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Research Article

The Performance of Calcium Silicate Board Partition Fireproof Drywall Assembly with Junction Box under Fire

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This study uses a metal stud partition fireproof drywall measuring 83 mm in thickness as a test specimen to explore the impact of an embedded junction box on the firefighting performance of the wall through one time of standard fire test on a 300 cm × 300 cm area and five times of standard fire test on a 120 cm × 120 cm area. The results show that the quality of calcium silicate board plays a big role in the fireproof effectiveness. The embedded junction box located on the backside of the fire can reduce the effectiveness of the wall, especially the area above the socket. The thickness of rock wool may increase the performance, but in a limited rate. External junction box may not impact the fireproofing performance of the wall but it still possesses some safety risks. An embedded junction box measuring 101 × 55 mm could already damage the fire compartment, and in reality there may be more complicated situations that should be noted and improved.

1. Introduction

The walls installed in fire prevention areas should be possessed of flame retardant effectiveness. For the trend of architectural engineering is towards increasing in dimension and high-rise, the conventional heavy building materials and high labor intensive methods are descending. Take panel closure walls, for example; the metal frame light panel closure system is well received for the characteristics of fixed construction method, shortened period, various techniques, light materials, and the stable material quality compared to concrete. Currently there are many studies on the performance issues of metal stud drywall partitioning system. Chuang et al. [1] proposed a direct impact of room temperature on the surface temperature of test specimen for a fire test, Ho and Tsai [2] proposed that the quality of board material plays a profound role on the fire ratings, Do et al. [3] provided microscopic study on the thermal conductivity of calcium silicate board, Lin et al. [4] conducted a shear behavior study of the combination of metal frames and calcium silicate boards, Maruyama et al. [5] conducted a study on the aging of calcium silicate boards and found that the strength could reduce over time, Nithyadharan and Kalyanaraman [6] provided a study on the strength of connection between screws and calcium silicate boards, Collier and Buchanan [7] used the finite element method to provide a prediction model on fire performance of drywall, and Nassif et al. [8] proposed a comparative study on the drywall thermal conductivity using a full-scale test and number simulation. These above are all conducted in the circumstances where the drywalls are reasonably installed. However, in reality, the quality control of the boards may not be good or the quality of commercially available boards may not be consistent with the ones sent to the laboratory for test; these are the actual causes impacting the fire ratings of metal stud drywall system. It is a practical issue to explore whether the devices, switches, or sockets on the boards can impact the fire ratings which also requires actual fire testing.

This study is different from the previously published studies in that it does not inform the manufacturers of the fire tests to be conducted and instead directly purchases the commercially available boards to be used as the test samples. The previously published studies all focus on the thermal conductivity of board material [3] or the numerical simulation of drywalls [7, 8] which are all in the ideal conditions where the boards are not damaged at the time

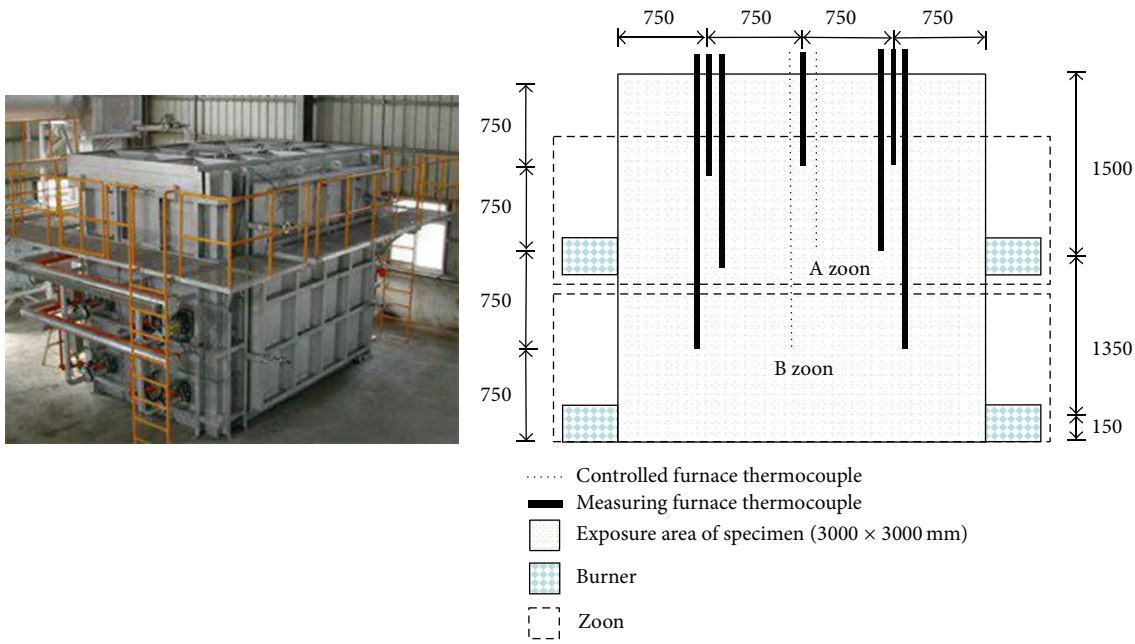


Figure 1: Full-size high-temperature furnace (inner size: 300 cm in width, 300 cm in height, and 240 cm in depth).

of fire. There have been no actual descriptions regarding the impacts of damaged boards on fire ratings. Therefore, this study especially explores whether socket installation can impact fireproofing walls in actual fire. It is learned from the previous tests that the side of calcium silicate board facing the fire may burst. Under material condition and coupled with the installed sockets on the board, we try to learn the remaining fire ratings of fireproofing drywall under poor conditions. In short, this study is to understand the actual fire ratings of metal stud drywall system. This study has never been done before and it is hoped that the results can make the constructors, vendors, and government agencies more vigilant in ensuring the quality of firewalls. This study conducts a total of six fire ratings tests. Test 1 uses the standards in ISO 834-1 [9] to perform on a test specimen measuring 300 cm (width) × 300 cm (height). From Tests 2 to 6, the test specimens receiving fire are measured to be 120 cm (width) × 120 cm (height) (sockets are embedded in some of the walls). To emphasize the validity of the tests and facilitate the future researches in understanding the type and performance of furnace for related studies, this study adds more description on the pressure, temperature, and structure of the test furnace as Sultan [10] proposed that the furnace size can generate different levels of radiant heat, causing impacts to the test results from different test labs.

