Thermal Performance of Plasterboard Lined Steel Stud Walls

Prakash N. Kolarkar

Mahen Mahendran

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Abstract: In response to the market demand for fire separations in the light industrial, commercial and residential buildings, a research project is currently under way to improve the thermal performance of cold-formed steel stud wall systems used in these buildings. Extensive fire testing of both non-load-bearing and load-bearing wall panels has been completed to date in the Fire Research Laboratory of Queensland University of Technology. This paper presents the details of this experimental study into the thermal performance of some small scale non-load-bearing walls lined with dual layers of plasterboard and insulation. The first two wall panels were built traditionally using lipped channels with two plasterboard linings on both sides and the cavity filled with and without glass fibre insulation. The third panel tested was built similarly, but with the insulation sandwiched between the plasterboards on either side of the steel wall frame instead of being placed in the cavity. Fire tests undertaken were based on the standard time-temperature curve recommended by AS 1530.4 (SA, 2005). Experimental results showed that the new stud wall system outperformed the traditional stud wall system giving a much higher fire rating.

Keywords: *Non-load-bearing walls, Gypsum Plasterboard, Cold-formed steel wall frames, Fire tests, Thermal performance, Insulation, Fire rating*

1. INTRODUCTION

Fire safety of light gauge cold-formed steel frame (LSF) stud wall systems is critical to the building design as their use has become increasingly popular in commercial, industrial and residential construction throughout Australia. Partition wall panels composed of a cold-formed steel frame lined with one or two plasterboards as side sheathing have been widely used in building

[1] PhD Researcher, [2] Professor, School of Urban Development, Faculty of Built Environment and Engineering, Queensland University of Technology, Australia.

constructions since 1940. These stud wall panels can be easily assembled to form load-bearing as well as non-load-bearing walls.

In response to a market demand for fire separations in the light industrial, commercial and residential buildings, plasterboard lining manufacturers have published fire resistance ratings for conventional stud wall systems. As part of a fire resistant construction, they satisfy three fire resistance requirements given in AS 1530.4, namely, stability, insulation and integrity (SA 2005).

a) Load-bearing capacity (Stability): For load-bearing elements of a structure, they shall not collapse in such a way that they no longer perform the load-bearing function for which they were constructed.
b) Insulation: For elements of a structure such as walls and floors which have a function of separating two parts of a building, the average temperature of the unexposed face of the element shall not increase above the initial temperature by more than 140°C while the maximum temperature at any point of this face shall not exceed the initial temperature by more than 180°C.
c) Integrity: Initial integrity failure shall be deemed to have occurred when a cotton pad is ignited or when sustained flaming, having duration of at least 10s, appears on the unexposed face of the element.

The walls are required to maintain structural integrity during a fire so as to avoid structural collapse and to prevent spread of flame and smoke into adjacent areas. Ultimate integrity failure shall be deemed to have occurred when collapse of the element takes place or at an earlier time based upon integrity and insulation criteria.

In Australia, plasterboard lining manufacturers provide fire resistance ratings of non-load bearing LSF stud wall systems. They have prescribed steel stud walls with single or multiple plasterboard linings achieving fire resistance ratings ranging from 60 to 120 minutes. These systems are based on full-scale fire resistance tests using the standard fire curve recommended by ISO 834 and AS 1530.4. Adequate fire rating of these wall systems is essential for many reasons such as “to achieve sufficient fire resistance and to prevent or delay the spread of fire and smoke within the building or from one building to another and to avoid sudden collapse of building components for the safety of the people and the fire fighting personnel and assure integrity over a specific interval of time to facilitate the safe evacuation of the people and allow the fire fighters to operate safely”. Hence, with increasing demand for higher fire ratings of these walls, more than two layers of plasterboard linings are being prescribed, which not only make the construction process very laborious but also the resulting walls become very heavy.

