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Improvement of Fire Resistance for Timber Framed Walls by Reinforcement of Heavy Timber Frame

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ABSTRACT

Fire resistance of new hybrid timber framed wall systems was evaluated in this study. These wall systems are composed of two major structural parts. One part is a heavy timber frame part designed to take charge of whole vertical load using heavy timber post and beam, and the other is an infill wall structure, designed to take charge of whole horizontal load and to provide an established level of fire resistance. A basic concept of this hybrid wall is adopted from a typical furniture structure with frame. A timber post and beam frame is constructed with Japanese Larch solid timber post(180mm by 180mm) and beam(180mm by 240mm). As infill wall systems, two types of walls are applied. One is a typical light timber framed wall with solid blocking and another is a structural insulated panel wall, in which polystyrene insulation is filled between two structural panels to make single structure. For all tested walls, two layers of 12.5mm thick type-X gypsum boards are used on fire exposed side. Prior to tests for hybrid walls, only infill walls are tested without heavy timber frame. All fire resistance tests are carried out in accordance with KS F 2257, and temperatures on several points within wall structure and unexposed wall surface are measured during fire tests. It is considered that the reinforcement of heavy timber frame is significantly efficient for improving the fire resistance of timber framed walls.

***Key words*:** fire resistance, hybrid wall, furniture structure, heavy timber frame, infill wall.

요 약

본 연구에서는 두 개의 주요 구조부분으로 구성된 새로운 하이브리드 목조 벽체의 내화성능을 평가하였다. 수직하중을 전적으로 담당하는 기둥-보 형태의 기본 골조에 두 가지 형태의 벽체가 채워졌을 때 이 전체를 내력 벽체로 가정하고 그 내화성능을 평가하고자 하였다. 하이브리드 벽체의 기본 개념은 뼈대를 갖는 전형적인 가구의 구조로부터 채용되었다. 기본이 되는 기둥-보 골조는 국산 낙엽송 소재로서, 기둥은 180mm X 180mm, 보는 180mm X 240mm 단면의 부재가 사용되었다. 기둥-보 골조의 내부에 채워지는 벽체는 두 종류로서, 하나는 블러킹이 사용된 일반적인 경골목구조 벽체이고, 또 하나는 구조용 패널 사이에 스티로폼 단열재가 채워져 일체화된 구조를 이루는 구조용 단열 패널 벽체이다. 내화성능 시험에 사용된 모든 벽체는 2 겹의 방화석고보드를 화염 노출면에 부착하였다. 모든 벽체는 우선 기둥-보 골조가 없는 상태에서 표준화염 조건에서 내화성능 시험을 수행하였고 다시 기둥-보 골조와 결합된 형태로 내화성능 시험을 수행하였다. 시험에 적용된 화염조건은 KS F 2257 의

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조건을 적용하였고 시험 중 구조체 내부 각 부위의 온도변화도 측정하였다. 본 연구를 통해 기둥-보 골조의 보강이 목구조 벽체의 내화성능 향상에 상당히 기여하는 것으로 확인되었다.

1. INTRODUCTION

Wall structures in timber buildings, generally constructed in Korea, are light timber framed walls, in which studs placed at regular intervals and structural panels attached to these studs are designed to resist the applied vertical and horizontal loads. In order to endow a certain level of fire resistance to these walls, additional panel type materials, such as gypsum boards of appropriate thickness, are attached to one side(fire exposed side) or both side of wall structure for delaying the heat transfer to inner part of structural assembly.

Recently, new hybrid timber framed wall systems to substitute the current typical light timber framed wall system have been developed in Korea. Basically, these wall systems are composed of two major structural parts. One part is a heavy timber frame part designed to take charge of whole vertical load using heavy timber post and beam, and the other is an infill wall structure, such as typical light timber framed wall or structural insulated panel wall, designed to take charge of whole horizontal load to provide an established level of fire resistance.

