Fire behaviour of non-load bearing double stud cold-formed steel frame walls

Comportamento ao fogo de paredes duplas em aço enformado a frio não portantes

Matheus H. Alves[1] | **Paulo A. G. Piloto**[2] | **Erica F. Aiko Kimura**[1] | **Giada Constantini**[3] | **Alessandro Ianni**[3] | **Alberto Meda**[3]

[1] Universidade Tecnológica Federal do Paraná, Brasil, matheus.alves@ipb.pt, ekimura@utfpr.edu.br
[2] Instituto Politécnico de Bragança, Portugal, ppiloto@ipb.pt
[3] Universitàt degli Studi di Roma "Tor Vergata", Italia, giada_costantini93@hotmail.it, alessandro_ianni@hotmail.it, alberto.meda@uniroma2.it

abstract

This work investigates the behaviour of Double stud Light Steel Frame (LSF) walls under ISO834 standard fire through a series of experimental tests. The walls were covered on both sides with one or two fire-resistant gypsum plasterboards (Type F), and the cavity of the steel frame was either empty, partially or fully insulated with ceramic fibre. The fire resistance of the assemblies is improved due to the existence of a wider cavity, the employment of additional gypsum plasterboard layers and the use of ceramic fibre cavity insulation. In partially insulated assemblies, significantly higher fire resistance is achieved when the ceramic fibre is placed towards the fire-exposed gypsum plasterboard. Moreover, the number of studs in contact with the unexposed gypsum plasterboard affects the fire resistance of the specimens. The experimental data acquired is useful to conduct further numerical analyses and experimental studies, as well as to understand the unique thermal behaviour of different configurations of double stud LSF walls at elevated temperatures.

Keywords: Fire resistance / Double stud LSF walls / Experimental tests / Ceramic fibre.

resumo

Este trabalho teve como objetivo avaliar experimentalmente o comportamento ao fogo de paredes duplas em aço leve não portantes submetidas à curva padrão de incêndio ISO834. As paredes analisadas foram revestidas em ambos os lados por uma ou duas placas de gesso resistentes ao fogo (Tipo F), sendo a cavidade preenchida ou não com isolamento total ou parcial em fibra cerâmica. A resistência ao fogo das paredes é significativamente aperfeiçoada devido à presença de uma cavidade maior, bem como pela utilização de camadas adicionais de placas de gesso e pela presença de isolamento na cavidade. No caso de paredes com isolamento parcial na cavidade, é obtida uma maior resistência ao fogo quando a fibra cerâmica de isolamento é posicionada em contato com a placa de gesso no lado exposto. Para além disto, o número de montantes em contacto com a face não exposta influencia a resistência ao fogo da parede. Os resultados obtidos são úteis para o desenvolvimento e validação de modelos numéricos avançados e metodologias simplificadas de cálculo, contribuindo também para uma melhor compreensão do comportamento térmico a elevadas temperaturas de paredes duplas fabricadas em aço leve.

Palavras-chave: Resistência ao fogo / Paredes duplas de aço leve / Testes experimentais / Fibra cerâmica.

1- INTRODUCTION

Double stud Light Steel Framing (LSF) walls are employed in buildings when enhanced thermal and acoustic insulation are required. They also play a key role in fire compartmentation, controlling fire spread in the case of fire events. Although the fire behaviour under standard fire conditions of conventional LSF walls is well understood, few studies assessed the thermal performance at elevated temperatures of varied configurations of double stud assemblies.

Shoub and Son (1973) investigated the performance under standard fire of load bearing LSF walls with two stud rows, each covered on both sides with one Type X gypsum plasterboard. The stud rows were separated by an air gap, and both were filled with glass fibre insulation. The specimens did not fail in terms of insulation requirements before failing structurally. The air gap between the wall modules did not affect the fire performance of the specimens, and the effects of glass fibre cavity insulation were not assessed by the authors.

Kodur and Sultan (2006) conducted experimental tests to assess the fire behaviour of loaded double stud LSF walls covered with one or two fire-resistant gypsum plasterboards on each side. The rows of the steel frame were set apart by an air gap, and the cavity was void or filled with rock fibre. The authors concluded that the use of rock fibre insulation decreases the fire resistance of the walls regarding integrity and structural requirements. However, for the whole test length, insulation failure was not detected. Also, when compared with uninsulated single-stud assemblies, double stud LSF walls with similar sheathing and cavity configurations exhibited improved load bearing capacity, which is due to their enlarged cavity size.

