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Summary

The conventional loadbearing wall systems generally used in Korea are composed of concrete and brick. Which materials have many defaults like long-term construction period and cost increase. Recently in us, a rapid increase in the usage of cold-formed steel section in housing and commercial building construction can widely be seen.
The loadbearing wall assembly composed of light gauge-steel and gypsum board can preferably be applied to residential and commercial building of 5 stories or below. In order that light-gauge steel framing can be prevalently introduced in our domestic housing market, the wall assembly must have sufficient fire-resistant performance.
Fire-resistant tests were conducted for the load bearing wall specimens of 7.2m^2 in size and fire tests were carried out on load-bearing wall systems by method of loading condition and unloading condition in full size of specimens in order to certify the fire-resistance properties. Through test results, the temperature slopes of each material such as steel, insulation and gypsum board were obtained, along with the vertical and horizontal deflection of specimens.
key word : fire resistance, load-bearing wall, gypsum-board, light gauge steel

1. Introduction

Concrete and masonry have so far been prevalently used as a favorite material to build multi-family housings in Korea, due to its material availability, its abundance of labor skills in concrete and masonry construction, and also its high acknowledgement to common users. However, lack of labor skills due to avoidance of 3D jobs and degradation of construction quality are a few of the problems that can be seen in today's construction sites. As a result, an alternative method to the conventional housing construction method has been developed, where the main structural system is framed by galvanized light-gauge steel of 1㎜ or so thickness. The objective of this research is to provide technical data for multi-family housings using light-gauge steel through fire-resistant performance tests on load-bearing wall specimens.

Korean Code in relation to fire-resistance is specified in Korean Building Code Article 56 and its subordinate article 560 where it is required for special architectural buildings in which people dwell or pass by and has high potential for fire development to have fire-resistant structure for its main structural frames. Fire-resistance performance criteria can be found in article 560 of the code issued by the Ministry of Construction and Transportation. (see Table-1)

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Table 1. Standard of fire resistance (unit : minute)

elements \ stroies		within 5 stories from top story	6~14 stories below from top story	15 stories below from top story
unload bearing wall	combustible area	60	60	60
	non-combustible area	30	30	30
load bearing wall, floor		60	120	120
column, beam		60	120	180
roof		30	30	30

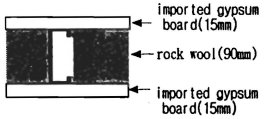
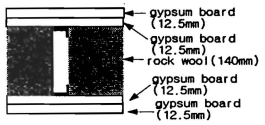
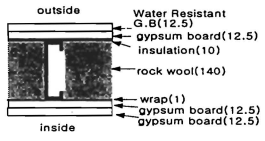
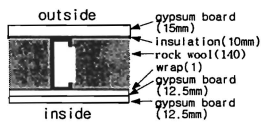
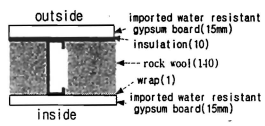
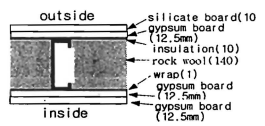
2. Fire-resistance tests on load-bearing wall specimens

It is important to note that load-bearing walls composed of steel studs and tracks have to meet fire-resistance performance criteria in order to protect human life and property in case of fire. This research therefore focuses on designing and assembling various wall specimens used for the building of multi-family housings with appropriate consideration to the wall's performance requirements and material property, and then carry out 1-hour fire-resistance tests to prove its fire-resistance performance.

