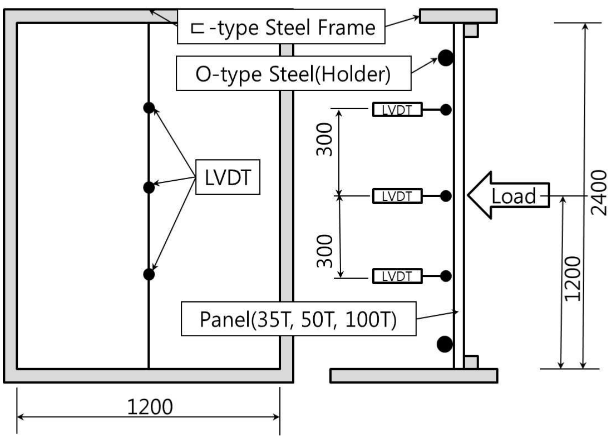


Figure 2. Specimen setting in the horizontal load resistance test

Table 2. Performance grade according to deformation in the horizontal load resistance test

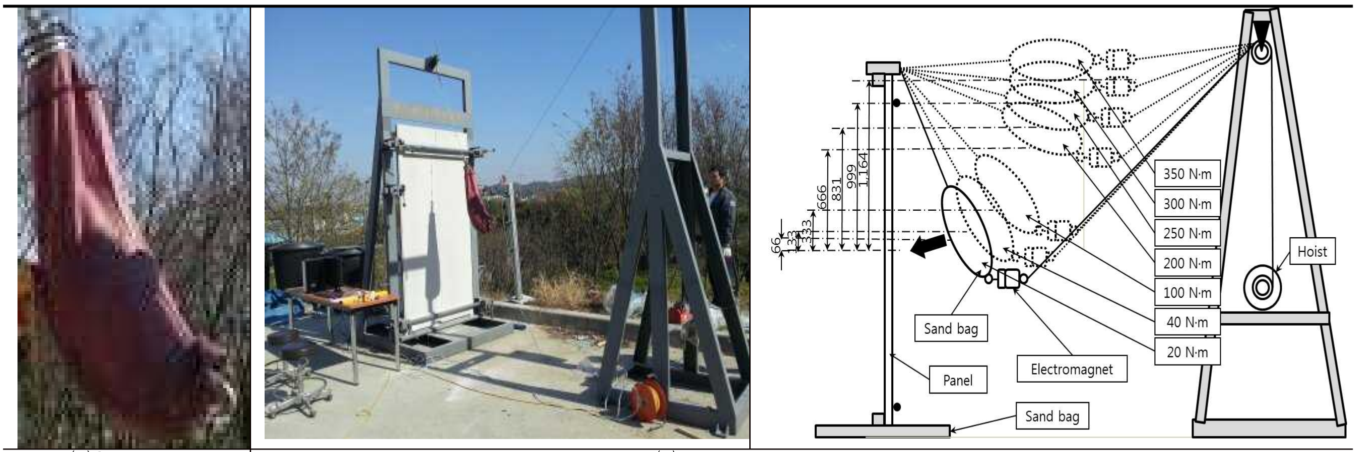
Grade	Load (kgf)	Max. flexure(mm)	Residual deformation(mm)
LD (light duty)	50	25	5
MD (Medium duty)	50	20	3
HD (Heavy duty)	50	15	2
SD (Severe duty)	50	10	1

LVDT | (b) Compression meter

Figure 3. View of horizontal load resistant tester

3.2.2 Impact load resistance

The tester used in the impact load resistance performance test consists of a steel frame on which a panel sized 1200mmx2400mm is fixed, as shown in Figure 4(b), a 30kg-weighted cylindrical bag filled with sand as shown in Figure 4(a) to load an impact, and a falling device that makes the sandbag fall from a certain height. The sandbag and the falling device are connected by an electromagnet. The panel sized 1200mmx2400mm was used in the impact load resistance test as in the horizontal load resistance test, and the sectional view of the panel is shown in Table 1. The test was conducted in compliance with KS F



(a)Sand bag (D230mm, 30kg)

(b) Impact load resistant tester

Figure 4. Test view of impact load resistance tester

2273 "Methods of Performance Test for Building Construction Panels." The 30kg-weighted sandbag was dropped from heights of 66mm, 133mm, 333mm, 666mm, 831mm, 999mm, and 1164mm, to apply an impact load of 20N.m, 40N.m, 100N.m, 200N.m, 250N.m, 300N.m, and 350N.m, respectively. The sandbag was dropped three times from each height to put the impact load on the wall, and then the breakage was examined. In addition, only the performance test method for the components was presented in KS with no performance requirements presented, and we referred to BS 5234, which has the grading criteria shown in Table 3, to grade impact load resistance performance.