2. Experimental Details

2.1. Fire Test Furnaces. This study uses two sets of test equipment that both can conduct material testing horizontally or vertically. The first furnace measures 300 cm in width, 300 cm in height, and 240 cm in depth. The second one measures 120 cm in width, 120 cm in height, and 120 cm in depth. Both equipment sets use electronic ignition and the control systems are computerized PID temperature controllers. The furnaces are manufactured by Kuo Ming Refractory Industrial Co., Ltd. The full-size furnace has 8 burners, of which only 4 are switched on for wall test. Two temperature control thermocouples are inside, controlling the operation of 2 burners each on the left and right sides. The remaining 7 thermocouples measure the furnace temperature and they are all inserted from the top of the test furnace (see Figure 1). The small furnace has 4 burners, of which only 2 are switched on for wall test. Two temperature control thermocouples are inside, controlling the operation of 1 burner on the left and right sides, respectively. The remaining 2 thermocouples measure the furnace temperature and they are inserted from the two sides of the furnace (see Figure 2). The inside ceiling and the wall of the furnace are covered by ceramic fiber wool made by Isolite Insulating Products Co. with the maximum temperature resistance at 1400°C, density at 240 kg/m^3, made of Al_2O_3 35.0%, SiO_2 49.7%, and ZrO_2 15.0%, and thickness at 30 cm and in white color. The bottom is composed of fire insulating bricks made by Kuo Ming Refractory Industrial Co., Ltd., and they are C-2 grade with the maximum temperature resistance at 1400°C and density at 1140 kg/m^3 and measuring 23 cm (L) × 11.4 cm (W) × 6.5 cm (thickness). The gaps and the connecting parts between the bricks are insulating clay. The external body of the entire furnace is made of steel boards and frames. The extension wire is WCA-H4/0.65x2, the external temperature resistance is 0~200°C, and the outer surface is surrounded by glass fiber. There is a ventilation port for the exhaust air in the back of the test furnace that is connected to the outdoor chimney. The transportation of test specimen is done by the 3.5 ton overhead crane inside the factory. Data recorder is made by YOKOGAWA, with all the equipment signals connecting to DS 600 data recorder

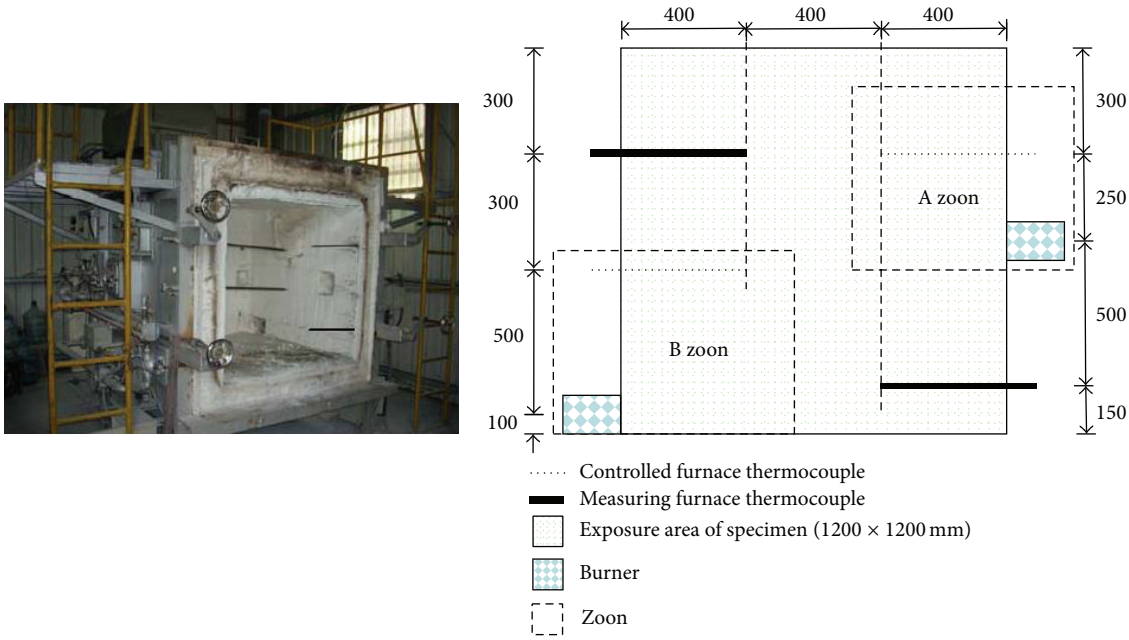


Figure 2: Small-size high-temperature furnace (inner size: 120 cm in width, 120 cm in height, and 120 cm in depth).

first and then being processed and sent to DC 100. Last, the data recorder converts the signals and exports them to an ASUS A55VD i5-3210 notebook computer via a network line, and the recorder captures the data every six seconds. There is a T-tube in the midheight of inner wall of the furnace, and that one of the end tip is connected to a pressure gauge that sends data to DS 600 data recorder. Each thermocouple inside the furnace is 10 cm away from the burning surface of the test specimen. The inside temperature of furnace is measured by K-type thermocouples made by Yi-Tai System Technology Co., Ltd. The specifications satisfy CNS 5534 [11] with 0.75 and above in the performance. The thermocouple wires are wrapped by heat resistance stainless steel pipes (16 gauge) measuring 6.35 mm in diameter. The pipes are placed inside other insulated stainless steel pipes measuring 14 mm in diameter with one opening end. The front end with heat conductivity protrudes 25 mm. All the thermocouples inside the furnace have been placed in an environment at 1000°C for one hour to increase their temperature measurement sensitivity, and the accuracy requirements are within ±3%.

2.2. Test Specimens. This study uses 9 mm calcium silicate boards that are commercially available (calcium silicate boards of Test 1: flexural strength: 125 kgf/cm^2, thermal conductivity: 0.14 w/mk, bulk specific gravity: 0.81 g/cm^3; calcium silicate boards of Tests 2~6: flexural strength: 124 kgf/cm^2, thermal conductivity: 0.13 w/mk, bulk specific gravity: 0.81 g/cm^3). It uses vertical closure boards and self-tapping screws to stabilize them. The screws are 3.5 mm in diameter, 25.4 mm in length, and 250 mm in spacing. The columns are the CH channel iron measuring 65 × 35 × 0.6 mm, the upper and lower slots are the C channel iron measuring 67 × 25 × 0.6 mm, and the spacing within the column is 406 mm. Rock wool used is measured 50 mm in thickness and 60 kg/m^3 and 100 kg/m^3 in density, respectively. For the embedded sockets, the external part is a switch panel measuring 120 mm × 70 mm and the internal part is a junction box measuring 101 × 55 × 36 mm. For the external sockets, the external part is a 120 mm × 70 mm switch panel and the internal part is a 120 × 70 × 47 mm junction box. The external switch panels are all made of ABS (Acrylonitrile Butadiene Styrene) and the inside is a galvanized iron box.