In this study, two types of hybrid timber framed wall assemblies are evaluated in terms of fire resistance. A basic timber post and beam frame is constructed with Japanese Larch solid timber post(180mm by 180mm) and beam(180mm by 240mm) which are dried using 'high temperature low humidity treatment method(120℃ of dry-bulb and 88℃ of wet-bulb temperature). These heavy timber post and beam are connected by Korean traditional jointing method without any steel of metal connectors.

As infill wall systems, two types of walls are applied. One is a typical light timber framed wall with solid blocking between studs and glass-fiber insulation material. Another is a structural insulated panel wall, in which expanded polystyrene(EPS) insulation is filled between two structural panels to make single structure, and each elements are connected together with light timber studs by common nails.

For all tested walls, two layers of 12.5mm thick type-X gypsum boards are used on fire exposed side. Prior to tests for hybrid walls, two types of only infill walls are tested without heavy timber portal frame. All fire resistance tests are carried out in accordance with KS F 2257(same as ISO 834), and temperatures on several points within wall structure and unexposed wall surface are measured during fire tests.

2. MATERIALS AND METHODS

2-1 Design of Hybrid Wall Systems

Design vertical loads should be applied for fire resistance tests of load bearing walls in general standards. In case of typical light timber framed wall, studs placed at regular interval and structural panels attached to these studs to take charge of vertical load during fire resistance test. This type of wall also takes charge of horizontal load in actual situation. Therefore, it is thought that some limitation for improving fire resistance has been existed in light timber framed wall systems.

In this study, reinforcement of heavy timber frame with post and beam members is considered. This post and beam structure can be responsible for whole vertical load, and free infill wall can take

charge of horizontal load and can provide a certain level of fire resistance. It is expected that non load bearing walls can be used as load bearing wall together with this heavy timber frame.

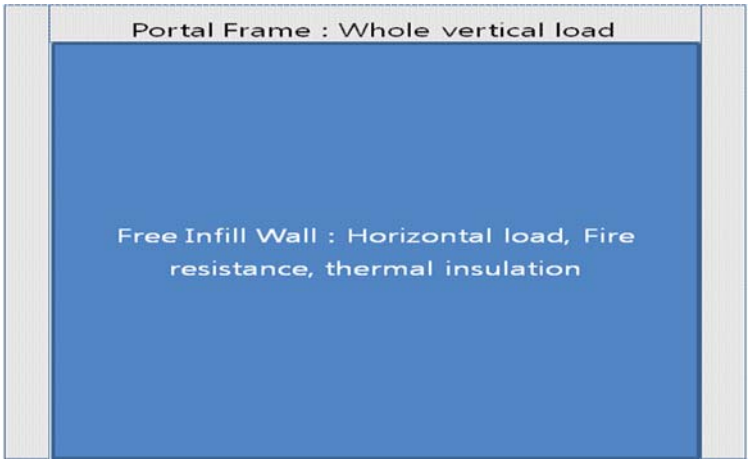


Fig. 1. Design concept of hybrid timber framed wall system.

2-2 Heavy Timber Post and Beam Frame

Heavy timber post and beam frame, which takes charge of whole vertical load, is composed of two Japanese Larch heavy timber post members(180mm by 180mm) and one beam member(180mm by 240mm). These members are pre-cut for connecting each other using automatic timber processing machine(K2, HansHundegger) and connected using Korean traditional jointing method without any steel or metal connectors.