Table 3. Performance grade according to impact energy in the impact load resistance test (BS Code)

Grade	Impact Energy (N・m)	Drop Height(mm)
LD	20	66
MD	20	66
HD	40	133
SD	100	133

3.2.3 Fire resistance test

The tester used in the fire resistance performance test could be heated in the standard heating curve set in KS F 2257-1 "Methods of Fire Resistance Test for Elements of Building Construction - General Requirements," and the specifications and performance of the tester are indicated in Tables 4 and 5. The fire resistance tester was operated like a gas burner. The steel frame was used for the outer surface, while ceramic fiber was attached to the inner surface to prevent the tester from being deformed. Heat was controlled with the burner valve on the control box, and the control box was programmed to heat the tester in compliance with the standard heating curve. To measure the heating temperature in the refractory furnace, a thermocouple was installed on the side. This could be monitored on the control box, and the data was also collected using a data logger. The panels and walls used in the fire resistance test are shown in Figure 1. The panels and walls to be placed in the fire resistance tester were manufactured to the size of 500mmx500mm. As shown in Figure 5, thermocouples were installed: two at the center(P1, P3), one on the upper part (P3) and one on the lower part(P4) to collect the data of the non-heating zones through the data logger attached to the control box.

Table 4. Specifications of fire-resistance tester

Name	Spec.
Chamber	Outside : Steal frame & Steal plate Inside : Ceramic fiber Inside size : 500x500㎜
Controller & Recorder	SDR100 Series (12 Channel)
Heat method	Gas burner

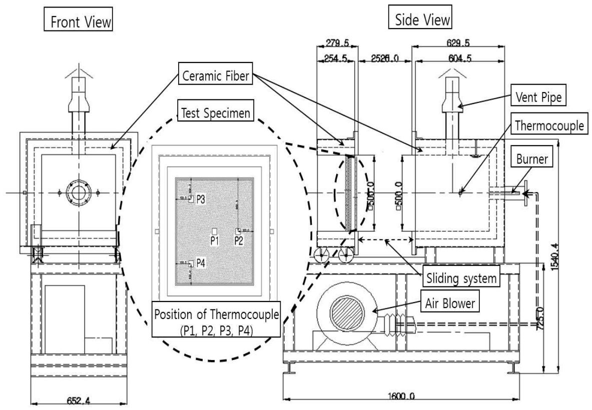


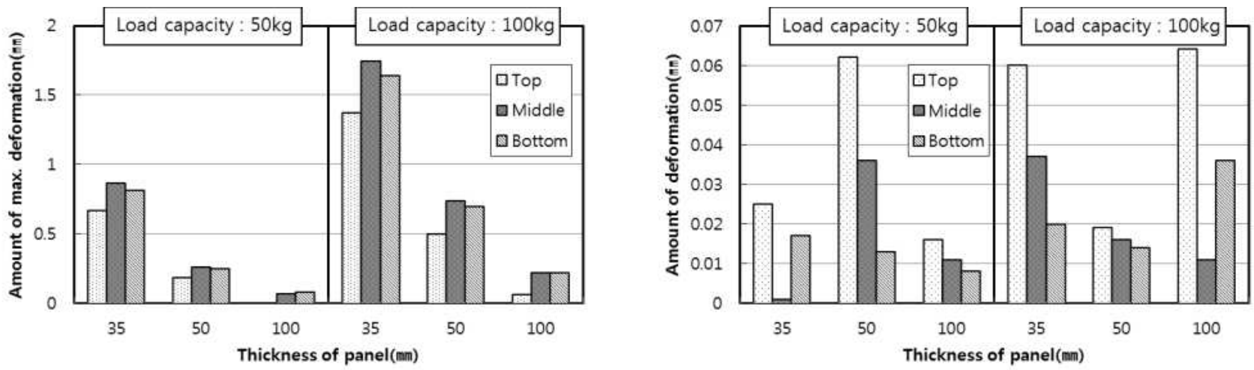
Figure 5. Fire-resistance tester set up for specimen