ISO 834-1 [9] specifies that the weak spot of the test specimen should be right in the center, so that we make the joining seam in the middle as shown in Figure 3. Six standardized 60-minute heating tests were performed as shown in Table 1. Test 1 is a full-size 3 m × 3 m furnace standard test. The test specimen is the board material provided by the supplier, not purchased. The density of the fireproof cotton is 60 kg/m^3. Test 2 is in the 1.2 m × 1.2 m small high-temperature furnace. The calcium silicate board is purchased, with the density of the fireproof cotton at 60 kg/m^3. Test 3 is in the 1.2 m × 1.2 m small high-temperature furnace, with the socket and junction box embedded in the backside of the test specimen, and that the density of the fireproof cotton is 60 kg/m^3. Test 4 is in the 1.2 m × 1.2 m small high-temperature furnace, with the socket and junction box embedded in the backside of the test specimen, and the density of the fireproof cotton is 100 kg/m^3. Test 5 is in the 1.2 m × 1.2 m small high-temperature furnace, with the socket and junction box installed externally in the backside of the test specimen, and the density of the fireproof cotton is 60 kg/m^3. Test 6 is in the 1.2 m × 1.2 m small high-temperature furnace, with the socket and junction box embedded in the front of the test specimen facing the fire, and the density of the fireproof cotton is 60 kg/m^3. As there is no law enforcing the placement height of socket and junction box on the firewall, this study hopes to observe the most basic damage. The socket and junction box are placed 60 cm above

Table 1: Test specimen standard.

	Exposed surface	Unexposed surface	Density of the fireproof cotton	Size of the metal stud partition fireproof drywall height (m) × width (m)
Test 1	None	None	60 kg/m^3	3.0 m × 3.0 m
Test 2	None	None	60 kg/m^3	1.2 m × 1.2 m
Test 3	None	Embedded internal socket	60 kg/m^3	1.2 m × 1.2 m
Test 4	None	Embedded internal socket	100 kg/m^3	1.2 m × 1.2 m
Test 5	None	Installed external socket	60 kg/m^3	1.2 m × 1.2 m
Test 6	Embedded internal socket	None	60 kg/m^3	1.2 m × 1.2 m

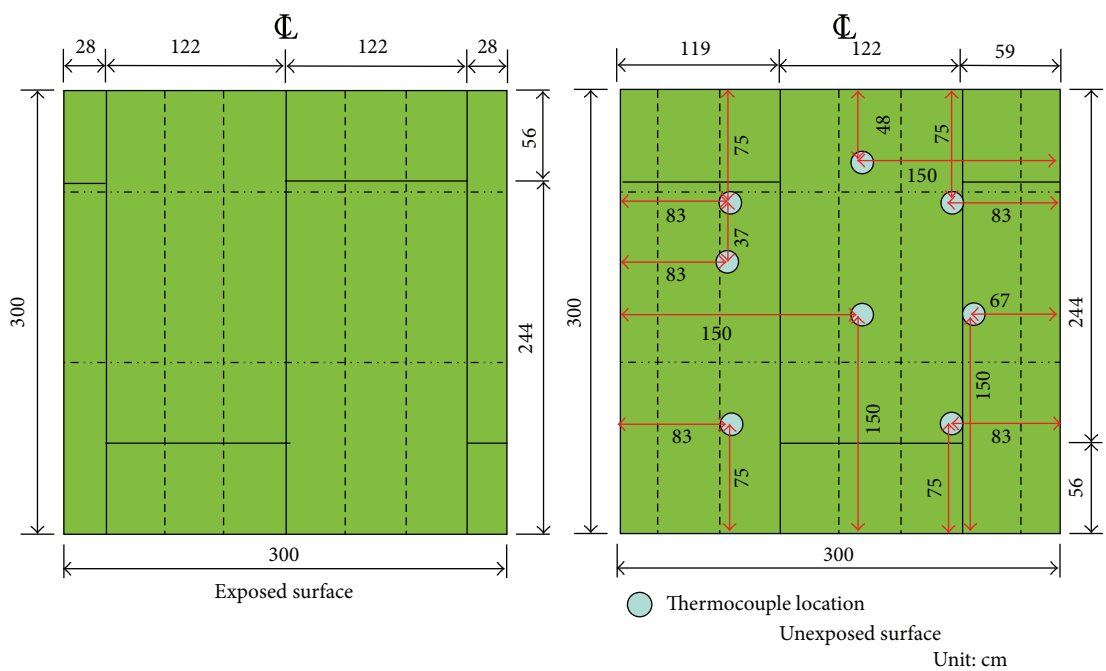


Figure 3: Test 1: the exposed surface and unexposed surface of specimen and geometry of the thermocouple (the arrangement of boards and measuring points of specimen).

the ground as the furnace pressure gets lower toward the bottom. Furnace pressure increases linearly with the height of the test specimen. However, the furnace pressure anywhere below 50 cm off the bottom is negative, so the socket and junction box are placed in the position with positive pressure.

2.3. Test Conditions. Test 1 follows the specifications of ISO 834-1 [9]. The fire area of the test specimen measures 3 m (height) × 3 m (width). The zero-pressure area is 50 cm high from the bottom of the furnace. According to ISO 834-1 [9], a linear pressure gradient exists over the height of furnace, and a mean value of 8 Pa per meter height may be assumed in assessing the furnace pressure condition. The furnace shall be operated such that a pressure of zero is established at a height of 50 cm above the notional floor level, so the furnace pressure at the uppermost brim of the specimen should not exceed 20 Pa. The standard heating curve of the test furnace is shown in (1), and the furnace pressure is recorded every 6 seconds by the computer. Consider

$$T = 20 + 345 \times \log_{10}(8t + 1), \quad (1)$$

where T: average standard furnace temperature (°C) and t: time (min).