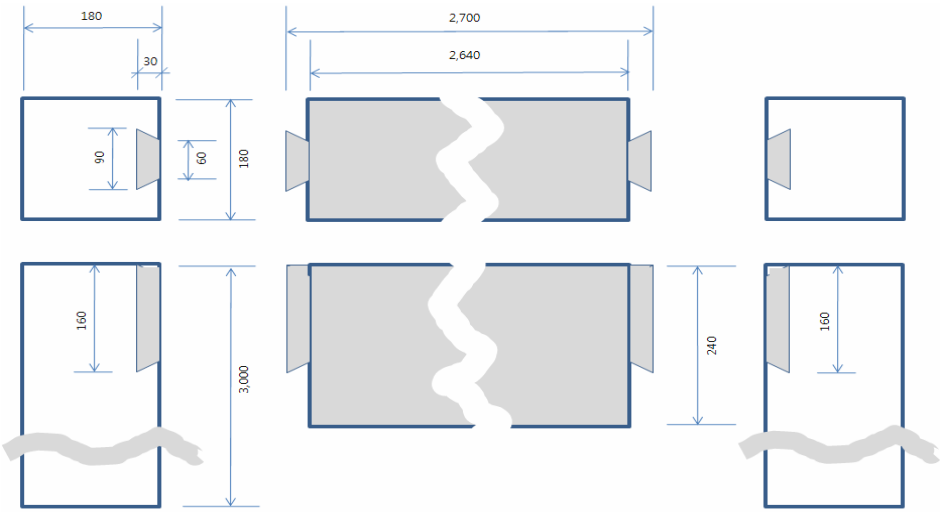


Fig. 2. Connections between heavy timber posts and beam(unit : mm).

2-3 Infill Walls

As infill wall systems, two types of wall systems are applied. One is a typical light timber framed wall system with solid blocking between studs(600mm interval)and glass-fiber matt as an insulation material. Another is a structural insulated panel wall system, in which expanded polystyrene(EPS) insulation is filled between two structural panels to make single structural elements, and each elements are connected together with two light timber studs.

2-3-1 Light timber framed walls

Components of two types of light timber framed walls are provided in Table 1. Japanese Larch studs are placed at 600mm interval and blockings are placed at the same interval between studs. Two layers of type-X gypsum boards are installed using 50mm long screw nails at 200mm interval on studs and blockings.

Table 1. Components of light timber framed walls

Components	Interior wall	Exterior wall
Studs, Blockings and Plates	38mm × 89mm	38mm × 140mm
Insulation	Glass Fiber (R-11)	Glass Fiber (R-19)
Exposed Side	2 Layers of type-X gypsum board (2 × 12.5mm)	
Unexposed side	1-gypsum board (12.5mm)	Structural OSB (11.1mm)

2-3-2 Structural insulated panel(SIP) Walls

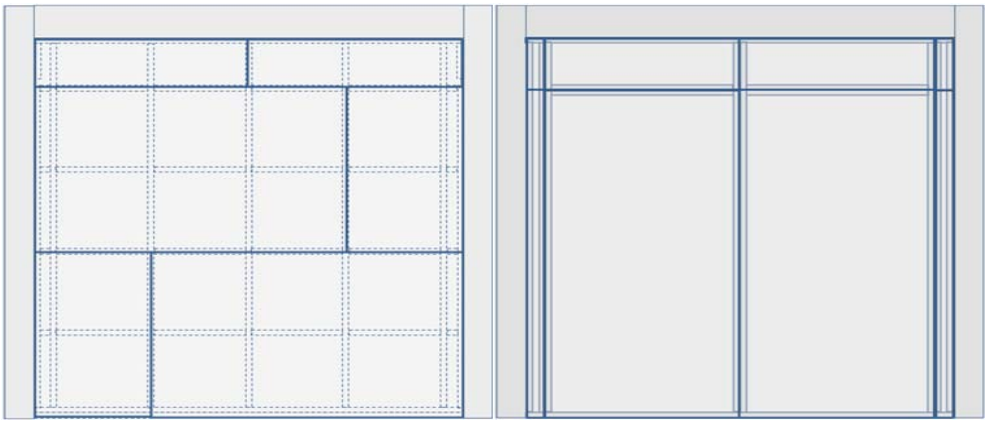
Components of two types of structural insulated panel walls are given in Table 2. Size of one structural insulated panel element is the same as structural OSB(1.22m by 2.44m). Two studs and blockings are used for connecting SIP elements. Components of fire exposed side of these walls are the same as that of light timber framed walls.