1) Test specimen

Wall specimens applied to multi-family housings are designed in consideration with the criteria for fire-resistance, sound insulation and thermal insulation, specified in the Building Code. Exterior, interior and unit-separating walls are developed in this process, and details for these wall specimens can be found in Table-2. According to fire-resistance test results on load-bearing walls of Steel Model House in 1996, walls composed of one layer 15㎜ type-X gypsum board did not meet one-hour fire-resistance performance, while walls with 2 layers of 12.5㎜ type-X gypsum board have shown positive results in meeting one hour fire-resistance performance. Accordingly, wall specimens using 2-ply type-X domestic gypsum board of 12.5 ㎜ thickness are mainly observed in this test. Furthermore, since load-bearing steel stud walls with one layer of 15㎜ type-X gypsum board on each side satisfies one-hour fire-resistance performance in U.S., tests are carried out to such wall specimens using one layer of 15㎜ foreign type-X gypsum board to prove its fire-resistance performance tests. Gypsum boards here used are waterproof and type-X gypsum boards specified in Korean Standard 3504, studs and tracks of type SGC 41 with allowable stress of 3,000kgf/㎠(42,000lb/inch^2)are used.

Table 2. Specimens of fire resistance

sorts	components	requisite time	numbers	size of structural element and insulation material	conditions of loading
interior wall		60min	1EA	studs:90×40×12×1 (o.c:450mm(17.7inch))	unloading
separation wall		〃	2EA	studs:140×40×12×1 (o.c:450mm)	unloading
exterior wall-1		〃	3EA	studs:140×40×12×1 (o.c:450mm), rock wool:60k	outside:2 (loading, unloading) inside:1 (loading)
exterior wall-2		〃	2EA	studs:140×40×12×1 (o.c:450mm) rock wool:60k	unloading
exterior wall-3		〃	2EA	studs:140×40×12×1 (o.c:450mm) rock wool:60k	loading
exterior wall-4		〃	2EA	studs:140×40×12×1 (o.c:450mm) rock wool:60k	unloading

2) Fabrication of wall specimens

Test specimens were assembled at FILK(Fire Insurers Laboratories of Korea). Structural light-gauge steel are roll-formed in accordance with KS D3854 from steel sheet(SGC 41) of POSCO, and as to type-X gypsum boards, products of a Korean firm (A) and a foreign firm (D) are used. Figure-1 shows detail of specimen and fixing method. The most important part during the fabrication of wall specimens is its framing method ; vertical studs, which transfer the upper load, should be tightly and exactly inserted to top and bottom tracks. Panhead screws are used to fasten structural members, one screw at each track-stud connection and also at each strap-stud joint. Another important factor to be considered is that screws used

for gypsum board should be exactly fastened to wall studs ; screws that were not fastened to studs during fabrication were re-screwed to studs. Each gypsum board is installed vertically parallel to studs, and one layer of wallboard covered the full height of the wall, from bottom track to top track. Buglehead screws are used to fasten the gypsum board to studs, with lengths of 25㎜ for one layer and 38㎜ for two layers. Screws are fastened at 30㎝ on center to vertical studs and horizontal tracks, and the distance from the end of gypsum board to screw center is within 10㎜ at each joining part.

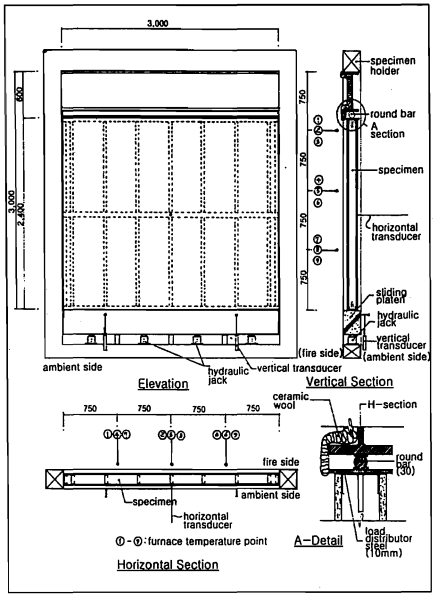


Fig 1. Detail of specimen & fixing method

During fire tests with loading, reaction force is applied to top and bottom track area ; therefore the top and bottom part of the gypsum board is cut short 5㎜ compared to vertical studs to avoid any load bearing on the wallboard.