From Tests 2 to 6, the heating temperature follows the standard heating curve in the ISO 834-1 [9]. The furnace pressure 50 cm high from the bottom is also set at zero. According to ISO 834-1 [9], every 1 meter in height adds 8 Pa, so the top of the test specimen has the furnace pressure at 5.6 Pa. The pressure by the junction box is about 0.8 Pa.

2.4. Test Measurements. In Test 1, 8 thermocouples are placed on the surface of the test specimen away from the fire as shown in Figure 3. All are done following the requirements of ISO 834-1 [9] to observe the temperature distribution of the surface away from the fire. Place the thermocouples on

the surface of the test specimen for Tests 2 to 6 as shown in Figure 4. Four are placed near the centers of the four edges of the specimen, one is located in the center of the wall, one is near the junction box panel, one is above the junction box panel, and the other is in the center of the rock wool. The temperature measurement is recorded by the computer every 6 seconds, and photos are taken during the experiment process.

3. Results and Discussion

3.1. Experiment Results. The time for Test 1 lasts 60 minutes. Seven minutes after the test started, the gap between top right corners of the unexposed surface away from the right frame starts showing a bit odorous white smoke. The temperature at all the detection points also shows a significant uptrend and keeps rising till the 11th minute when it shows a downtrend till the 27th minute and then goes up again all the way till the test ends. At the 27th minute, the highest temperature is at the upper left center at 73.9°C. At this point, a horizontal crack appears on the surface not facing the fire on the left panel and the center. At the 37th minute, the horizontal crack on the left keeps extending toward the center. At the 60th minute when the test ends, the highest temperature at the upper left center is 97.6°C and the highest average temperature is at 89.5°C (see Figure 5). It never goes over the requirements for ISO 834-1 [9] and therefore meets the demand of the fire ratings of 60 minutes.

Test 2 lasts 40.5 minutes. Six minutes into the test there seems to be an explosion. The temperature inside the rock wool center also shows a clear uptrend at this time, indicating that the calcium silicate board facing the fire is damaged due to the rising temperature. At the 8th minute, the cross-shaped gap not facing the fire starts generating smoke. At the 12th minute, the temperature inside the rock wool center continues going up, indicating that the rock wool continues touching the higher temperature. At the 39th minute, the temperature in the middle heats up to 180°C (see Figure 6). According to the fire ratings requirements in ISO 834-1 [9], the fire performance is determined to be damaged if the highest temperature by the back side is more than 180°C and therefore the test specimen does not meet the fire ratings requirements of 60 minutes.

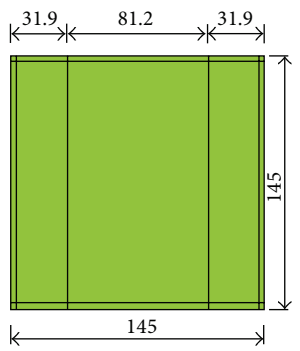
Test 3 lasts 40 minutes. Six minutes into the test there seems to be an explosion. The temperature inside the rock wool center also shows a clear uptrend, indicating that the calcium silicate board facing the fire is damaged due to the rising furnace temperature. At the 15th minute when the furnace temperature is at 750°C, the temperature at the detection point is already above 180°C and afterward it quickly approaches the furnace temperature, indicating that the rock wool center is totally on fire. The calcium silicate board facing the fire and part of the rock wool are also burned, resulting in the continuously higher temperature measured from the surface not facing the fire. At the 19th minute, the junction box panel has begun to melt and the heated gas begins to spring from the gap between the box and the board, leading to the significant increase in the temperature of the upper junction box measured by the thermocouple. At the 31st minute, the detection point goes over 180°C (see Figure 7), failing to meet the fire ratings requirements of ISO 834-1 [9].

Test 4 lasts 43.8 minutes. Six minutes after the test started there seems to be an explosion. The temperature inside the fireproof cotton center also shows a clear uptrend, indicating that the calcium silicate board facing the fire may have been damaged due to the rising furnace temperature. At the 17th minute, the temperature inside the rock wool center is already more than 180°C and at 20th minute it quickly approaches the furnace temperature, indicating that the rock wool center is totally on fire. The calcium silicate board facing the fire and part of the rock wool are also burned. At the 25th minute, the junction box panel has begun to melt. At the 34th minute, the temperature at the upper junction box goes over 180°C (see Figure 8), failing to meet the fire ratings requirements of ISO 834-1 [9].

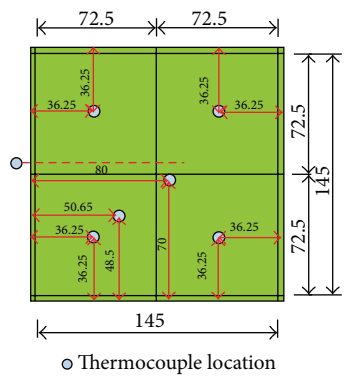
Test 5 lasts 39 minutes. Six minutes into the test there seems to be an explosion. The temperature inside the rock wool center also shows a clear uptrend after the 7th minute, indicating that the calcium silicate board facing the fire is damaged due to the rising temperature. After the 7th minute, the cross-shaped gap not facing the fire starts generating smoke. At the 25th minute, the junction box has begun to melt due to heat. At the 29th minute, the part connected to the screw is totally melted and then falls off. At this point, the temperature at the junction box is 53.9°C because the box has already fallen off and away from the furnace (see Figure 9). The temperature gradually goes up to 62.6°C and then gradually goes down. Although this seems to stay within the requirements of ISO 834-1 [9], the screws protrude and are exposed in the surface not facing the fire after the junction box is melted, so that the thermocouples are not too far away from the screws as they should. The temperature of the screws taken at the 31st minute is 236.9°C. At this point, all the detection points on the surface not facing the fire have not exceeded 180°C, but the exposed screws have indeed exceeded 180°C (see Figure 10) after the external junction box melts. At the 37th minute, the temperature in the middle center is more than 180°C, failing to meet the 60 minutes of fire ratings requirements of ISO 834-1 [9].

Test 6 lasts 37.6 minutes. Six minutes into the test there seems to be an explosion. The temperature inside the rock wool center also shows a clear uptrend, indicating that the calcium silicate board facing the fire is damaged due to the rising temperature. At the 9th minute, the cross-shaped gap not facing the fire starts generating smoke. At the 12th minute, the temperature inside the rock wool center continues going up, indicating that the rock wool continues touching higher temperature. At the 36.8th minute, the temperature in the middle heats up to 180°C (see Figure 11), failing to meet the 60 minutes of fire ratings requirements of ISO 834-1 [9].