Magarabooshanam et al. (2019) conducted standard fire tests on loaded double stud LSF walls covered on both sides with two fire-resistant gypsum plasterboards, with the stud rows separated by an air gap. The specimens did not reach insulation failure before failing structurally. The presence of two sheets of gypsum plasterboards on both sides, a wider cavity and the air gap between stud rows improved the performance of the walls.

Double stud LSF walls present a unique thermal performance at elevated temperatures, which is mainly due to the enlarged cavity size and the gap between the stud rows. However, the behaviour in standard fire conditions of different configurations of double stud LSF walls, e.g., cavity insulation arrangements and the number of protective layers, is poorly understood. Thus, experimental tests are necessary to determine the fire resistance of these walls and provide comparative results to support further numerical analysis and fire design guidelines.

Therefore, this investigation assesses the fire resistance of different configurations of small-scale non-load bearing double stud LSF walls exposed to ISO834 (1999) standard fire to improve the knowledge about their fire performance. The walls are covered with one or two Type F fire-resistant gypsum plasterboards and the cavity is either void, fully or partially insulated with ceramic fibre blankets. The results of the fire tests are evaluated under the requirements of EN 1363-1 (2012) regarding the insulation criterion.

2- EXPERIMENTAL INVESTIGATION

The experimental program consisted of different configurations of specimens with 975 mm wide and 1000 mm high, see Table 1. The steel frame was composed of two stud rows (exposed and unexposed), with seven studs and two tracks classified as class 4 cold-formed sections (C100x45 mm) with 1.0 mm nominal thickness. Specimens 1 through 5 had three studs in the exposed stud row, whilst Specimens 6 through 8 had four studs in the same position. All steel connections were made with self-drilling screws and the stud rows were connected using three rectangular galvanized steel plates with a nominal thickness of 0.46 mm, see Fig. 1.

The exposed stud row is attached to a 1000x1000x100 mm steel test frame (internal dimensions) on its top, bottom and left sides, using five hexagonal head anchor bolts for each side, spaced at 200 mm centres. Only the right side of the exposed stud row was kept unrestrained by a 25 mm gap, properly insulated with ceramic fibre, as required by EN 1364-1 (1999). Due to the size limitations of the test frame, the unexposed stud row remained projected from the furnace, and the connection between the stud rows at the wall ends was made with four hexagonal head bolts, see Fig.1.

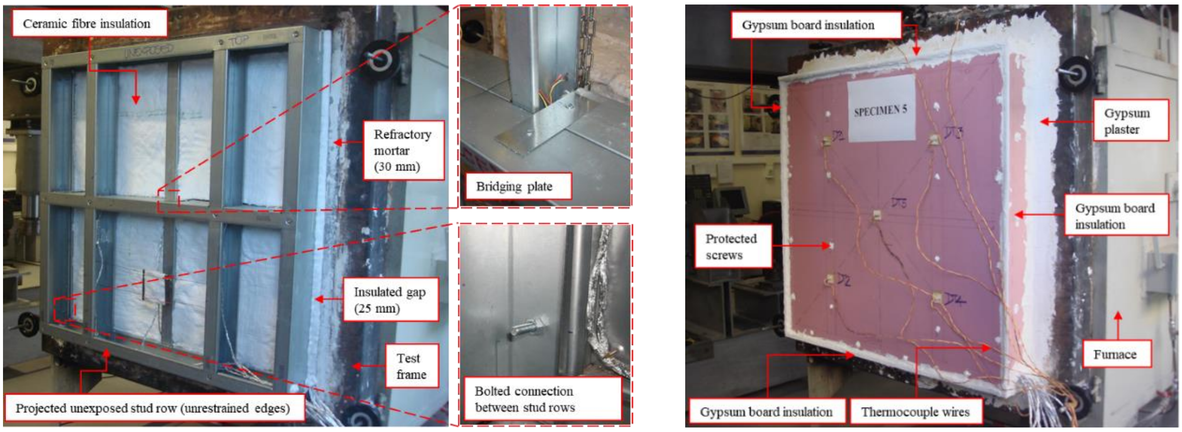
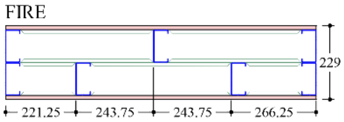
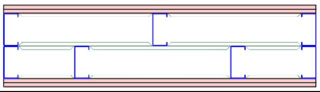
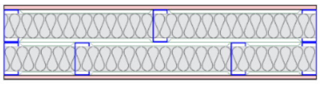
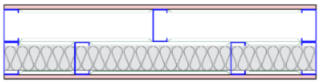
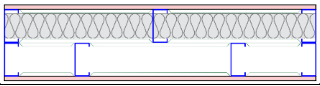
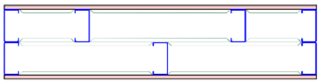
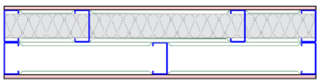
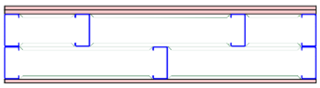


Fig. 1 | Details of the test set-up.