3) Fixing of specimen with holder

The wall specimen used for the fire-resistance tests is prefabricated outside the holder and later moved then mounted to it, unlike cases in U.S., New Zealand and Canada where test specimens are assembled within the test holder. The fixing is achieved by tying up the specimen to the connection bar through a 20㎜ diameter hole located approximately 50㎝ from the end of the wall's bottom track. The upper part is fixed through 3 similar holes. To obtain an uniform applied load on the specimen a steel plate of 10 ㎜ thickness is used on the upper part of the top track. And a round bar of 30㎜ diameter is used to simulate the actual behaviour of the wall members. This is to avoid the development of moment when axial load is transferred. The boundary conditions differ somewhat from the past cases found in U.S.[1),2)], New Zealand[3)], and Canada[4)]. These countries use the fixing method where screws are fastened at 30㎝ on center ; the wall specimens are in a fixed condition and therefore have greater load-bearing capacity than in a hinged condition. Also in a hinged condition, it is harder to transfer exactly the load to the center of members, and there is possibility that it shows a state different from the actual behaviour.

4) Sensor attachment

It is important to verify the actual behavior during the fire testing since it is the first time in Korea that fire tests with loading on load-bearing steel stud walls are undertaken. For that purpose, Cromel-anamel(CA) thermocouples are set on the steel stud and also on both the fire-heated and ambient side of the gypsum wallboard during wall assembly. To check the

heat flow on the steel stud, 3 thermocouples are installed vertically on the center of the web of the stud located in the middle of the wall panel, and 2 horizontally, for a total of 5 thermocouples per each wall panel. And thermocouples are also set at each layer of the gypsum board to examine the temperature flow of the finishing materials(see Figure-1). The 5 thermocouples set on the ambient side of the wall specimen are to measure the insulation capacity, which is one of the elements to verify whether the fire tests are suitable or not. Since KS 2257 (Load-bearing test method for architectural structure) specifies that load-bearing elements of the wall should sustain structural load-bearing, it should be measured quantitatively. Therefore contraction height of 100㎝ for members in axial direction, in accordance with the ISO code[5], is utilized for the fire test with loading.

5) Test

For the fire-test with loading, the first step is to apply a certain load on the load-bearing wall specimen. In this project, fire testing started after applying approximately 20 minutes of load on the wall specimen when it became stable. Applied load for this test is obtained through the load defined in KS F 2257[6], which value is 1.2 times greater than the allowable long time stress intensity. The applied loads are seen in Table-3. Actual loading is then applied with the weight of the specimen holder and the specimen itself included.

Table 3. Amounts of loading

types	web size of stud(mm)	loading per 1 stud(kg)	numbers of studs	amounts of loading(kg)	imposing loading(kg)
interior wall	90(3.5inch)	1,260(2,772lb)	9	11,340(24,948lb)	13,608(29,938lb)
exterior wall	140(5.5inch)	1,610(3,542lb)	9	14,490(31,878lb)	17,388(38,254lb)

6) Test result

(1) Exterior wall-1

The wall specimen is assembled with gypsum boards produced by Korean maker (A). Since exterior walls must be safe from fire from within and also from outside the room, fire-tests were executed for both the inner and outer side of the wall specimen. Test results show that buckling was seen after 27 minutes in case of heating of the exterior side and 39 minutes in case of fire-heating on the inner side of the wall. Test results are quite different from the results seen in tests of January 1997. That is, early tests indicated that crack took place after 50 minutes of fire-heating on wall specimens using type-X gypsum boards produced by Korean maker (B), but contrary to expectation, tests carried out in this project showed early signs of crack.

Non-loading fire tests on wall specimens with newly produced ('97. 6.) type-X gypsum boards from maker (B) resulted in the failure of one-hour fire-resistance performance because

the temperature of the steel stud exceeded 500℃(932F) after 44 minutes, which temperature is the maximum level for the steel stud to meet in a load-bearing wall assembly. This shows the different gypsum board's fire-resisting performance according to its production time. Test results can be summarized in Table-4.