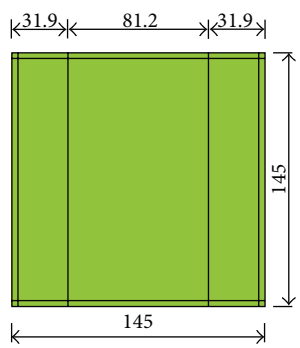
3.2. Comprehensive Discussion. The board used in Test 1 is provided by the supplier. These board materials are known as the laboratory grade. Although there are some cracks on the surface facing the fire during the experiment, the surface does not explode, and the integrity is good by visual inspection (see Figure 12). After testing it for 60 minutes,



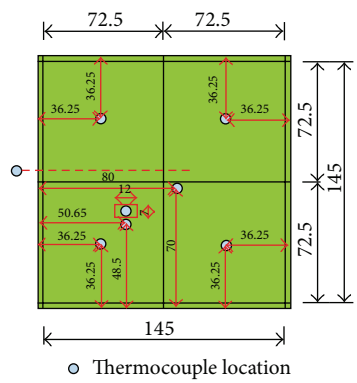
Test 2: the exposed surface of specimen
Unit: cm



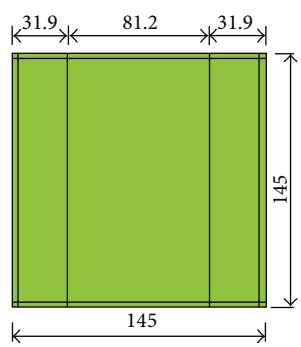
Test 2: the unexposed surface of specimen
Unit: cm



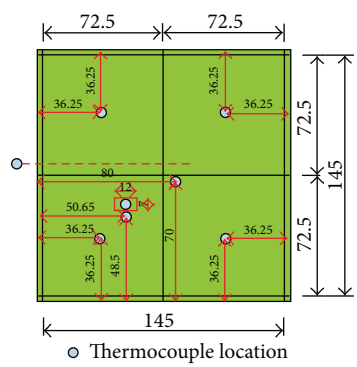
Test 3: the exposed surface of specimen
Unit: cm



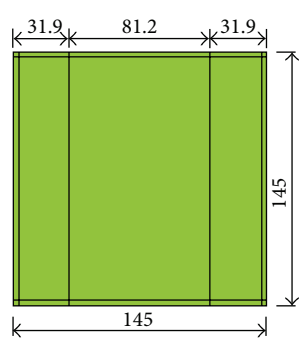
Test 3: the unexposed surface of specimen
Unit: cm



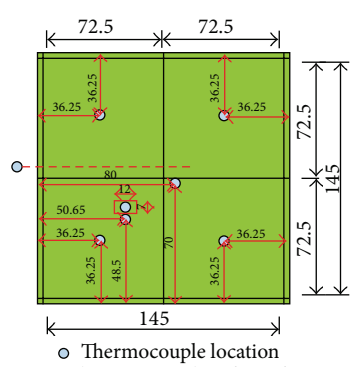
Test 4: the exposed surface of specimen
Unit: cm



Test 4: the unexposed surface of specimen
Unit: cm



Test 5: the exposed surface of specimen
Unit: cm



Test 5: the unexposed surface of specimen
Unit: cm

Figure 4: Continued.

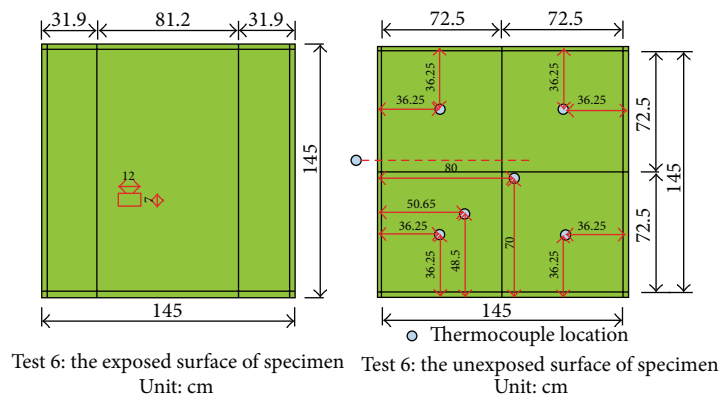


Figure 4: Test 2~Test 6: exposed surface and unexposed surface of specimen and geometry of the thermocouple (the arrangement of boards and measuring points of specimens for Test 2~Test 6).

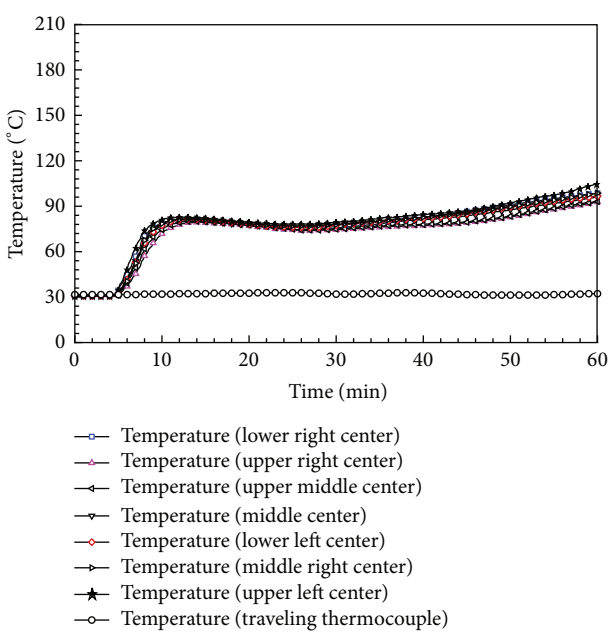


Figure 5: Time-temperature chart for the specimen in Test 1.