4. Test results

4.1 Horizontal load resistance

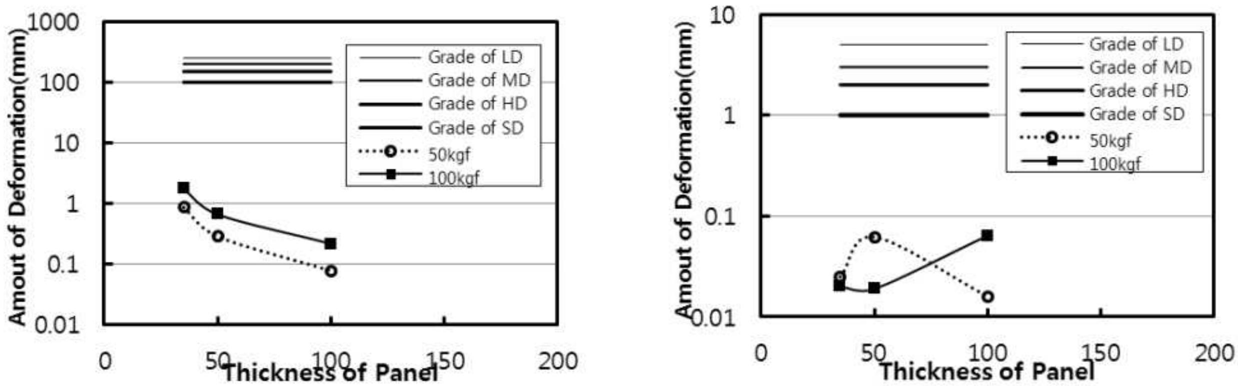
When a load of 35kgf was put on 35T, the maximum deformation and the residual deformation were shown to be 0.287mm and 0.062mm, respectively. When a load of 100kgf was put on 50T, the maximum deformation and the residual deformation were shown to be 0.078mm and 0.016mm, respectively. When a load of 100kgf was put on 100T, the maximum deformation and the residual deformation were shown to be 0.217mm and 0.064mm, respectively.

Figures 7(a), (b) illustrate and the maximum deformation and the residual deformation by panel thickness. The results show that the thicker the



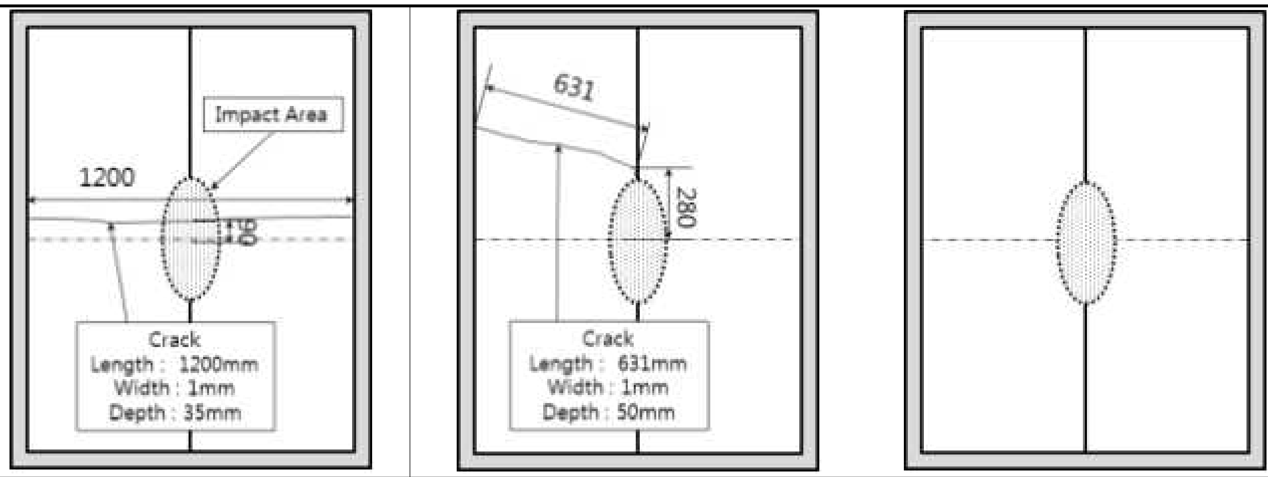
(a) Max. deformation according to thickness of panel (b) Residual deformation according to thickness of panel

Figure 6. Deformations according to panel type in the horizontal load resistant test



(a) Max. deformation according to thickness of panel (b) Residual deformation according to thickness of panel

Figure 7. Deformations in the horizontal load resistant test compared to the standard grade



35T(200N・m-2nd Impact) | 50T(100N・m-1st Impact) | 100T(3500-3rd Impact)

Figure 8. Crack generation of panel after the impact load resistance test. The dotted circle indicates the area of impact by the sand bag.

panel, the smaller the maximum deformation, from which it is inferred that the secondary section modulus increased as the wall became thicker. There was no clear pattern found because the measurements were too small compared to the size of the panels used in the test. Considering that KS requires the precision of the displacement meter to reach 0.1mm, it can be determined that there was almost no residual deformation. The measurements of the maximum deformation and the residual deformation were rated based on the BS code. All the panels tested are classified into the SD grade as shown in Figure 8, by which they can be used even in heavy industrial settings.