Table 4 Testing results of exterior wall -1

fire side	test date	fire resistance(min)	special observation	remarks
outside	'97.6.2	27	21mins : falling off gypsum board 28mins : beginning of deformation	loading, A's product
inner side	'97.6.2	39	18mins : falling off gypsum board 40mins : take place rapid deformation	loading, A's product
outside	'97.6.27	43	44mins : excess high temperature 45mins : excess mean temperature of steel	unloading, B's product

Actual test circumstances can be seen in Figure 2 & 3, and temperatures measured for the steel stud in wall specimens and gypsum board are showed in Figure 4 & 5.

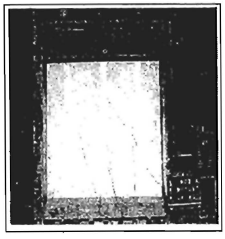


Fig 2 Specimen before test(ambient side, B's product)

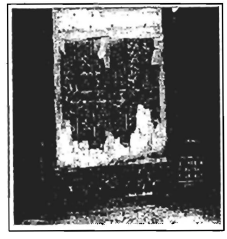


Fig 3 Fire side of specimen after test(B's product)

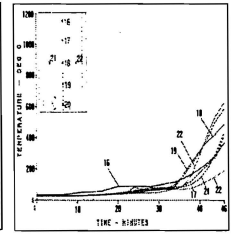


Fig 4 Temperature distribution of steel stud(B's product)

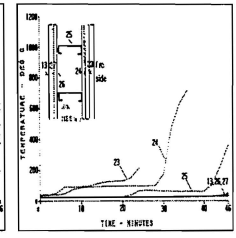


Fig 5 Temperature distribution of layer of shielding (B's product)

(2) Unit-separating walls

Non-loading fire tests are executed on unit-separating walls composed of 2-ply 12.5㎜ gypsum board, product of Korean company (A) ; that is, fire-resistance performance is checked solely by measuring the temperature of the steel, without applying any load on the specimen. Tests resulted in the failure of one-hour fire-resistance performance with the steel stud exceeding the maximum temperature of 500℃(932F) after 42 minutes. Following remarks can be noted as a result of the tests applied on exterior wall-1 and unit-separating wall : fire-resistance performance of gypsum boards differ from the ones produced by company (B), and therefore the wallboards used in the test specimens were changed to products of company (B). Also, even if the boards are produced by one single company, the products show variances in their performance according to its production date, as noted by the test result of 49 minutes fire-resistance performance of gypsum boards produced by company (B) but at a later date ('97.6). Test results are shown in Table-5.

Table 5. Testing results of separation wall

fire side	test date	fire resistance (min)	special observation	remarks
outside	'97.6.4	41	25mins : falling off one layer of gypsum board (fire side) 42mins : excess high temperature 49mins : excess mean temperature of steel	unloading, A's product
outside	'97.6.10	48	20mins : falling off one layer of gypsum board 49mins : excess high temperature	unloading,B's product('97.6)

Stud temperature inside the wall and temperature distribution of each gypsum board according to its layers can be seen in Figure 6~9.

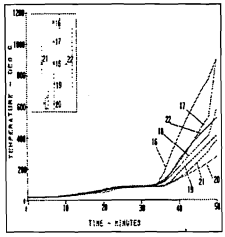


Fig 6 Temperature distribution of steel stud(A's product)

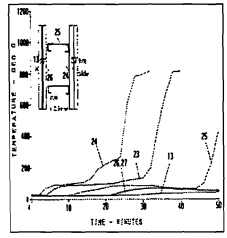


Fig 7 Temperature distribution of shielding (A's product)

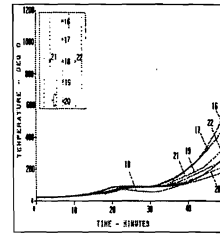


Fig 8 Temperature distribution of steel stud(B's product)

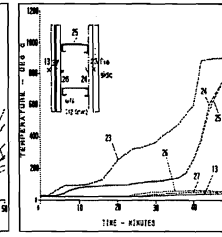


Fig 9 Temperature distribution of layer of shielding (B's product)

(3) Exterior wall-4

Which endured the requisite time described in the fire regulation. Gypsum board which is used on the inner side is residue of the fire test of Jan 1997. We considered that the quality of gypsum board affected on the performance of load-bearing wall seriously. In the following test, we conducted fire test on the outside of wall without loading. The temperature of steel stud exceeded 500℃(932F) at the time of 51mins, which means that if there were some lack of fire protection performance on the fire side's materials; it is very difficult for load-bearing wall to endure the required time of one hour. Table 6 shows the results.