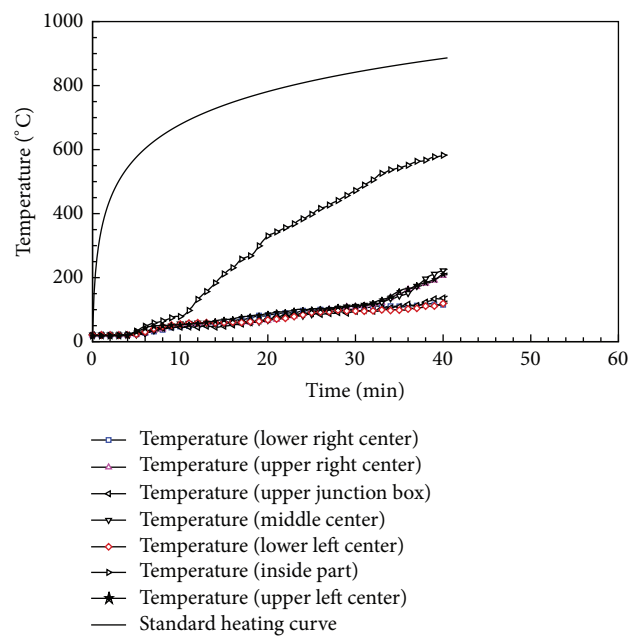


Figure 6: Time-temperature chart for the specimen in Test 2.

the fire resistance meets the requirements of ISO 834-1 [9] and the 60 min of fire ratings. From the 11th to the 27th minute, the temperature shows a steady decrease, indicating that there is some moisture inside the board and the rock wool to absorb the heat. The temperature at the surface on the backside then starts going up only after the material itself is totally dried. This often occurs in firewall tests when the material is more consistent. For example, the metal sandwich wall in Chuang et al. [1] shows such phenomenon. The metal surface does not get burned, and the insulation layer (rock wool) in between can consistently absorb heat for a while. Only when the heat reaches saturation will the temperature on the surface not facing the fire continue to go up. Therefore, when using material's thermal conductivity [3] and the numerical simulation of partitioning material combination [7, 8] to predict whether it meets certain fire ratings, it is based on the circumstance where the board surface facing the fire does not explode. However, looking at the other tests in this study and knowing that theory along may not be enough, the consistency of material properties also needs to be considered.

Tests 2 to 6 use the commercially available calcium silicate boards. These boards are claimed to have passed the fire ratings inspection, but every test finds that at the 6th minute the surface facing the fire explodes. Without the protection from the calcium silicate board, the fire in the furnace can directly damage the rock wool. The rock wool may have some strength and tension due to the glue added in during the production, but it starts to have pores after the glue is damaged [12]. Thus, the heat can penetrate the rock wool and directly reach the calcium silicate board not facing the fire. After being heated up, the rock wool can experience small

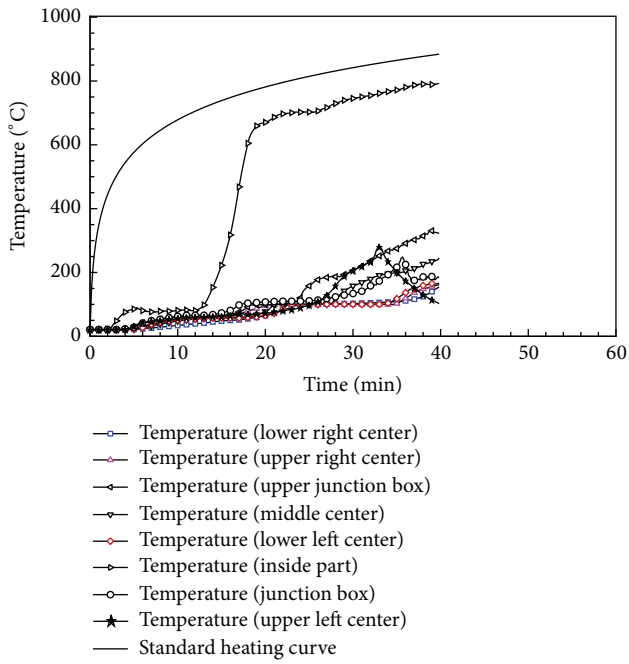


Figure 7: Time-temperature chart for the specimen in Test 3.

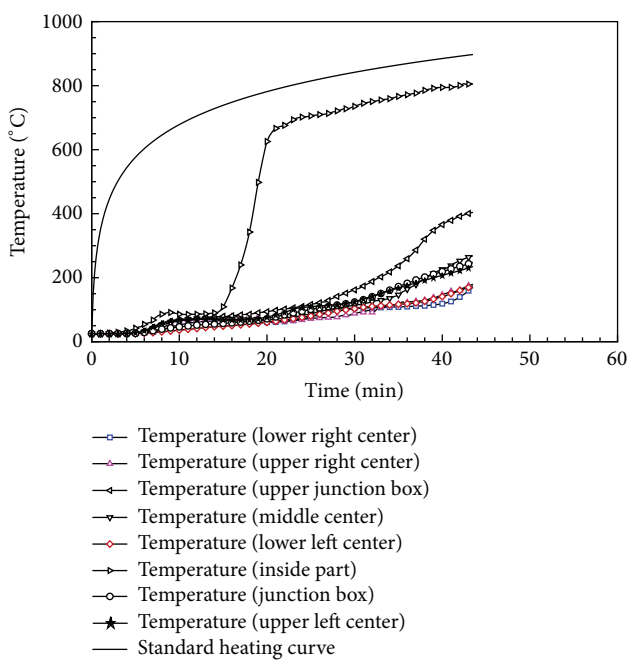


Figure 8: Time-temperature chart for the specimen in Test 4.

contraction in some parts (see Figure 13), and the fire can go through the unfilled part to reach the calcium silicate board not facing the fire, resulting in the test specimen not meeting the 60 minutes of fire ratings. The calcium silicate boards from Tests 2 to 6 all explode at the 6th minute. First, it means that these materials are of the same production process and formula. Second, it means that the temperature of the furnace rises at a normal rate, making the surface facing the fire in

Figure 9: The result of the unexposed surface of the sample in Test 5.