Moreover, the walls were covered with 12 mm-thick type F fire-resistant gypsum plasterboards, with a density of 770 kg/m³ at 20 ºC. The gypsum panels were attached to the steel frame using self-drilling screws. Also, a gypsum plasterboard was used to cover the edges of the unexposed stud row projected from the furnace, see Fig. 1. Additionally, as shown in Table 1, the cavity of the test specimens was empty, partially or fully insulated with 75 mm-thick ceramic fibre blankets, with a nominal density of 128 kg/m³ at 20 ºC.

Different configurations of type K thermocouples were employed to measure temperature over time at different regions of the wall specimens using an MGC Plus by HBM with 1 Hz of acquisition frequency. The regions of the walls corresponding to the average temperatures through the cross-section of the specimens, the maximum temperature on the unexposed side and the ambient temperature are shown in Section 3. Also, as a means of comparison, a FLIR BT Series T365 Infrared Camera was installed at 3.20 m distance from the specimen to measure the average (IR-AVE) and maximum (IR-MAX) temperature on the

Table 1 | Configurations of the double stud LSF walls.

Specimen	Specimen Configuration	Ceramic Fibre Insulation		Number of Gypsum Plasterboard Layers Exposed x Unexposed
		Thickness	Position	
1		-	-	1x1
2		-	-	2x2
3		2x75 mm	Exposed and unexposed stud rows	1x1
4		1x75 mm	Unexposed stud row	1x1
5		1x75 mm	Exposed stud row	1x1
6		-	-	1x1
7		1x75 mm	Exposed stud row	1x1
8		-	-	2x1

unexposed surface within a temperature scale of 15-250 ºC. The data acquisition frequency was 1.25 Hz and the ambient temperature and emissivity of the gypsum plasterboard were 20 ºC and 0.8, respectively. Extensive details on the instrumentation of the tests can be found in Alves (2020).

The tests were performed by exposing one side of the specimen to ISO834 (1999) fire curve in a gas-fired furnace equipped with four burners with 90 kW of power each, with the internal temperature controlled by a PID based on temperature measurements of one plate thermocouple. According to EN 1363-1 (2020), the specimens are considered to have failed when the insulation criterion (I) is reached, whether regarding the requirements for the average ($T_{ave} = T_0 + 140\ °C$) or maximum ($T_{max} = T_0 + 180\ °C$) temperature on the unexposed protection layer, considering an initial temperature of $T_0 = 20\ ºC$.

3- RESULTS AND DISCUSSION

The results obtained in the fire tests are shown in Table 2, in which the fire resistance ratings (FRR) are defined for this building element according to the standard EN 13501-2 (2009).

Table 2 | Experimental results obtained for the fire resistance of the specimens.

Specimen	Experimental				
	T_{ave} [min]	T_{max} [min]	Fire rating [FRR]	Increase in T_{ave} [min]	Increase in T_{max} [min]
1	73	74	I60	-	-
2	116	116	I90	43	42
3	190	186	I180	117	112
4	128	132	I120	55	58
5	187	179	I120	114	105
6	69	65	I60	-	-
7	182	188	I180	113	123
8	99	97	I90	30	32

3.1. Specimen 1 and Specimen 6

Fig. 2 presents the history of the average and maximum temperatures through the cross-section and on the unexposed side of Specimens 1 and 6.

A temperature plateau is noticed in the first 4-16 minutes of fire exposure due to free water evaporation in the gypsum plasterboard on the exposed side. During this plateau, the