Table 6. Testing results of exterior wall-4

fire side	test date	fire resistance	special observation	remarks
outside	'97.6.27	49mins	45mins : falling off one layer of gypsum board (fire side) 51mins : excess high temperature 54mins : excess mean temperature of steel	unloading, B's product('97.6)
inside	'97.6.5	67mins	54mins : falling off one layer of gypsum board(fire side) 68mins : excess high temperature 69mins : excess mean temperature of steel	unloading, B's product('97.1)

Figure 10~13 shows stud temperature inside the wall and temperature distribution of each gypsum board according to its layers.

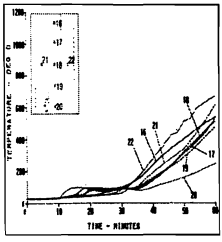


Fig 10 Temperature distribution of steel stud(outside is fire side)

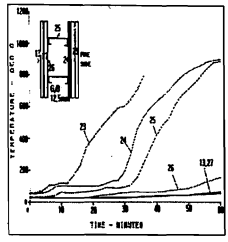


Fig 11 Temperature distribution of layer of shielding(outside is fire side)

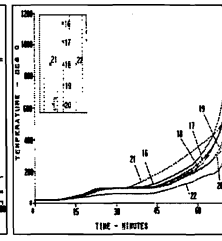


Fig 12 Temperature distribution of steel stud(inside is fire side)

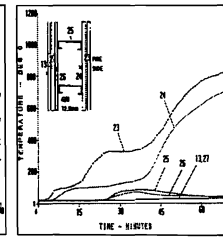


Fig 13 Temperature distribution of shielding(inside is fire side)

(4) Exterior wall-2

Fire side is on the inside of wall with nonloading. It certified the required time. On the contrary, fire test on the outside of wall the temperature of steel stud exceeded the high temperature on steel member after 30mins. According this result we thought that it was very difficult for load-bearing wall to satisfied with one hour by one layer of each side with gypsum board 15mm(5/8') in Korea. Testing results are in table 7.

Table 7 Testing results of exterior wall-2

fire side	test date	fire resistance (min)	special observation	remarks
outside	'97.6.11	29	22mins : falling off one layer of gypsum board(fire side) 30mins : excess high temperature 32mins : excess mean temperature of steel	unloading, B's product ('97.6)
inner side	'97.6.9	73	61mins : falling off one layer of gypsum board(fire side) 74mins : excess high temperature 75mins : excess mean temperature of steel	unloading, B's product ('97.1)

Stud temperature inside the wall and temperature distribution of each gypsum board according to its layers can be seen in Figure 14~17.

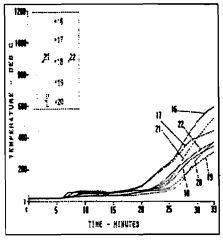


Fig 14 Temperature distribution of steel stud(outside is fire side)

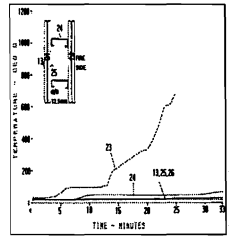


Fig 15 Temperature distribution of shielding (outside is fire side)

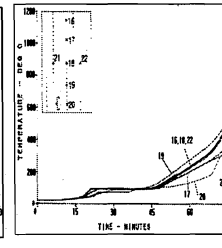


Fig 16 Temperature distribution of steel stud(inside is fire side)