Table 2. Components of Structural Insulated Panel(SIP) walls

Components	Interior wall	Exterior wall
SIP	OSB + EPS + OSB (11.1mm, 89mm, 11.1mm)	OSB + EPS + OSB (11.1mm, 140mm, 11.1mm)
Studs and Blockings	2 - 38mm × 89mm	2 - 38mm × 140mm
Exposed side	2 Layers of type-X gypsum board (2 × 12.5mm)	

2-4 Hybrid Walls

Two types of infill walls are combined with heavy timber post and beam frame as shown in Fig. 3. Two end studs and top plate are connected with timber post and beam using common nails. Components of fire exposed side are the same as that of infill walls.



(a) Light-timber framed infill wall (b) Structural Insulated Panel(SIP) infill wall
Fig. 3. Layout of hybrid timber framed wall systems.

2-5 Fire Resistance Tests

All fire resistance tests for only infill walls and hybrid wall systems are carried out in accordance with KS F 2257(same as ISO 834). All walls are 3m x 3m in outside dimension. Vertical loads for interior walls and exterior walls are about 60kN and 93kN, respectively. These values are calculated from typical light timber wall using No. 2 grade Japanese Larch studs and plates. Temperatures on several points within wall structures(Fig. 4) and unexposed wall surfaces, and vertical deformation of walls are measured during fire tests.

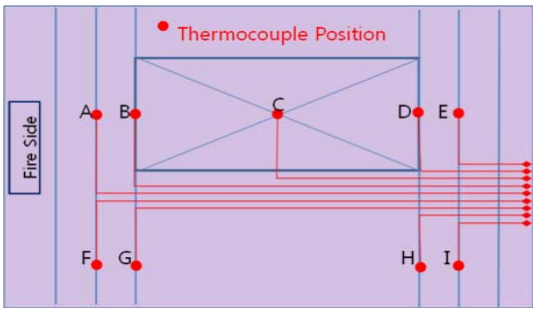


Fig. 4. Temperature measurement positions within timber framed walls.

3. RESULTS AND DISCUSSIONS

3-1 Structural Fire Resistance

Structural failures and vertical deformations of tested walls were observed during fire resistance tests. Structural fire resistance based on failure observation is provided in Table 3.
Table 3. Structural fire resistances.

Type of walls		Fire resistance (min)	Remarks
Light timber framed wall only (38mm × 89mm studs)	LTF-24	70	Failure
Light timber framed wall only (38mm × 140mm studs)	LTF-26	100	Failure
SIP wall only (38mm × 89mm studs)	SIP-24	60 +	No Failure
SIP wall only (38mm × 140mm studs)	SIP-26	90 +	No Failure
Heavy timber Frame + Light timber framed wall (38mm × 89mm studs)	PB-LTF-24	70 +	No Failure
Heavy timber Frame + Light timber framed wall (38mm × 140mm studs)	PB-LTF-26	90 +	No Failure
Heavy timber Frame + SIP wall(38mm × 89mm studs)	PB-SIP-24	60 +	No Failure

In KS F 2257, vertical deformation measured during fire resistance tests for load bearing walls, should not exceed 1/100(30mm in this study) of wall height. As shown in Fig. 5, all tested walls in this study satisfied this regulation. In case of Light timber framed walls, there was no significant improvement in wall deformation by post and beam portal frame reinforcement. SIP walls, however, showed some decrease of vertical deformation by this reinforcement.

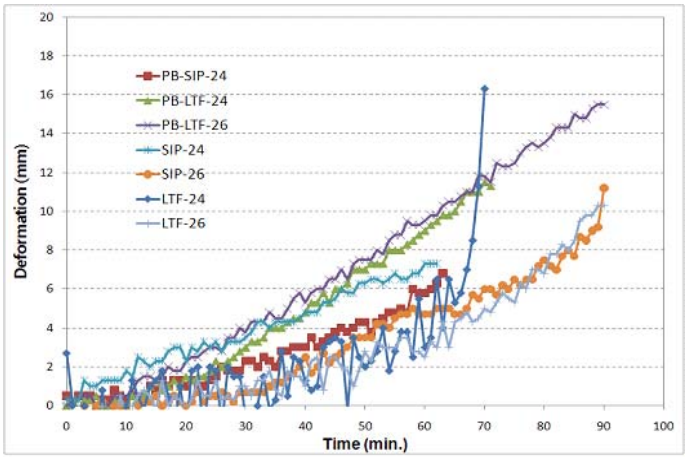


Fig. 5. Vertical deformation measured during fire tests.