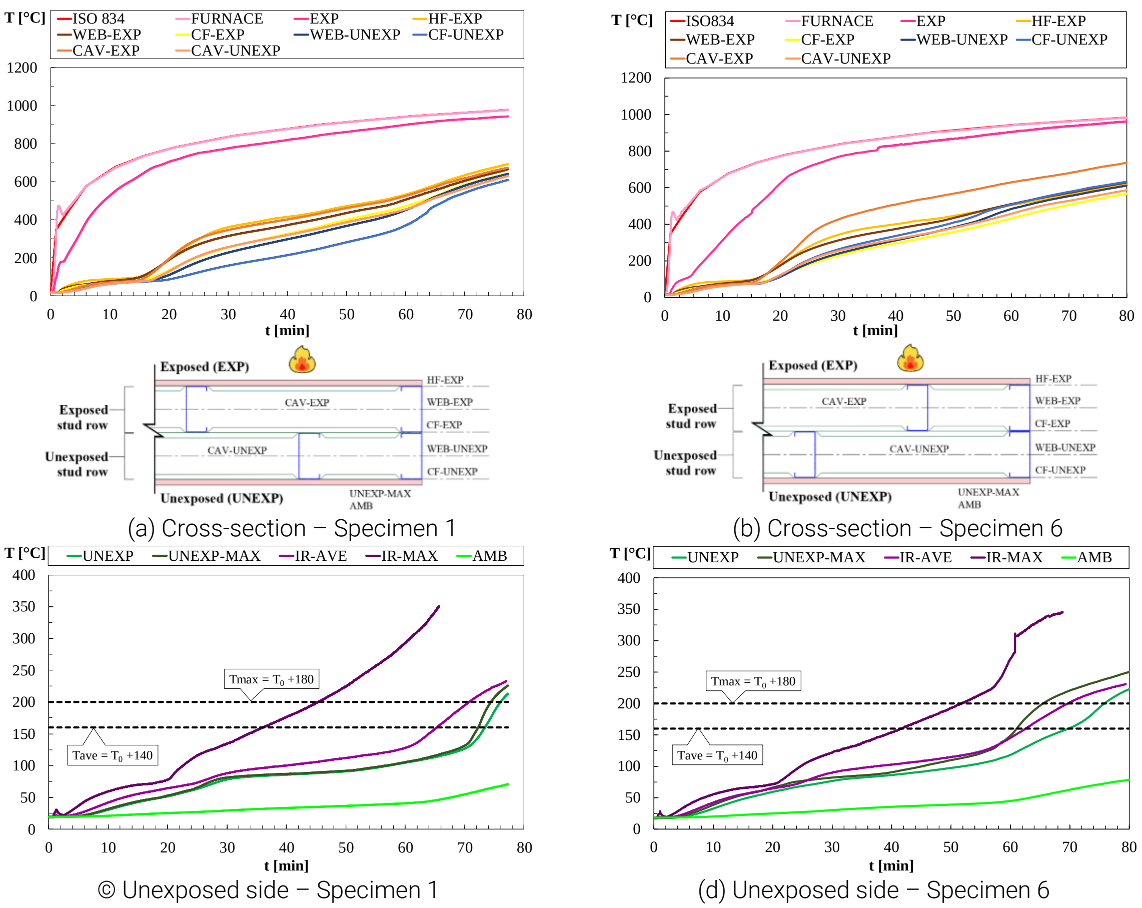


Fig. 2 | Temperature profiles of Specimen 1 and Specimen 6.

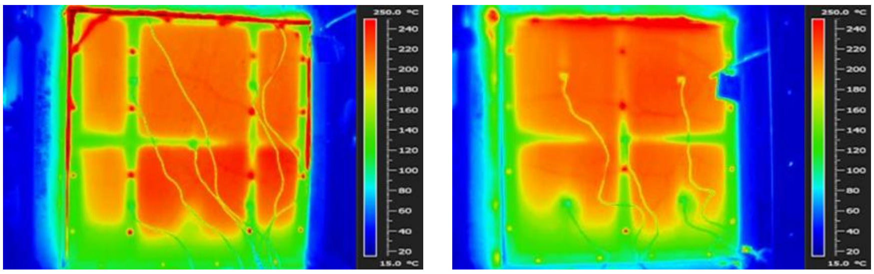
heating rate of steel is almost uniform. However, after 16 minutes the gypsum plasterboard on the exposed side starts to crack and steel and cavity temperatures rise significantly. After 30 minutes, the temperature inside the cavity increases significantly, but the difference between CAV-EXP and CAV-UNEXP was around 90 ºC and 170 ºC in Specimen 1 and Specimen 6, respectively. This is due to the enlarged cavity depth of double stud walls, which slows heat transfer through the cross-section, allowing for a more regular heat distribution because of natural convection within the enclosure.

As seen in Fig. 3, despite showing large cracks, the gypsum plasterboard on the exposed side did not fall off during the tests.

Regarding the temperatures on the unexposed side, it was noticed that the temperature difference between UNEXP and UNEXP-MAX towards the end of the test is higher for Specimen 6 when compared with Specimen 1. In Specimen 6, the disk thermocouples were attached to the gypsum plasterboard areas in direct contact with the cavity, where higher temperatures are expected, whereas in Specimen 1 the disk thermocouples were in contact with the surface of the gypsum plasterboard backed by steel studs. This can also be verified by comparing the infrared measurements shown in Fig. 4. Thus, the arrangement of the steel studs influences the temperature readings, and therefore the fire resistance of the wall.