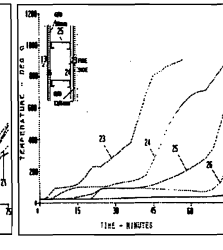


Fig 17 Temperature distribution of shielding (inside is fire side)

(5) Interior wall

It was common and popular for north america and european countries to satisfy one hour using 15mm(5/8inch) fire rating gypsum board. There are many types relating to one hour fire resistance by gypsum board, for examples UL Directory[7] published from Underwriter's Laboratory Inc. and each catalogues[8] come from gypsum companies. There will be some differences when we are going to adapt the exact type of load-bearing wall structures described the above references. Because of different conditions such as amounts of imposed load, method of making specimen, curing, fire testing method and laboratories facilities, etc, between our country and foreign countries. In order to have certified fire resistant

performance of load-bearing wall with foreign gypsum board, wall specimen were attached with gypsum board on each side with thickness of 15mm(5/8inch). The gypsum board came from Canada and its fire rating certified by ULC. Results of fire testing with the method of our country and nonload show that steel stud temperature exceeded the steel's mean temperature of 400℃(752F) about 39mins. With this result we concluded that it is very difficult to retain one hour fire endurance time with one layer of gypsum board 15mm on each side(5/8inch). Table 8 shows the fire test results.

Table 8. Testing results of interior wall

fire side	test date	fire resistance (min)	special observation	remarks
outside & inside	'97.6.20	38	39mins : excess mean temperature of steel 40mins : excess high temperature 46mins : falling off one layer of gypsum board(fire side)	unloading, imported product

Temperature of steel stud and each layer of gypsum board is expressed in figure 18~19.

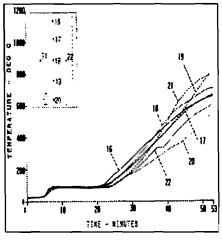


Fig 18 Temperature distribution of steel stud

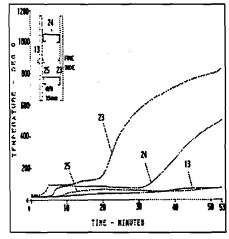


Fig 19 Temperature distribution of shielding

(6) Exterior-3

Fire test was done with loading. Axial deformation exceeded its limit at 25mins and 31mins, respectively.

According to results of exterior wall-3 and interior wall composed of one layer of 15mm(5/8inch) gypsum board, we concluded that it is difficult to attain one hour fire resistance for load-bearing wall made of gypsum board with existing fire test method in Korea. Test results are expressed in table 9 and temperature gradients of steel stud and each layer of gypsum board are expressed in figure 20 ~ 23.

Table 9 Testing results of outside wall-3

fire side	test date	fire resistance(min)	special observation	remarks
outside	'97.6.25	24	25mins : falling off one layer of gypsum board(fire side) & occurring rapid deformation	loading imported product
inside	'97.6.24	30	30mins : falling off one layer of gypsum board(fire side) 31mins : occurring rapid deformation	loading imported product

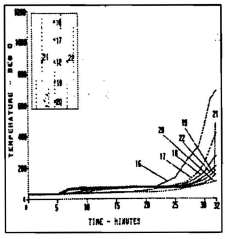


Fig 20 Temperature distribution of steel stud (outside is fire side)

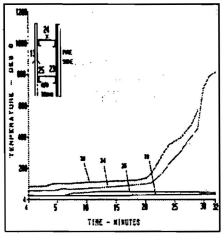


Fig 21 Temperature distribution of shielding (outside is fire side)

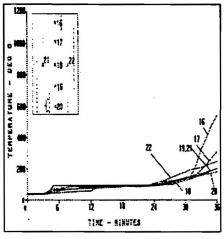


Fig 22 Temperature distribution of steel stud (inside is fire side)

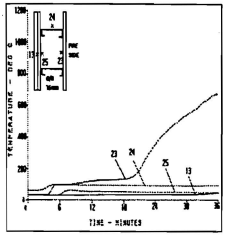


Fig 23 Temperature distribution of shielding (inside is fire side)