3-2 TEMPERATURE MEASUREMENTS

3-2-1 On unexposed surfaces

In KS F 2257, temperatures measured on 12 positions of unexposed surfaces should not exceed 140℃ in average and 180℃ in maximum value. Fig. 6 shows maximum temperatures of each wall during fire resistance tests. As shown in this figure, all tested walls satisfied this regulation except for light timber framed wall(38mm×140mm studs) reinforced with heavy timber post and beam

frame. It is thought that rapid increase of this wall was caused from the occurrence of flame after 80 minutes exposure through the wall on upper position, as shown in Fig. 7.

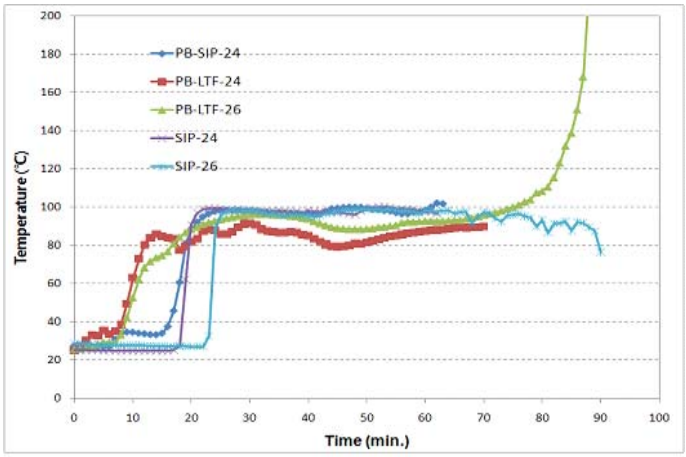


Fig. 6. Maximum temperatures on unexposed surfaces during fire tests.

Fig. 7. Flame occurrence in light timber framed wall(38mm×140mm studs) reinforced by heavy timber frame after 80 minutes of fire exposure.

3-2-2 Within wall structures

Results of temperature measurement within wall structures are shown in Fig. 8 to Fig. 11. As shown in these figures, one layer of 12.5mm thick type-X gypsum board can provide 15-20 minutes of fire resistance, 40 minutes for two layers, and 80 minutes for three layers, considering charring temperature(about 300℃) of wood part(stud or OSB).