(a) Specimen 1 (b) Specimen 6

Fig. 3 | Exposed surfaces of Specimen 1 and Specimen 6 after the fire test.

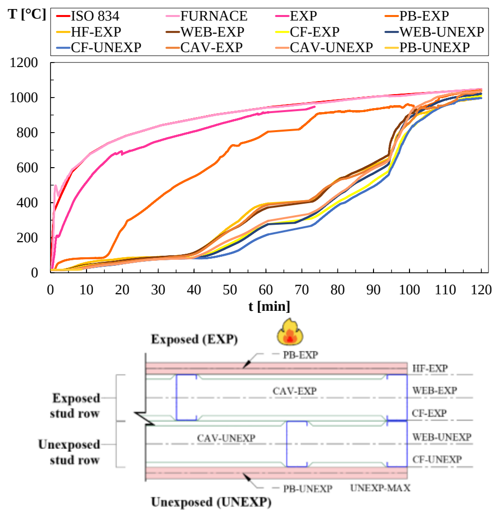


(a) Specimen 1 (b) Specimen 6

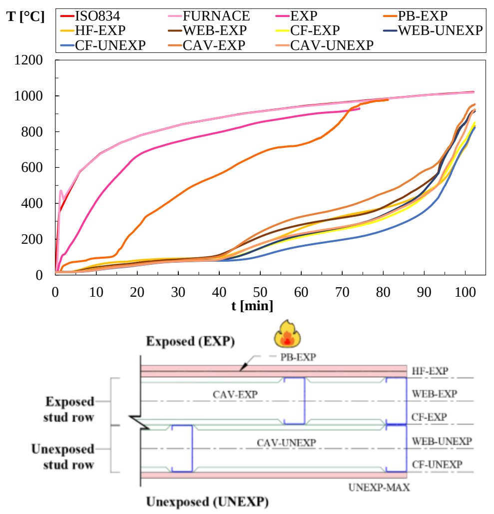
Fig. 4 | Infrared results for Specimen 1 and Specimen 6 after 70 minutes of fire exposure.

3.2. Specimen 2 and Specimen 8

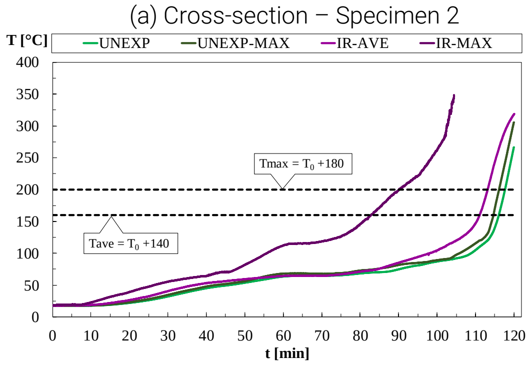
Fig. 5 presents the results for Specimens 2 and 8. When compared with Specimens 1 and 6, the temperature evolution of the specimens protected with two gypsum plasterboards on the exposed side showed a more irregular temperature profile through the cross-section, especially Specimen 2. The results of PB-UNEXP are not shown for Specimen 2 due to malfunction of the thermocouples. The temperature of PB-EXP in both specimens increased



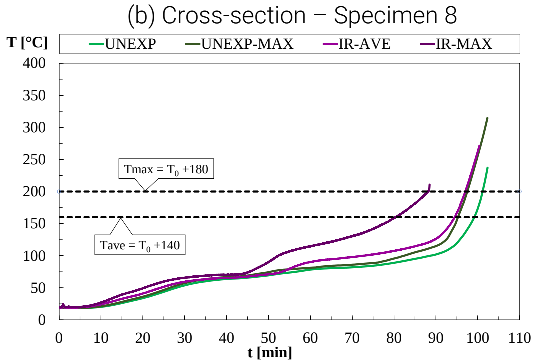
(a) Cross-section – Specimen 2



(b) Cross-section – Specimen 8



(c) Unexposed side – Specimen 2



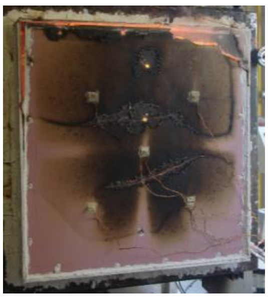
(d) Unexposed side – Specimen 8

Fig. 5 | Temperature profiles of Specimen 2 and Specimen 8.

after the first temperature plateau, evidencing the occurrence of cracks in the gypsum plasterboard in contact with the furnace side. Temperatures increased at a slow rate until 40 minutes, which is related to the additional protection layer on the exposed side. It is noteworthy that the temperature of PB-EXP remained almost flat, at high temperature level, between 60-69 minutes in Specimen 2 and between 50-55 minutes in Specimen 8, which means that more heat is being transferred to the large cavity. The inflexions observed in the time-temperature curves are due to the enlargement of the cracks and eventual fall-off of the gypsum plasterboards.