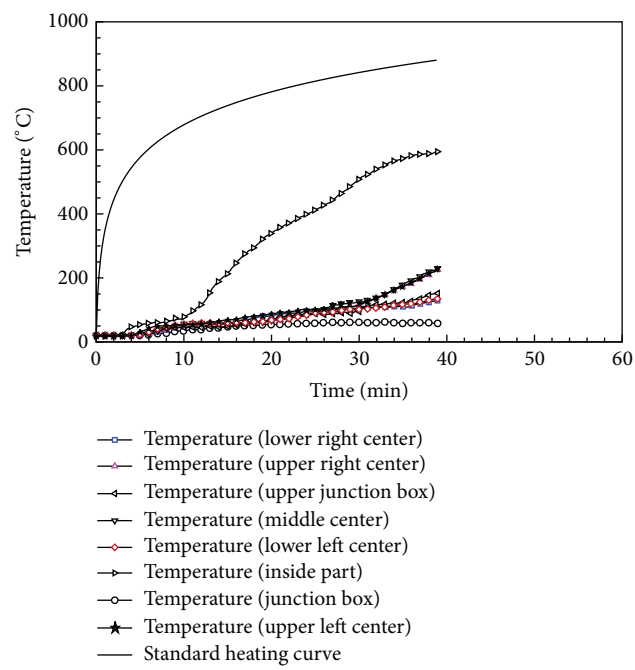


Figure 10: Time-temperature chart for the specimen in Test 5.

these 5 tests explode at the same time, which is beneficial to the subsequent discussion. From the results of Tests 2 to 6 we learn that when the test specimen loses the protection on the side facing the fire, the fire ratings are about 30 minutes at best. Although Tests 2 to 6 use smaller test pieces, the fire ratings are only 30 minutes, indicating that the bigger pieces may have the frame bent and the rock wool fallen off to have even shorter fire ratings. This can be reflected in reality where the rock wool not being filled in completely and boards used for remodeling not meeting the requirements can fail the fire ratings and compartment. This goes to show the importance of board quality directly related to the fire safety [2].

A calcium silicate board mainly consists of inorganic silicate and lime. Manufacturers all use different formula,

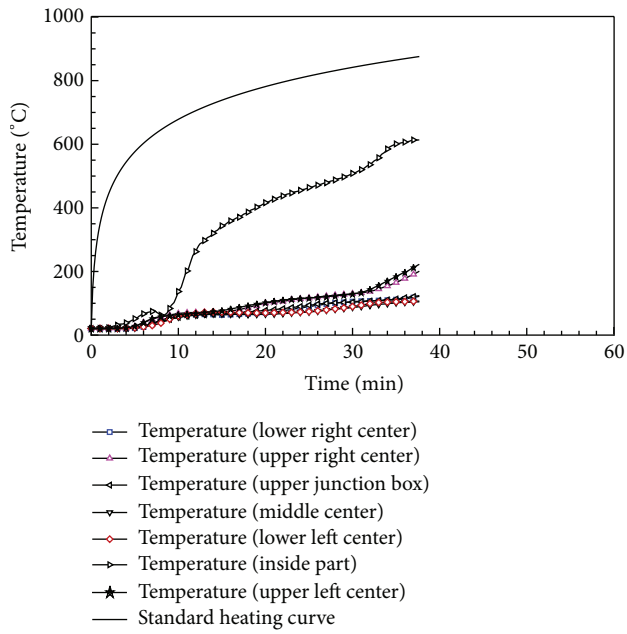


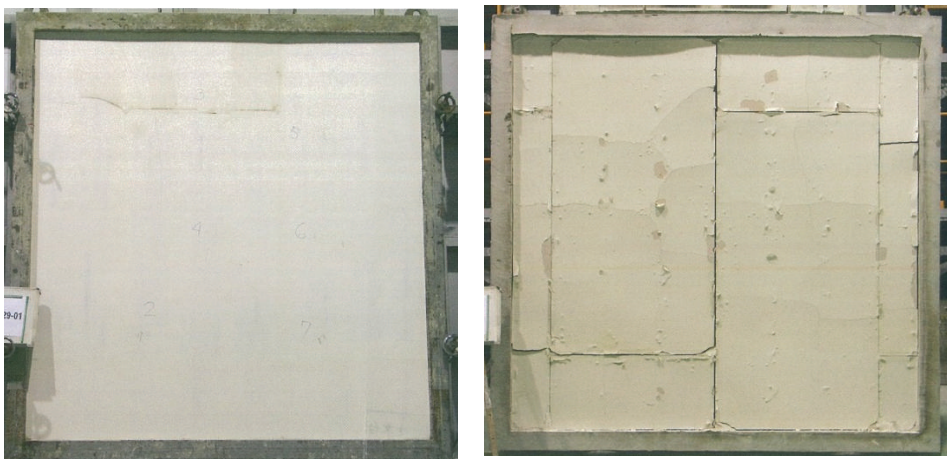
Figure 11: Time-temperature chart for the specimen in Test 6.

and some may mix in a certain proportion of coal ash to replace cement to reduce the production cost. Also, the board is made by high-pressure steam curing, so if the material ratio varies, the poor control of high-pressure steam environment may cause the strength variance of the calcium silicate boards, further impacting the heat resistance during the fire test. The impact can be observed from Test 1 and the other tests. Before taking the possible cut-corners of the suppliers or poor quality into consideration, this is just to show what the circumstances may be if the calcium silicate boards are in poor quality. This can really happen in Taiwan and other places, so extra attention is needed for this issue. The commercially available board materials need to put sample inspection or other controlling methods to prevent the inconsistency of quality between the ones in the market and the ones sent for tests.

This study is to understand the actual firefighting performance of the walls in daily life. For example, Tests 1 and 2 show that the products presumably made by the same company but in reality containing different materials can have almost 20 minutes of difference in their fire ratings. Tests 3 to 6 show the impact of socket and junction box on firewalls. Reviewing the firewall fire ratings tests conducted worldwide, there is not yet any test conducted with installed socket and junction box. Embedding socket and junction box into the drywalls requires breaking the wall body, and it is almost unavoidable to mount them on the wall. The installed amount may be more than just one and there are more varieties (such as for Internet or telephone lines), so these combined issues really need to be resolved. When an unqualified board is installed with socket and junction box, the actual fire performance can make people worry.

Comparing the results from Tests 3 and 4 with Test 2, we can see that the embedded junction box impacts significantly on the fire performance of the wall body. Fire performance is determined together by the calcium silicate boards on the two sides and the fireproof cotton in between. When the calcium silicate board on the side not facing the fire is damaged, a weak spot is produced. Hot air can come out from this spot. The metal junction box (fastened to the frame through screws and metal bars) is installed in after cutting a hole on the board not facing the fire, and there should be some gaps in between the metal box and the calcium silicate board. The frame can also deform after being heated, making the gap even bigger, and the surrounding edges and the place above can be affected by the heat. Although panels and sockets may be installed outside of the junction box, they are not noncombustible materials and therefore will still be melted by the hot air or burned (see Figures 14 and 15).