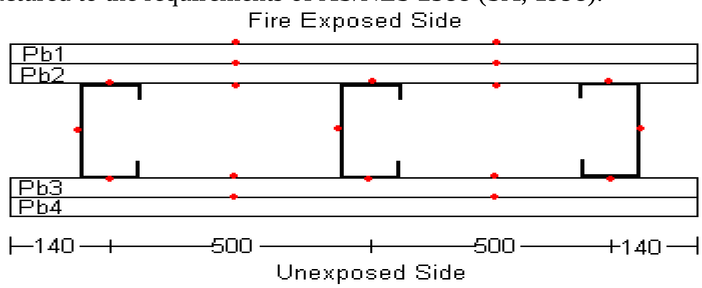
Efforts have also been made to improve the fire ratings of the wall systems by using different types of insulations in the wall cavities, but only contradicting results were obtained. Sultan and Lougheed (1994) performed several small scale fire resistant tests on gypsum board clad steel wall assemblies (914 mm x 914 mm) and using glass fibres, rock fibres and cellulose fibres as cavity insulation. They noted that the rock and cellulose fibre cavity insulations improved fire resistance rating by approximately 30 minutes when compared with non-insulated wall assemblies, whereas only a small benefit was noted in the case of specimens using glass fibres. The cavity side of the exposed gypsum board of insulated wall assemblies heated up more rapidly reaching temperature levels of 700^0C much earlier when compared to that in non-insulated wall assemblies. Following the calcination of the exposed board, the exposed side of the cavity recorded much higher temperatures when compared to that in non-insulated wall assemblies.

Sultan (1995) carried out full scale fire resistance tests on non-load-bearing gypsum board wall assemblies and noted that when rock fibre?? was used as cavity insulation the fire resistance rating increased by 54% over the non-insulated wall assembly. Use of glass fibre as cavity insulation did not affect the fire performance while cellulose fibre insulation reduced the fire resistance. Feng et al. (2003) conducted fire tests on non-load bearing small scale wall systems and reported that the thermal performance of wall panels improved with the use of cavity insulation.

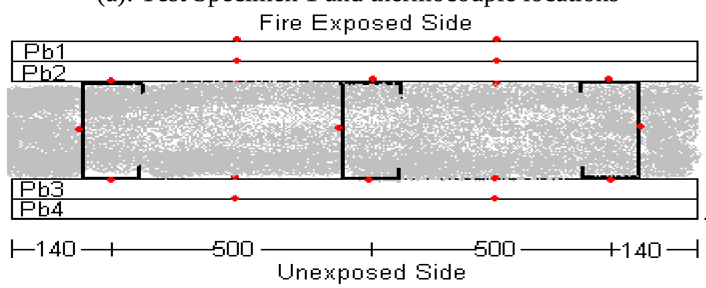
In summary, past research has produced contradicting results about the benefits of cavity insulation to the fire rating of stud wall systems and hence further research is needed. There is also a need to develop new wall systems with increased fire rating. This research therefore proposed a new wall system that uses a thin insulation layer between two plasterboards on each side of stud wall frame instead of cavity insulation and undertook extensive fire tests of both non-load bearing and load bearing walls to increase the knowledge in this field and to improve the fire ratings of the existing wall models. This paper presents the details of fire tests of some non-load-bearing walls, examines and compares their thermal performance, and makes suitable recommendations.

2. TEST SPECIMENS

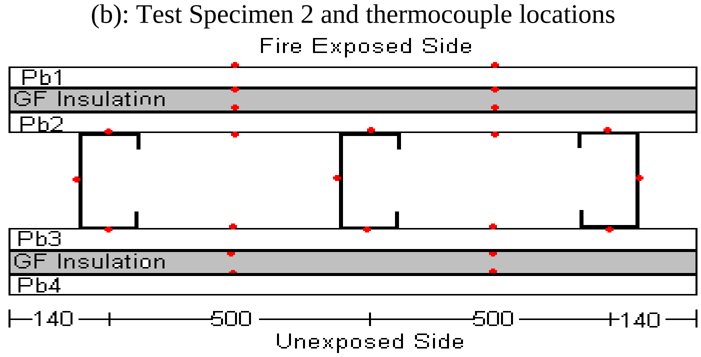
Tests were conducted on three small scale wall assemblies each measuring 1280 mm in width and 1015 mm in height. The wall assemblies typically consisted of three commonly used cold-formed steel studs lipped channel sections spaced at 500 mm. The studs were fabricated from galvanized steel sheets having a nominal base metal thickness of 1.15 mm and a minimum yield strength of 500 MPa. Test frames were made by attaching the studs to top and bottom tracks made of unlipped or plain channel sections. For Test Specimen one, the steel frames were lined on both sides by two layers of gypsum plasterboards manufactured by Boral Plasterboard under the product name FireSTOP (see Figure 1a). Test Specimen 2 was similarly built, but with the cavity filled with two of 50 mm thick glass fibre mats. Test Specimen 3 was also built like Test Specimen 1, but with a single mat of 25 mm thick glass fibre insulation sandwiched between the plasterboards thus forming composite panels on either side of the steel stud frame as shown in Figure 1c. All the plasterboards were manufactured to the requirements of AS/NZS 2588 (SA, 1998).