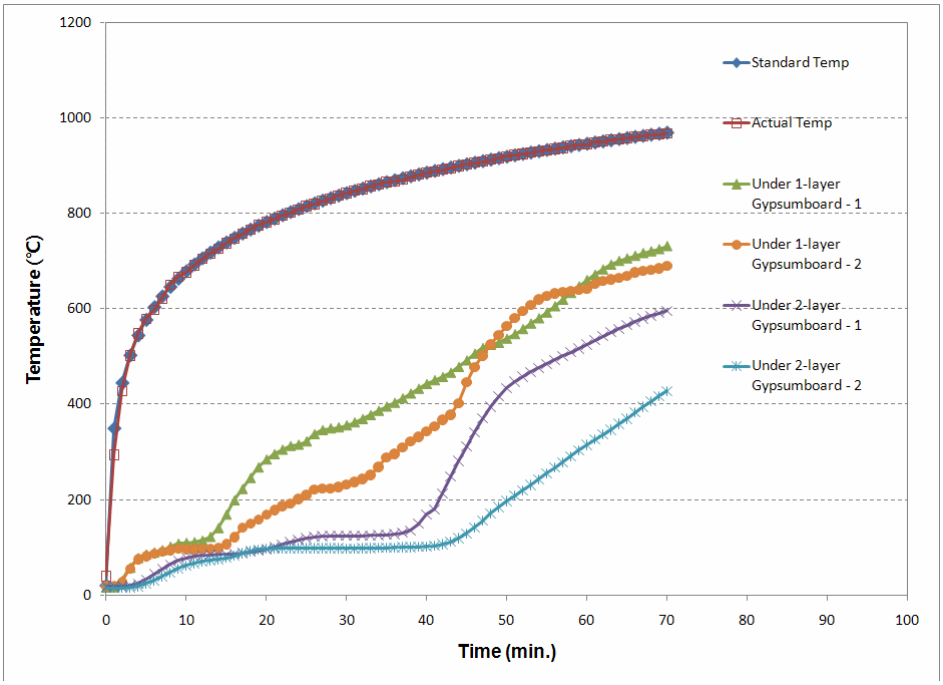


Fig. 8. Temperature changes measured within light timber framed walls(LTF-24).

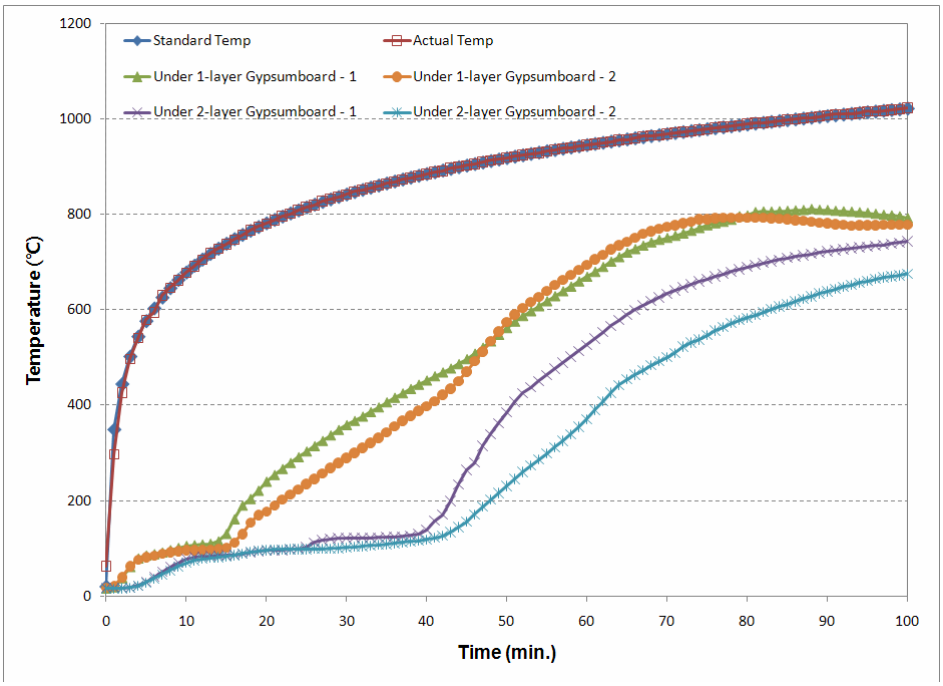


Fig. 9. Temperature changes measured within light timber framed walls(LTF-26).