4.2 Impact load resistance

Tables 5 and figure 8 are the results of an impact load resistance performance test of three types of extruded cement panel with a-hemihydrate gypsum, each of which has thickness of 35mm(35T), 50mm(50T), and 100mm (100T).

The 35T extruded cement panel was resistant even to the third impact with a load of 100N.m. However, at the third impact with a load of 200N.m, it had a crack (1200mm long, 1mm wide and 35mm deep) about 90mm up from the center of the panel.

The 50T extruded cement panel was resistant to the third impact with a load of 40N.m. However, at the first impact with a load of 100N.m, it had a crack (651mm long, 1mm wide, and 50mm deep) about 280mm up from the center only on the left side of the panel. The test was conducted twice, and the test results were identical. It was considered that 50T had lower impact load resistance than 35T due to some separation at the bond between panels which caused load to be concentrated on one side of the panel.

The 100T extruded cement panel was resistant to the third impact with 350N.m. When the grade presented in BS code was applied, 35T and 100T were classified as SD, while 50T was HD.

Table 5. Results of impact load resistance test

	35T	50T	100T
20N・m	Test OK	Test OK	Test OK
40N・m	Test OK	Test OK	Test OK
100N・m	Test OK	Fail	Test OK
200N・m	Fail	-	Test OK
250N・m	-	-	Test OK
300N・m	-	-	Test OK
350N・m	-	-	Test OK
Grade	SD	HD	SD