As seen in Fig. 6, long fire exposure affected severely the integrity of the unexposed gypsum plasterboard. In terms of insulation requirements, using two gypsum plasterboards on both sides (Specimen 2) and only on the exposed side (Specimen 8) increased the fire resistance of the assembly by 40 and 30 minutes, respectively.

(a) Specimen 2



(b) Specimen 8

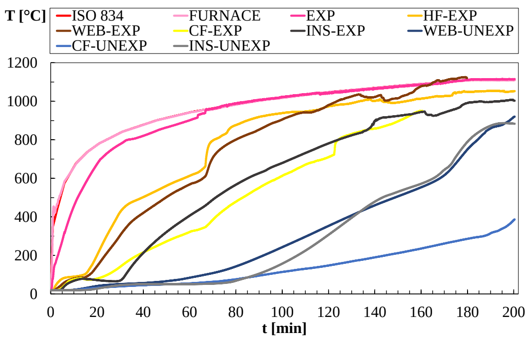
Fig. 6 | Unexposed surface of Specimen 2 and Specimen 8 after fire exposure.

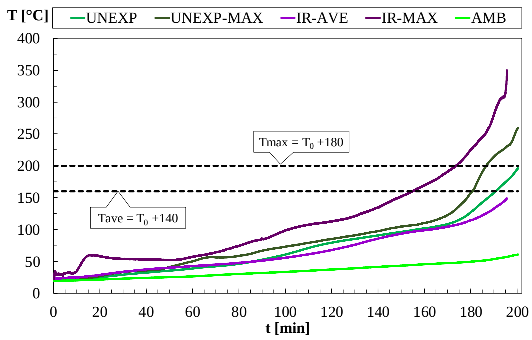
3.3. Specimen 3

Specimen 3 had both cavities filled with ceramic fibre insulation. From Fig. 7, HF-EXP increases at a much higher rate when compared with tests without cavity insulation. At 30 minutes, the temperature of HF-EXP was 60 ºC higher than the same temperature on Specimen 1. On the contrary, at the same time instant, CF-EXP was on average 114 ºC lower than that of Specimen 1. This behaviour is attributed to the small thermal conductivity of the ceramic fibre. Thus, ceramic fibre increases the temperature gradient of steel sections, as reported by others (Kesawan and Mahendran, 2018).

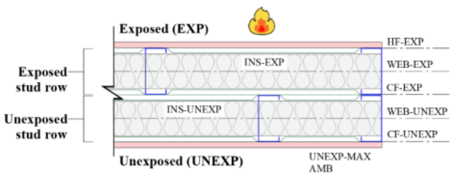
Also, the temperature inside the ceramic fibre rises smoothly throughout the tests, although portions of the exposed gypsum plasterboard detached from the frame at the end of the test. This means that ceramic fibre reduces heat transfer through the cross-section of the walls, even when submitted at temperatures as high as 1070 ºC, maintaining its integrity during the entire test. Fig. 7 shows that there is a difference between UNEXP and UNEXP-MAX during the test. This is because, in cavity-insulated specimens, higher temperatures are expected to be located around steel profiles due to the relatively smaller thermal resistance of steel. Such an effect can also be seen in the infrared results shown in Fig. 8.

Fig. 9 shows the condition of the unexposed surface of Specimen 3 and the time instants where fall-off of the gypsum plasterboard on the fire-exposed side occurred.



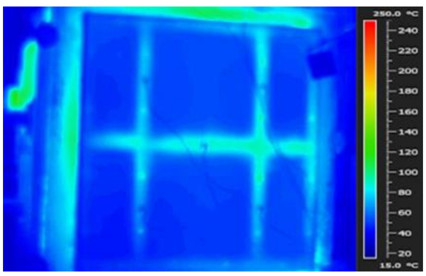


(b) Unexposed side – Specimen 3

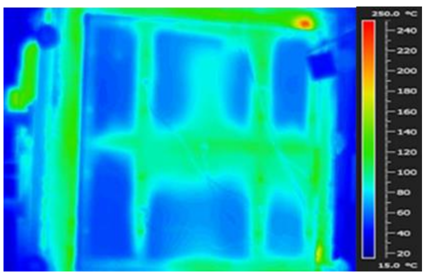


(a) Cross-section – Specimen 3

Fig. 7 | Temperature profile of Specimen 3.