(a): Test Specimen 1 and thermocouple locations



(b): Test Specimen 2 and thermocouple locations



(c): Test Specimen 3 and thermocouple locations

Figure 1: Details of Test Wall Specimens

3. TEST SET-UP

A custom built adaptor was fitted to the large furnace available at Queensland University of Technology in order to reduce the flame opening size to 1290 x 1010 mm by the use of a single burner (Figure 2a). The tests were carried out by exposing one face of the specimens to heat in this propane-fired vertical furnace (Figure 2b). The furnace temperature was measured using four type K mineral insulated and metal sheathed thermocouples symmetrically placed about the horizontal and vertical centre lines. The average temperature rise of these thermocouples served as the input to the computer controlling the furnace according to the cellulosic fire curve given in AS 1530.4 (SA, 2005). A number of type K thermocouples were placed on each test specimen as shown in Figures 1 (a) to (c) to obtain the temperature variation across the depth of the wall specimens. The specimens were allowed to expand freely during the test. The vertical edges of the specimen were kept free to allow lateral deformations. All the gaps and openings around the specimen were sealed using Isowool. The specimens were installed in the furnace as shown in Figure 2. Three Linear Variable Differential Transducers (LVDT's) were mounted on a wooden beam acting as a support bridge outside the specimen to measure the mid-height lateral deflection of the studs. Lateral deflections towards the furnace were recorded as negative. The failure of the small scale test specimens was based on the integrity and insulation criteria in AS 1530.4 (SA, 2005). The furnace and specimen temperatures were recorded using an automatic data-acquisition system at intervals of one minute.

(a) Test Specimen in the specially built adapter in the large furnace

(b) Test Specimen subjected to fire on one side

Figure 2: Fire Testing of Small Scale Wall Specimens

4. OBSERVATIONS AND RESULTS

In all the wall specimens the fire side plasterboards 1 and 2 (Pb1 and Pb2 in Figures 1(a) and (b)) had partially collapsed towards the end of the fire test. They fully collapsed due to their extreme brittleness when the specimens were removed from the furnace and placed on the laboratory floor for inspection. Plasterboard 3 (base layer on ambient side) was also damaged at the centre in all the specimens. Studs of Test Specimen 1 (without insulation) were seen to be the least affected by fire whereas those of Test Specimen 2 (with cavity insulation) were the most affected.

In Test Specimen 2, the cavity insulation was burnt out completely, whereas in Test Specimen 3 the insulation on the fire side had disappeared fully but the insulation on the ambient side between the plasterboards 3 and 4 was partially intact. The unexposed wall surface of both the specimens showed no signs of damage or effect of temperature right up to the end of test. Figures 2, 3 and 4 show the photographs of Test Specimens 1, 2 and 3 after the fire test, respectively. Numerous thermocouples were installed across the width of the wall, located at mid-height of the wall as shown in Figure 3.

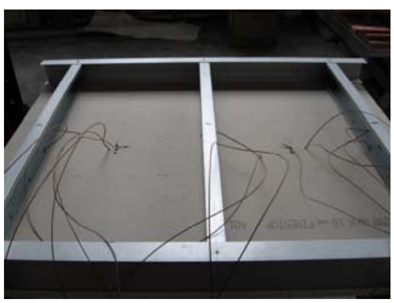


Figure 3: Installation of K type wire thermocouples in Test Specimens

Figure 4: Failure of Test Specimen 1 built without insulation

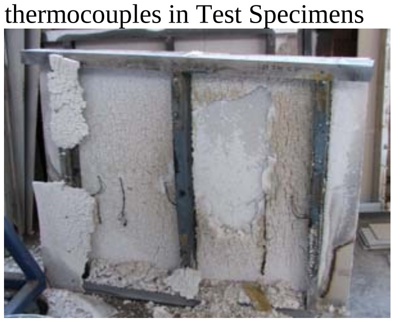


Figure 5: Failure of Test Specimen 2 using glass fibre as cavity insulation

Figure 6: Failure of Test Specimen 3 using glass fibre as external insulation

Figure 7 shows that the average furnace time-temperature profiles for the three tests traced very closely to the standard time-temperature curves specified by AS1530.4. This proved that the fire tests had been undertaken as per the standard fire test requirements. The furnace temperature of Test Specimen 1 showed a deviation from the standard curve, but only after 180 minutes.