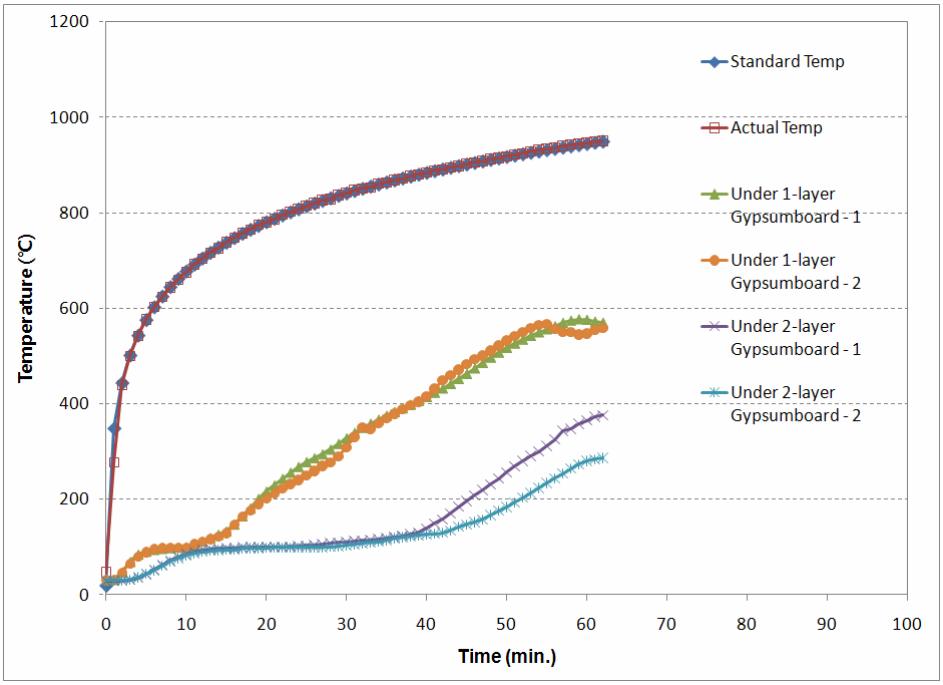


Fig. 10. Temperature changes measured within Structural Insulated Panel walls(SIP-24).

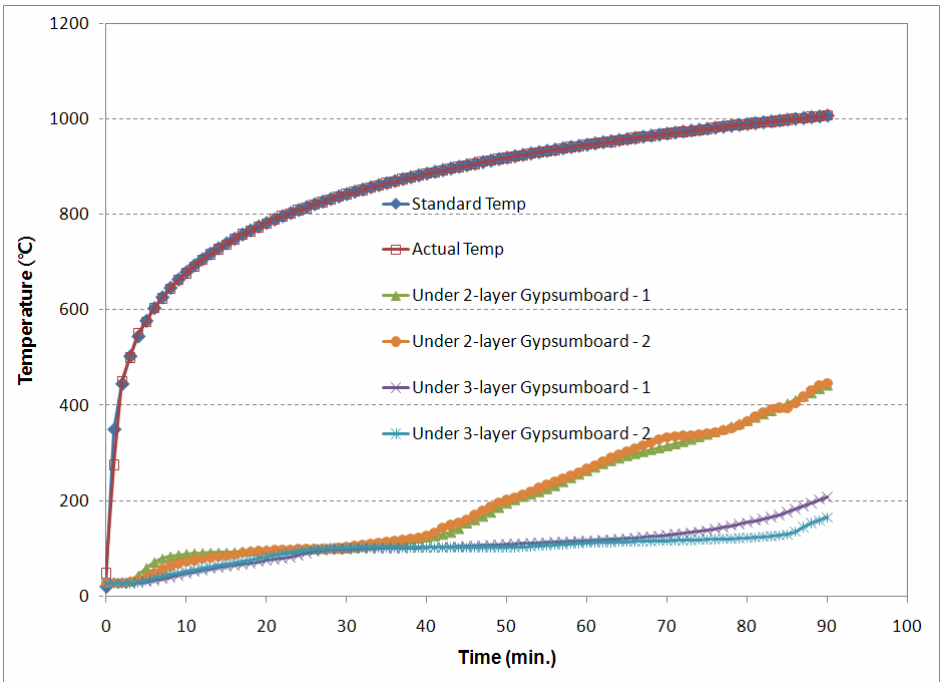


Fig. 11. Temperature changes measured within Structural Insulated Panel walls(SIP-26).

4. CONCLUSIONS

New hybrid timber framed wall systems, which are combined with infill walls and heavy timber post and beam frames, showed good fire resistance. Considering the increased feasibility of infill wall by reinforcement of heavy timber post and beam frame, which takes charge of whole vertical load, other infill walls to get the improved fire resistance, thermal insulation and horizontal load resistance can be developed in the future.

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