The junction box panel in Test 3 starts to smoke at the 8th minute, and it starts to melt at the 19th minute and totally melts to make the panel fall to the ground at the 27th minute, and at the 31st minute the surface temperature not facing the fire exceeds the limitation in ISO 834-1 [9]. The fire ratings of Test 2 manage to be maintained at 39 minutes, but Test 3 only has 31 minutes. The two have a difference about 8 minutes; so it shows that installing socket and junction box on the surface facing away from the fire can raise the regional temperature of the socket and junction box and the space above them. Test 4 attempts to increase the rock wool density (from 60 kg/m^3 to 100 kg/m^3) to improve the fire ratings while keeping other conditions constant. The junction box panel starts to smoke at the 10th minute, starts to melt at the 25th minute, and totally melts at the 32nd minute. Eventually at the 34th minute, the surface away from the fire exceeds the maximum temperature allowed in ISO 834-1 [9]. The areas with higher temperature in Tests 3 and 4 are all nearby the socket and junction box and the space above them, so it is somewhat risky when the calcium silicate board away from the fire is damaged. This also explains that adding the rock wool density may not greatly improve the fire ratings. This study attempts to add in even more rock wool density; however, in this type of drywall system, rock wool with even higher density cannot be added in anymore. As 5 cm in thickness and 100 kg/m^3 in density are considered to be the limits, there are no tests with even higher density of rock wool. Test 5 is to understand the impact of external box on the firewall. As the calcium silicate board away from the fire is penetrated by two screws, the overall temperature distribution is more even. However, the commercially available board materials have poor quality so they do not meet the 60 minutes of fire ratings requirements. At the 37th minute of the test, the side away from the fire has already exceeded the maximum temperature allowed in ISO 834-1 [9]. Overall, the fire performance is better than in Tests 3 and 4 but about the same with Test 2. Test 6 is for the box embedded on the side facing the fire of the calcium silicate board. As the commercially available boards have poor quality, the whole side explodes at the 6th minute; therefore, the impact of embedding the junction box into the fire side is not so obvious. The temperature distribution of the side not facing fire is similar to Tests 5 and 2, without sudden changes in extremely high temperature. As the board



Unexposed surface Exposed surface

Figure 12: The result of the specimen after 60 min standard fire test in Test 1.

Figure 13: The result of the exposed surface of the specimen in Test 5.

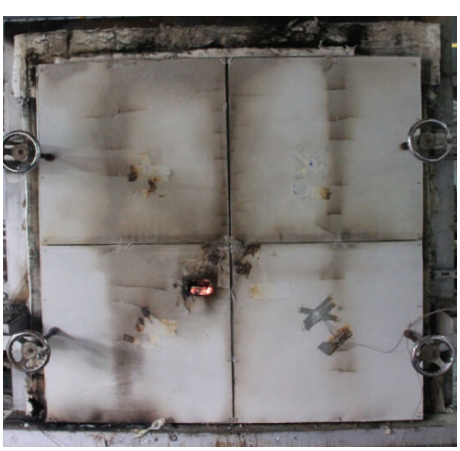


Figure 14: The result of the unexposed surface of the specimen after 40 min standard fire test in Test 3.

Figure 15: The result of the unexposed surface of the specimen after 43.8 min standard fire test in Test 4.

facing fire has poor quality, it can still explode even without the junction box embedded in. Therefore, to study how embedded junction box into the side facing the fire, it is necessary to select material with better quality in the future for further testing.

The above analysis revealed the following:

(1) When surfaces are flamed and fell, the flame retardant effectiveness is decreased for 20 mins (the flame retardant effectiveness is 40 mins) (without junction box inserted in).

(2) When surfaces with inserted junction box are flamed and fell, the flame retardant effectiveness is further decreased for 9 mins (the flame retardant effectiveness is 31 mins).

(3) When surfaces with inserted junction box are flamed and fell and the density of mineral wool is increased

from 60 kg/m^3 to 100 kg/m^3, the flame retardant effectiveness is increased for 3 mins at most (the flame retardant effectiveness is 34 mins).

(4) When junction box fixed on the surfaces is not affected by flame, the flame retardant effectiveness is 37 mins.

(5) When junction box inserted on the surfaces is not affected by flame and the flamed surfaces fall, the flame retardant effectiveness is approximately 36.8 mins.

Following the above analysis we can see that the commercially available boards have significantly weaker fire performance, and embedding junction box into the side away from the fire would not only reduce the fire ratings even more but also concentrate the weak spot in the upper junction box. Adding rock wool density may help improve the fire ratings but the effectiveness is not so significant. The junction box used in this study measures 101 × 55 mm and is close to the 100 × 57 mm specified in National Electrical Code [13]. Although the dimensions meet the requirements, there could be risks in the test. In reality, drywall may not have just one junction box. Boxes may be installed on the two sides of the wall. Therefore, the most risky circumstance is to have several boxes installed on the two sides of the wall and on the higher spots. There are no clear regulations provided around the world. In the facilities with higher fire ratings, the socket panels may be made of metal materials but the center sockets are still made of plastics to prevent conductivity. They can melt under high temperature and generate hot air; therefore, embedded socket and junction box into the firewall can significantly reduce the fire performance. Tests 2 to 6 only use the smaller furnace. Using the full-size 3 m × 3 m for test certainly makes the situation even more dangerous and the fire ratings even shorter. Therefore, only having good quality control of the boards and avoiding socket and junction box can effectively meet the real fire ratings of the firewall. This study uses the poor boards as the test specimen to inform building designers and government agencies to pay more attention to this issue.

4. Conclusions

Installing an embedded junction box to the drywall can pose a certain level of risk. A box measuring 101 × 55 mm can already damage the fire compartment. In reality, there are a lot of more boxes installed on the wall, so this requires more attention and improvement. The conclusions are as follows:

(1) When surfaces are flamed and fell, the flame retardant effectiveness is decreased for 20 mins (the flame retardant effectiveness is 40 mins) (without junction box inserted in).

(2) When surfaces with inserted junction box are flamed and fell, the flame retardant effectiveness is further decreased for 9 mins (the flame retardant effectiveness is 31 mins).

(3) When surfaces with inserted junction box are flamed and fell and the density of mineral wool is increased from 60 kg/m^3 to 100 kg/m^3, the flame retardant effectiveness is increased for 3 mins at most (the flame retardant effectiveness is 34 mins).

(4) When junction box fixed on the surfaces is not affected by flame, the flame retardant effectiveness is 37 mins.

(5) When junction box inserted on the surfaces is not affected by flame and the flamed surfaces fall, the flame retardant effectiveness is approximately 36.8 mins.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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