Figures 8 (a) to (c) show the time-temperature profiles across Test Specimens 1, 2 and 3, respectively. From these three figures, it can be seen that the studs of Specimen 3 were much better protected due to the external layer of insulation. The stud temperatures in Test Specimen 3 remained almost constant (about 100^0C) up to 85 minutes (from the start of the fire test) beyond which it rose rapidly. In Test Specimens 1 and 2 this sudden increase in stud temperatures was seen to happen much earlier (ie. after about 60 minutes), leading to earlier lateral deformations of the studs (see Figure 12). The temperature was found to be more uniform across the studs of Specimens 1 and 3 due to the faster transmission of heat by radiation in the cavity. The low conductivity of the insulation in the cavity of Specimen 2 reduced the heat flow towards the cold flanges of the studs but at the same time quickened the temperature rise of the hot flange due to the additional heat redirected from the surface of insulation. This caused the hot flange of Test Specimen 2 to heat up more rapidly than that of Test Specimens 1 and 3 and remained high over the entire test period (see Figure 9) leading to their earlier damage. The hot flange temperature of the stud in Specimen 3 surpassed that of Specimen 1 after about 150 minutes. This was probably due to the heat redirected towards the cavity by the external insulation on the ambient side.

The central studs in all the specimens showed higher temperatures at any time than the end studs, with the difference more pronounced in Specimen 2. Figure 10 shows the effect of external insulation versus cavity insulation on the temperature across the critical central stud. It can be seen that over the entire duration of the test, even the hot flange temperature of the central stud of Specimen 3 was lower than the cold flange temperature at the corresponding time in Specimen 2. In load bearing walls this would translate into much lower thermal strains and the associated thermal stresses in the steel frames. Figure 11 also shows the beneficial effect on the stud temperatures of the externally insulated wall specimen over the non-insulated wall specimen over a large initial time period (approximately 150 minutes) of fire exposure. Due to the rapid reduction in the strength and stiffness of cold-formed steel studs, large scale specimens (i.e. having two layers of plasterboard on either side of cold-formed steel frame) even with the non-load-bearing condition may not survive beyond this time due to the slenderness of the studs and the weight of the intact ambient side plasterboards.

The temperatures of fire side plasterboards of Test Specimen 2 were seen to rise more rapidly than that for Test Specimen 1 and 3. In Specimen 2, the exposed plasterboards 1 and 2 fell at around 130 and 150 minutes, respectively, whereas in Specimen 3 they fell at around 165 and 195 minutes, respectively. The fall off times of the exposed plasterboards in Test Specimen 1 could not be recorded.
Table 1 shows the unexposed surface temperatures of all the specimens at the end of 60, 120 and 180 minutes from the start of the fire test.

Table 1: Temperature of Unexposed Surface during Fire Tests

Specimen	Cavity insulation (90 mm)	External Insulation (25 mm)	Temperature in ^{0}C of unexposed surface after		
			60 min.	120 min.	180 min.
1	Nil	Nil	59	72	91
2	Glass fibre	Nil	56	71	113
3	Nil	Glass fibre	48	68	76

The unexposed surface temperature of the cavity filled specimen exceeded that of the non-insulated specimen after a period of 2 hours of heat exposure. This was probably due to the heat transmitted by thermal bridging to the ambient side from the steeply rising hot flange temperature of the studs. The external insulation layer on the ambient side of Test Specimen 3 helped the wall in achieving the best insulation properties over the entire duration of the test as seen from Table 1 and Figure 13.