(a) t = 100 minutes



(b) t = 130 minutes

Fig. 8 | Infrared results for Specimen 3 at different time instants.

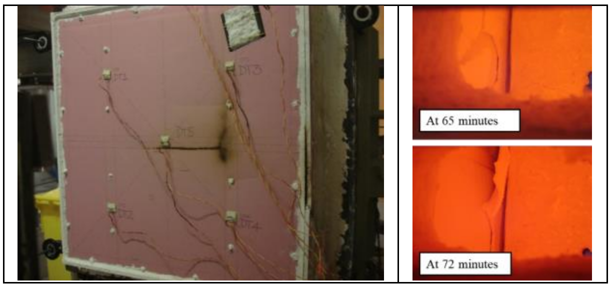
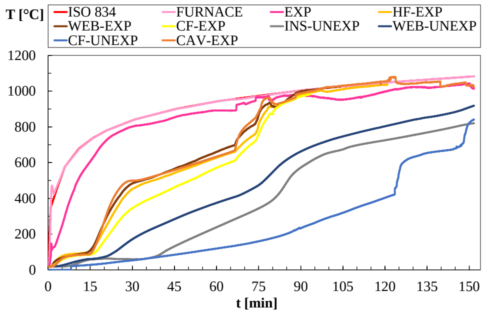


Fig. 9 | Unexposed surface of Specimen 3 after fire exposure and time instants where fall-off of the exposed gypsum plasterboard occurred.

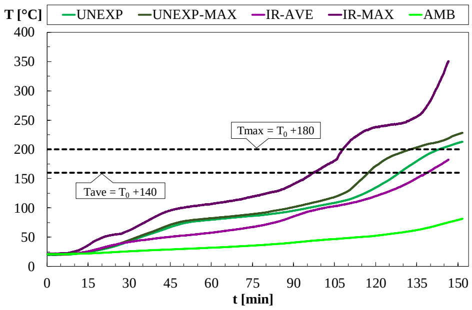
3.4. Specimen 4

Fig. 10 presents the time-temperature profile of Specimen 4. It was noticed that after the appearance of the first cracks, the temperatures of the exposed stud row increased at a higher rate when compared with the temperatures of the unexposed cavity, which is due to the presence of ceramic fibre inside the latter. As shown in Fig. 10, the studs on the unexposed stud row are in direct contact with the exposed cavity. Therefore, the temperatures of WEB-UNEXP are higher than INS-UNEXP. Also, CF-UNEXP steeply rises after 120 minutes, as gaps between the studs and insulation may exist. The temperature recorded 200 mm away from the unexposed surface rises smoothly up to 75 ºC, after 150 min.

Moreover, as shown in Fig. 11, wide cracks and fall-off of the exposed gypsum plasterboard occur at 18 and 67 minutes, respectively, explaining the sudden rise of the temperatures on the exposed stud row, see Fig. 10.



(a) Cross-section – Specimen 4



(b) Unexposed side – Specimen 4

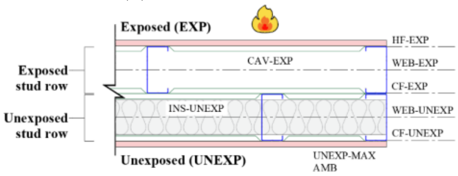


Fig. 10 | Temperature profile of Specimen 4.