2) Test of fire protective performance of gypsum board

According to the above various fire tests on load bearing wall, the qualities of gypsum board are different by the production time and manufactures. So we conducted the fire protective performance of gypsum board. We concluded that fire protective performance of gypsum board is much related to fire resistance of load-bearing wall made by steel stud and gypsum board. Our country defines the test method of fire protective performance of gypsum board(Type X) in KS F 3504(Gypsum board). According to korean standard, gypsum board with 12.5mm(1/2inch) and 15mm(5/8inch) thickness must endure at least 8mins and 10mins respectively. Fire protection tests were accomplished at FILK and measured the split time of specimen. Figure 24 shows tool and test specimen used in the experiment. Specimens were made by gypsum board(Type X) and water resistant gypsum already applied to the specimen for fire resistant test of load bearing wall. Table 10 shows the sorts of specimen and test results.

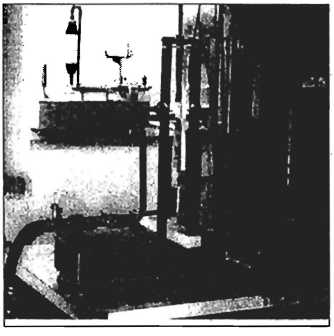


Fig 24 Fire endurance test of gypsum board

Table 10. Testing results of fire property on gypsum board

sorts		KS standard (mins)	results				date of production
			endurance time			state	
A's product	G.B 15mm (5/8inch)	10	5mins58 seconds	8mins 46seconds	7mins 37seconds	×	'97.6
	G.B 12mm (1/2")	8	5mins25 seconds	5mins 20seconds	5mins 04seconds	×	
	water resistance G.B 15mm	-	3mins59 seconds	9mins 07seconds	60mins	-	
B's product	G.B 15mm	10	240mins	270mins	280mins	○	'97.1
	G.B 12mm	8	160mins	77mins	170mins	○	
	G.B 15mm	10	47mins 08seconds	12mins 54seconds	66mins 05seconds	○	'97.6.7
	G.B 12mm	8	7mins 06seconds	11mins 58seconds	9mins 52seconds	×	
	water resistance G.B 12mm	-	7mins 04seconds	7mins 46seconds	6mins 12seconds	-	
C's product	G.B 15mm	10	5mins 10seconds	6mins 7seconds	6mins 18seconds	×	'97.6.12
	G.B 12mm	8	3mins 34seconds	4mins 4seconds	4mins 38seconds	×	

In order to compare the performance of gypsum board, we conducted test with a Canadian specimen of gypsum board, the results of tests are expressed in table 11.

Table 11. Testing results of fire property on gypsum board imported canada

sort	KS standard(min)	result				date of testing
		endurance time			statue	
G.B 15mm	10	79mins30seconds	29mins13seconds	113mins34seconds	○	'97.6

Though test results of fire protective performance of various gypsum board, it can be learned that there were many variations according to thickness, manufacturing company, time etc.

3) Fire resistant test by the newly developed gypsum board

Domestic gypsum board manufacturing companies(3) decided to make gypsum board better than before. So they made the new gypsum board by adding some more fire protective materials. The newly developed products are two types ; gypsum board(Type X) and water resistant gypsum board(Type X). Each company made 2 sorts of specimen with the newly developed two types of gypsum board. The structural members and the imposed load are expressed in table 12 and 13. Fire tests were conducted by loading and the components of specimen and results are expressed in table 14. In test, we realized that there were some increase of retardation to the extent of 25~30 mins on the first layer of gypsum board falling time in fire side and on the axial deformation than the above fire testing. All of specimens satisfied the requisite time. Results instructed that the quality of gypsum board on fire protective are very important for load bearing wall consisted of steel stud and gypsum board to resist fire.