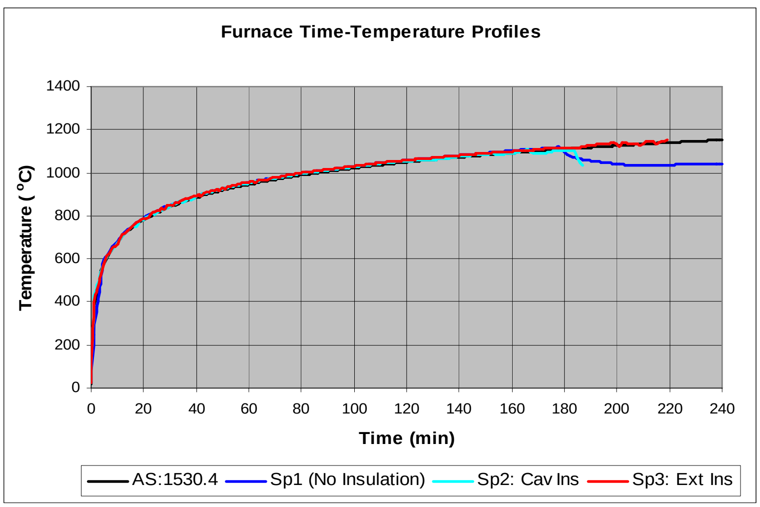
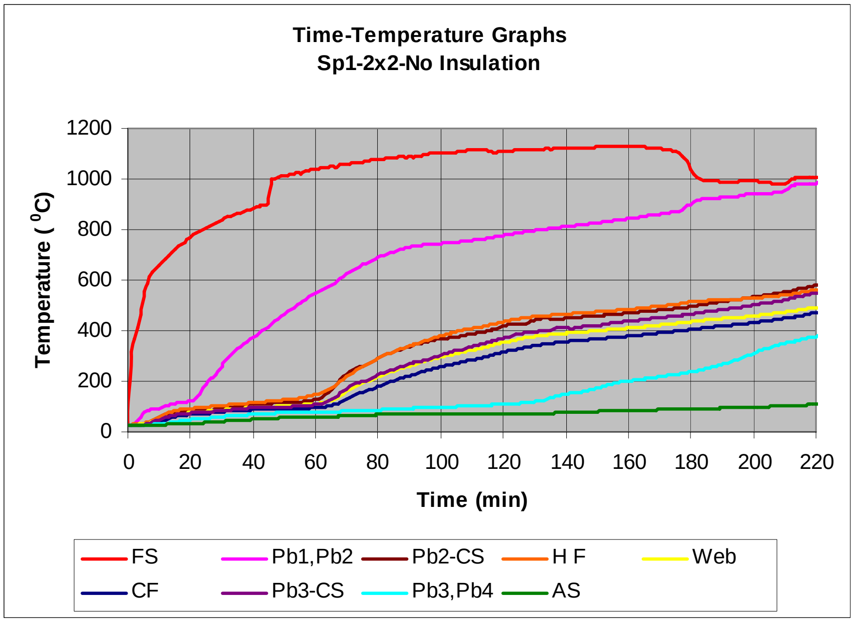
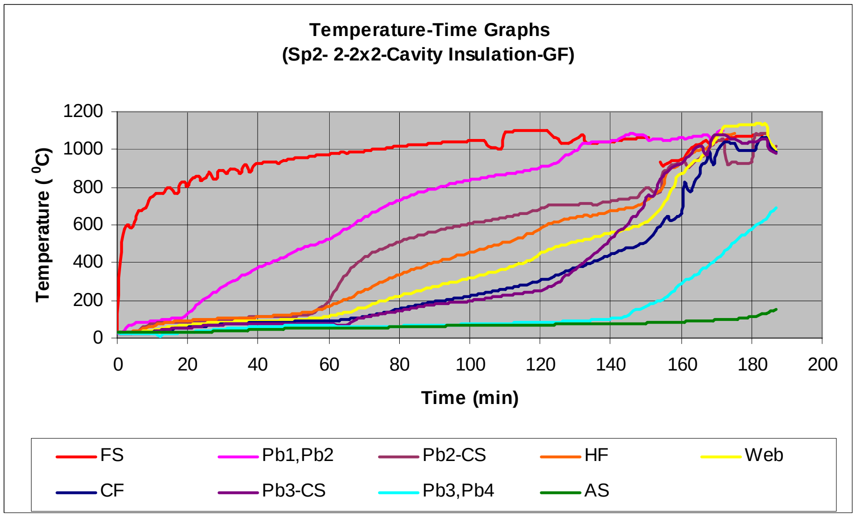