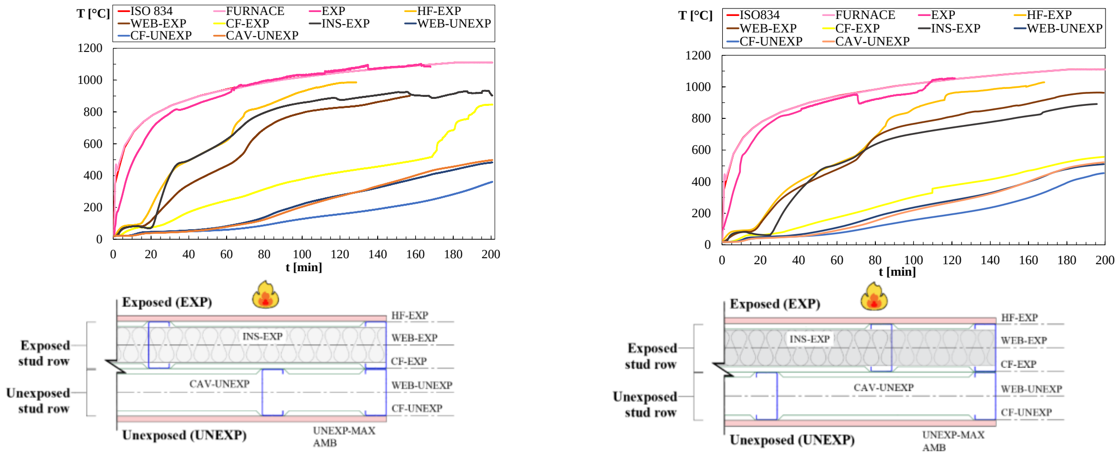
3.5- Specimen 5 and Specimen 7

Specimens 5 and 7 were partially filled with ceramic fibre facing the exposed gypsum plasterboard. Since the ceramic fibre is placed inside the exposed stud row, the heat absorbed by it is slowly released to the remaining cavity and surfaces of the wall, that is, the heating rate of the unexposed stud row is considerably smaller when compared with Specimen 4, in-

Fig. 11 | Unexposed surface of Specimen 4 after fire exposure and time instants where fall-off of the exposed gypsum plasterboard occurred.

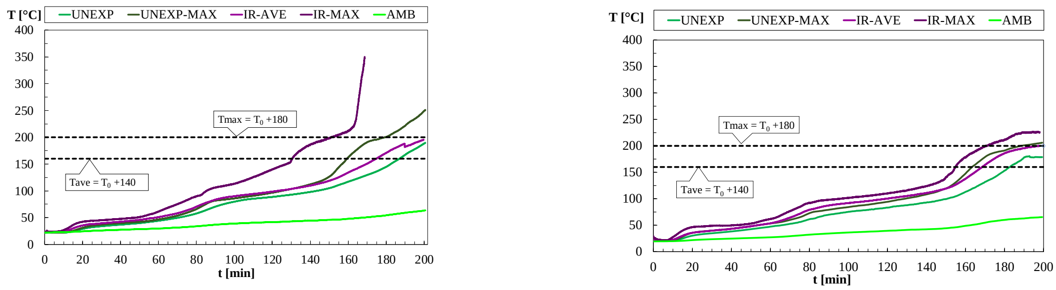
cluding the average and maximum temperatures on the unexposed side, see Fig. 12. For that reason, higher fire resistance is achieved when the exposed gypsum plasterboard is backed by insulation and the remaining cavity is empty, see Table 2.

As shown in Fig. 13, the unexposed surface of Specimen 5 was damaged towards the end of the fire test, which is linked with the loss of integrity of the exposed gypsum plasterboard, as well as eventual gaps between the steel frame and insulation blanket.



(a) Cross-section – Specimen 5

(b) Cross-section – Specimen 7



(c) Unexposed side – Specimen 5

(d) Unexposed side – Specimen 7

Fig. 12 | Temperature profiles of Specimen 5 and Specimen 7.

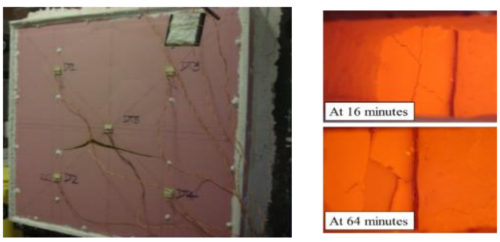


Fig. 13 | Unexposed surface of Specimen 5 at the end of the test and integrity failure of the exposed gypsum plasterboard at different time instants.

4- CONCLUSION

A wider cavity enhances the fire resistance of double stud LSF walls as it reduces the heat transfer through the cross-section. The employment of ceramic fibre insulation in both cavities increases the fire resistance of the wall by a factor of 2.6. It was verified that when the ceramic fibre is placed in the exposed stud row, higher fire resistance is achieved when compared with the specimen using the ceramic fibre in the unexposed stud row, which is due to the slow heat release from the ceramic fibre to the void unexposed stud row. Furthermore, the use of two gypsum plasterboards on both sides increased the fire resistance of the wall by 60 %, while two gypsum panels fixed only on the fire exposed side increases the fire resistance by 40 %. Also, the number of studs in contact with unexposed gypsum plasterboard impacts the fire resistance of the assembly due to the small thermal resistance of steel. As double stud LSF walls show a unique behaviour under fire, this investigation provides valuable experimental results related to their performance under fire, which can be useful to support further numerical analyses and the development of simplified design methods.

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