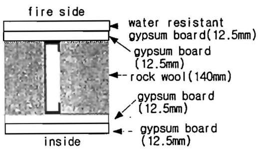
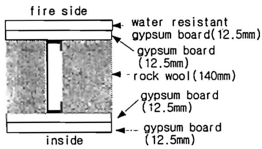
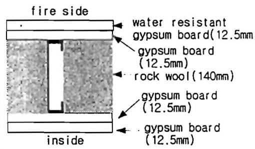
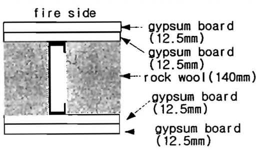
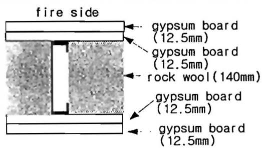
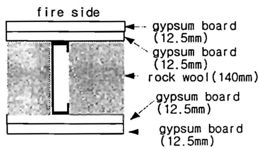
Table 12. Major structural elements

member	dimension(am)	tensile strength
steel stud	140×40×12×1.4(5.5×1.57×0.5inch)	4,100kgf/cm^2(57,400psi)
steel track	140×40×1.4(5.5×1.57inch)	〃
steel strap	50×1.4(2inch)	〃

Table 13. Condition of loading

name	web size(mm)	testing load per stud(kg)	imposed load(kg)
exterior wall	140(5.5inch)	2,410(5,302lb)	2,892(6,363lb)

Table 14. Results of Fire resistant testing on newly developed gypsum board

sorts	A's product	B's product	C's product
section			
result	good for 1 hour	good for 1 hour	good for 1 hour
section			
result	good for 1 hour	good for 1 hour	good for 1 hour

3. Conclusions

To evaluate fire resistant performance load bearing walls such as interior, exterior and unit separation wall made by steel stud with about 1mm(at least 20gauge) thickness and with one or two layer of 12.5mm(1/2inch), 15mm(5/8inch) thickness gypsum board on each side, we conducted full-scale fire tests and obtained the following results.

1) In order to retain the structural integrity, the fire protective performance of gypsum board is very important Fire protective performance of gypsum board defined at KS F 3504 at present is not enough on requite fire endurance time for load bearing wall made by steel stud and gypsum board, so it will be necessary to improve the quality and enforce the standard. Continuous research will be necessary also in order to evaluate the relation between fire protective performance and fire resistance of load bearing wall more quantitatively.

2) It is possible to certify one hour fire resistance for load bearing wall by attaching 2 layers of gypsum board with 12.5mm (5/8inch) on each side and filled with rock wool in wall cavity.

3) On the contrary USA or other countries, one layer of 12.5mm(5/8inch) gypsum board on one side is impossible to endure one hour for load bearing wall by fire method of the

domestic fire resistance test with load and without loading. There will be many variances between USA and Korea. The major inferential variances may be the testing method related to fixing conditions between specimen and specimen holder, boundary condition and amount of imposed load. It will be more useful and reliable on the structural safety of load bearing wall made by steel stud and gypsum board in fire to evaluate fire resistance test by ASTM E 119 and KS F 2257 at the same laboratory and by their testing method.

References

1) ASTM E119, Standard Test Methods for Fire Tests of Building Construction and Materials. 1995
2) ASTM E72, Standard Test Methods of Conducting Strength Tests of Panels for Building Construction, 1995
3) J.T.Gerlich, P.C.R.Collier, A.H.Buchanan, Design of Light Steel-Framed Walls for Fire Resistance, Fire and Materials Vol 96. 1995, pp 79~96.
4) L. R. Richardson and M. Batista, Revisiting the Component Additive Method for Light-Framed Walls Protected by Gypsum Board, Fire and Materials Vol.21, 1997, pp 107~114.
5) ISO 834, Fire-Resistance Tests Elements of Building Construction,1975
6) KS F 2257. Method of fire resistance test for structural parts of buildings, 1993
7) Underwriters Laboratories Inc, Fire Resistance Directory, 1996
8) Gypsum Association, Fire Resistance Design Manual Eleventh Edition, 1984.