Figure 7: Furnace Time-Temperature Profiles for Test Specimens 1, 2 and 3

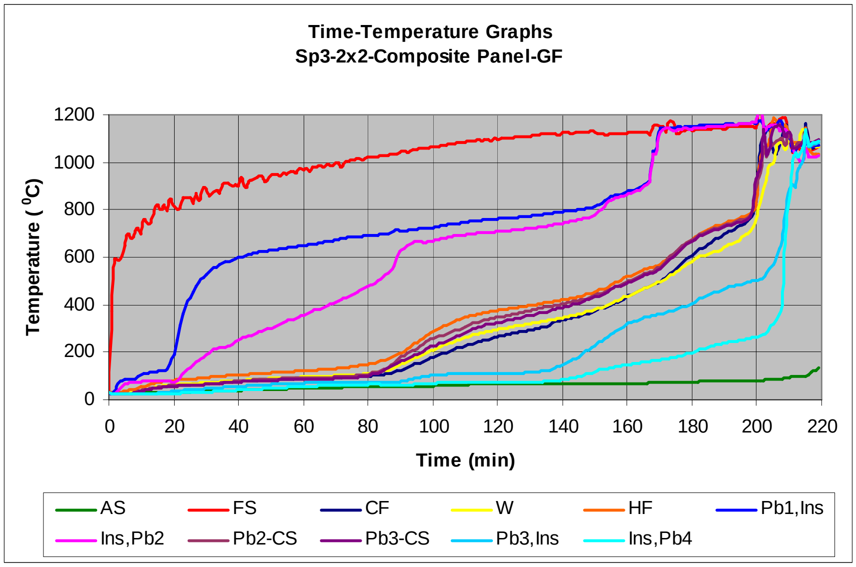


(a): Time-Temperature profiles across Test Specimen 1



(b): Time-Temperature profiles across Test Specimen 2

Figure 8: Time-Temperature Variation across the Small Scale Wall Specimens



(c): Time-Temperature profiles across Test Specimen 3
Figure 8: Time-Temperature Variation across the Small Scale Wall Specimens

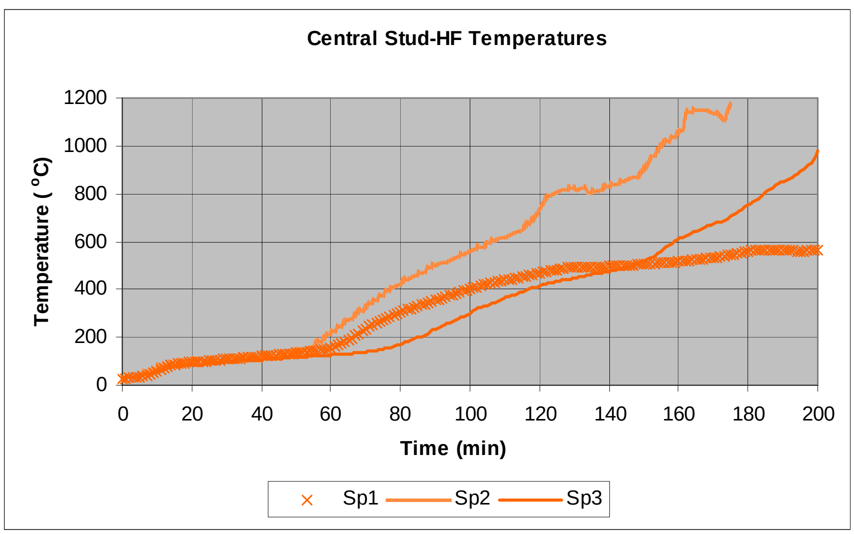


Figure 9: Time-Temperature Profiles
(Hot flange of central stud of Test Specimens 1, 2 and 3)