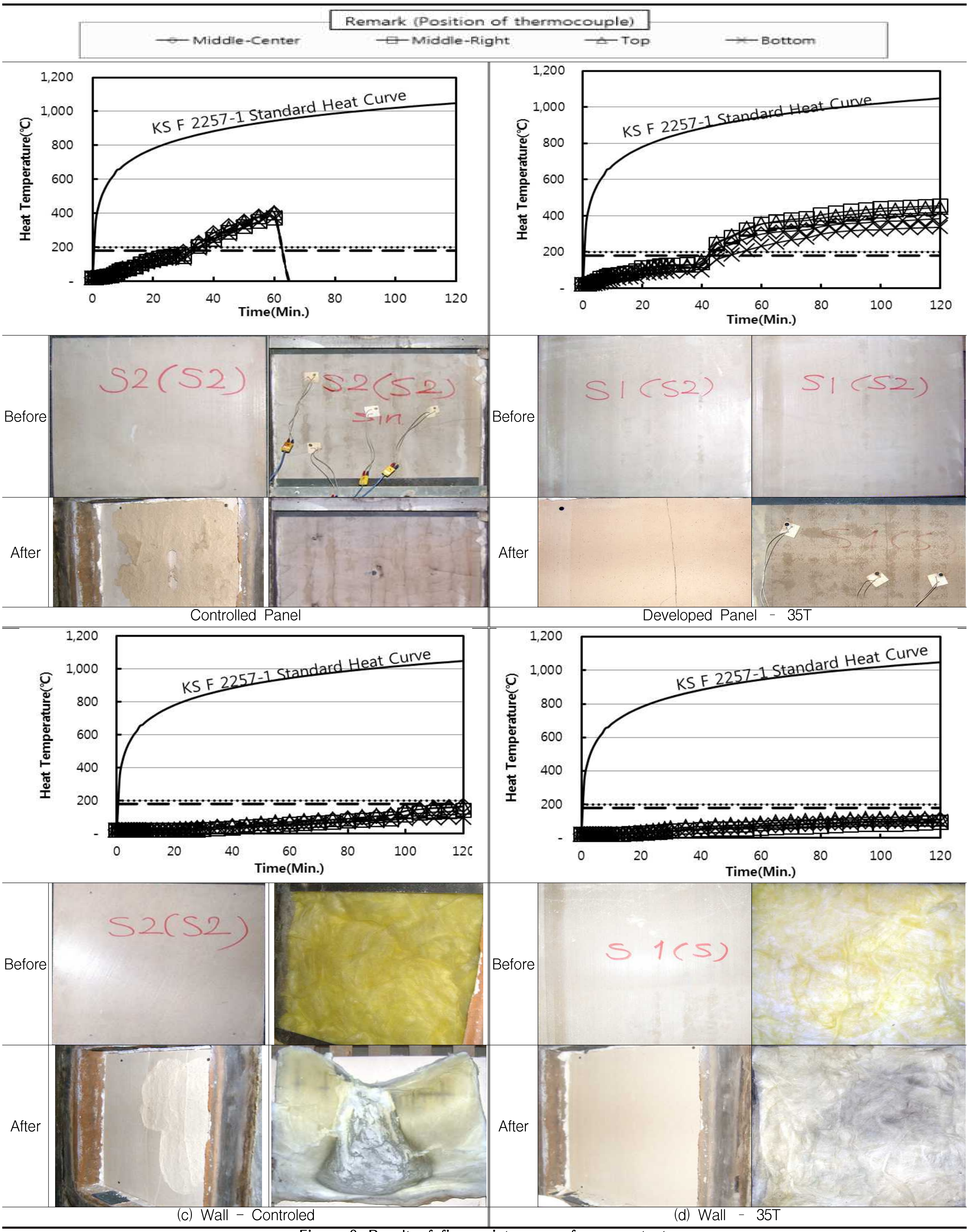


Figure 9. Result of fire resistance performance test

4.3 Fire resistance

Figures 9(a), (b) show the results of a comparative test fire resistance between the 35mm-thick extruded cement panel with a-hemihydrate gypsum and the existing 35mm-thick extruded cement panel(Controled).

An inflection was found on Control 30 minutes after heating, which is believed to have been due to the evaporation of pore fluid near the surface of the panel. Moreover, an explosive spalling was found with an explosion sound 60 minutes after heating (at 945℃) on the heating zone.

The average temperature of the non-heating zone was 387℃, and cracks were found all over the non-heating zone. According to fire resistance performance set in KS F 2257, Control was shown to have a fire resistance of 35 minutes. The average temperature of the non-heating zone was found in a gradual curve on 35T by 40 minutes after heating, which is believed to have been due to the evaporation of internal pore moisture and water of crystallization in a-hemihydrate gypsum.

There was no explosive spalling found by 120 minutes (1049℃), while cracks were found in the vertical direction on the heating zone. At this time, the average temperature of the non-heating zone was 405℃, and the fire resistance performance test showed a fire resistance of 42 minutes.

As shown in Figures 9(c), (d), for Control, an explosion sound was generated 60 minutes after heating, explosive spalling was found on the heating zone, and the glass wool between the panels was damaged by heat. However, the average temperature of the non-heating zone was 140℃ 2 hours after heating, and it has a fire resistance of 2 hours. For 35T, no explosive spalling was found on the heating zone 2 hours after heating, and the glass wool between panels was found to be in good condition. At this time the average temperature of the non-heating zone was 103℃, and 35T was shown to have a fire resistance of 2 hours, which was about 37℃ lower than that of Control. It is believed that the chemically bound water in gypsum absorbed heat and was dehydrated, lowering heat transfer velocity and reducing the thermal stress as a result.

5. Conclusions

The extruded cement panel with a-hemihydrate gypsum developed to improve fire resistance was tested in terms of horizontal load resistance, impact load resistance and fire resistance to verify the safety of the panel when applied to interior materials and boundary walls between housing units.

1) Through the results of a test of horizontal load resistance by panel thickness, it was found that the thicker the panel, the less the maximum deformation. This is because that the secondary section modulus was affected by the panel thickness. All the panels used in the test were classified as SD, which means the panels can be used in harsh settings like heavy industrial settings.
2) Through the test of impact load resistance by panel thickness, it was found 35T and 100T were classified as SD while 50T was classified as HD. Based on the results, it was verified that the panels can be used not only for interior materials and boundary walls between housing units in high-rise apartments, but also in public spaces and industrial settings.
3) Through the test of fire resistance of 35T and Control manufactured with an equivalent size to 35T, there was no explosive spalling found

on 35T, and the fire resistance of 35T was 7 minutes longer than that of Control, although it failed to achieve fire resistance of 2 hours. Based on the results, it was verified that they can be used as interior materials and boundary walls between housing units in high-rise apartments.

4) From the results above, the safety of extruded cement panel with a-hemihydrate gypsum was verified for use as interior materials and boundary walls between housing units.

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