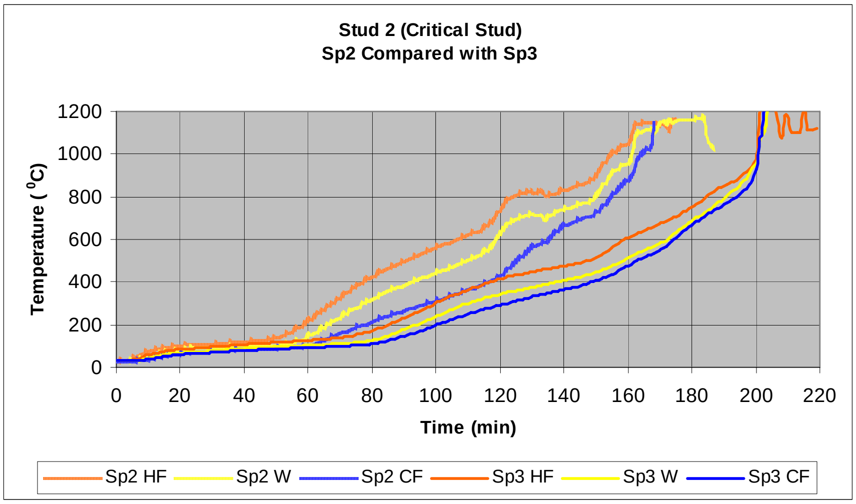


Figure 10: Time-temperature Profile for the Central Stud
in Test Specimens 2 and 3

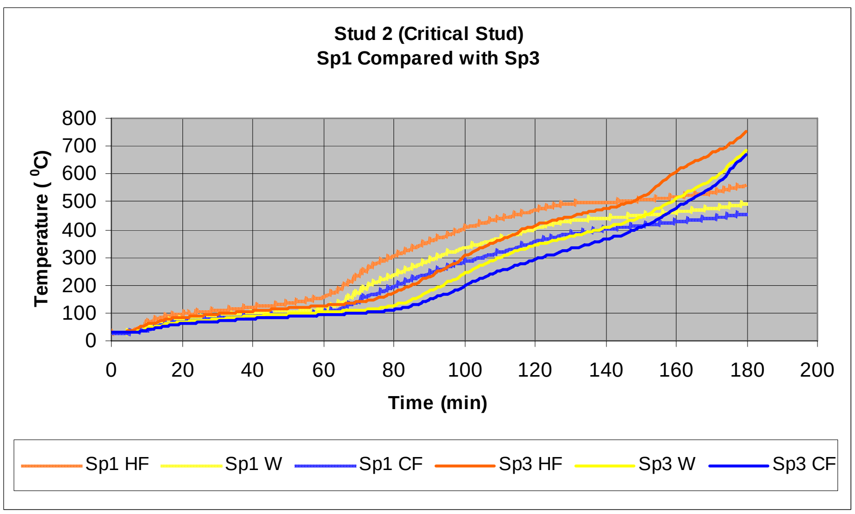


Figure 11: Time-temperature Profile for the Central Stud
in Test Specimens 1 and 3

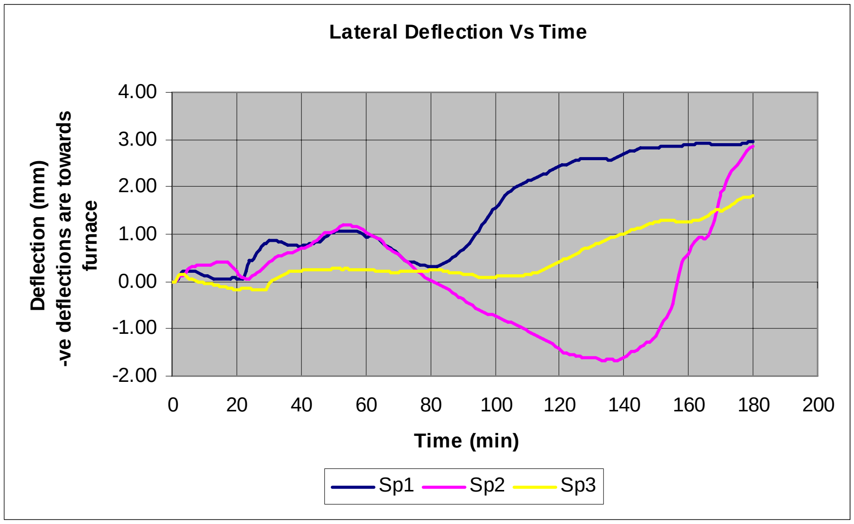


Figure 12: Lateral Deflection-Time Profile of Specimens 1, 2 and 3

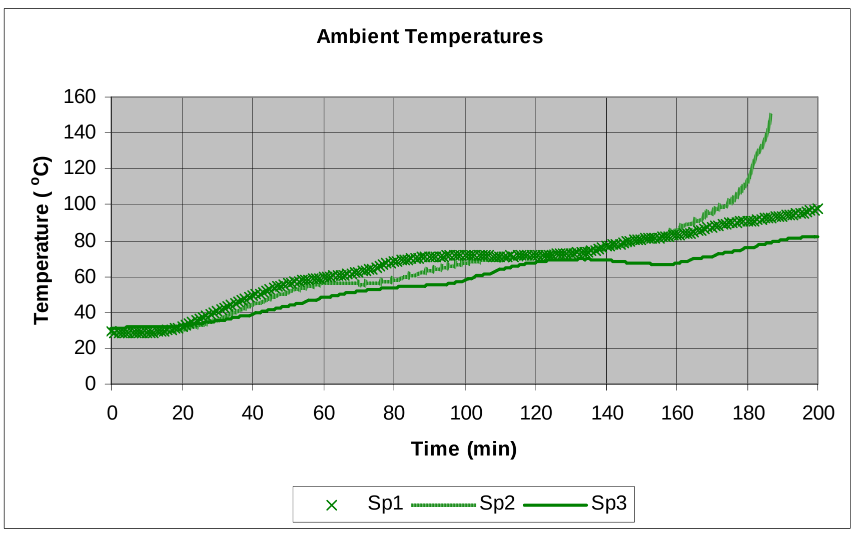


Figure 13: Ambient Side Time-Temperature Profile of Specimens 1, 2 and 3

Following symbols were used in Figures 7 to 13.

AS 1530.4: Standard Time-temperature Relationship
FS: Average temperature of the exposed face of the wall specimen.
Pb1, Pb2: Average temperature of the interface between Pb1 and Pb2.
Pb2-CS: Average temperature of the cavity facing surface of Pb2
Pb3-CS: Average temperature of the cavity facing surface of Pb3
Pb3, Pb4: Average temperature of the interface between Pb3 and Pb4.
Pb1, Ins: Average temperature of the interface between Pb1 and insulation layer.
Ins, Pb2: Average temperature of the interface between Insulation layer and Pb2
HF: Average temperature of the hot flanges of the three studs
W: Average temperature of the webs of the three studs
CF: Average temperature of the cold flanges of the three studs
Sp1/2/3 HF: Hot flange temperature of specimen 1/2/3
Sp1/2/3 W: Web temperature of specimen 1/2/3
Sp1/2/3 CF: Cold flange temperature of specimen 1/2/3
AS: Average temperature of unexposed surface (Ambient Side) of the specimen

Detailed thermal performance results for the cold-formed steel stud wall systems as discussed in this paper have shown that the use of cavity insulation is detrimental to the fire rating of walls. It has led to not only higher temperatures in the steel studs, but also a larger temperature gradient across its depth. This is expected to lead to premature failures of steel studs in load-bearing walls. In contrast, lower temperatures and a more uniform temperature distribution were present in the studs of wall systems made with external insulation. The use of external insulation offered greater thermal protection to the studs resulting in a more uniform temperature distribution across their cross-section thereby producing minimum early lateral deformation (thermal bowing). This would be of immense value in load-bearing walls, as their structural failure is usually brought about by the excessive secondary moments developed by increasing eccentricities caused by thermal bowing, which are further amplified if the walls are not allowed to expand freely in the vertical direction. Also the difference in temperature of the individual studs in the externally insulated specimen was not significant as the radiation of heat in an open cavity is very fast leading to a quick balance of temperatures in the individual studs. This helps in reducing the build up of internal stresses in the frame caused by the unequal expansions of the individual studs. The insulating properties of the new model were also found to be much better than the conventional models. These observations imply that the new wall system with external insulation is likely to provide improved performance under the three fire rating criteria of stability, integrity and insulation. Research is continuing to investigate the thermal and structural performance of stud walls using numerical modeling.

5. CONCLUSIONS

This paper has described an experimental study of the thermal performance of cold-formed steel stud wall systems used as non-load bearing walls. This study has shown that the use of cavity insulation led to poor thermal performance of stud walls. In contrast, the thermal performance of externally insulated steel stud walls was superior than the traditionally built stud walls with or without cavity insulation. Details of fire tests and the results are presented and discussed in this paper.

6. ACKNOWLEDGEMENTS

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