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ABSTRACT

It is necessary to study fire safety in buildings because the lack of knowledge in the behavior of materials has taken too many lives. However, this field has designed innovating construction systems and materials such as structural insulated panels (SIP), this is a much more practical alternative for fastest constructions, reducing the amount of material waste, offering cleaner and lighter works, its thermal insulation properties in possible fires and better durability in construction in the account of the various internal compositions. The objective of this article is to evaluate and analyze the fire resistance of two SIP for dividing and structural walls, made up of a core of expanded polystyrene (EPS) with dimensions of 3150x3000mm, one covered with cement board and the other one covered with gypsum plasterboard, both are treated with intumescent paint. The samples were exposed to the fire curve based on the ISO 834: 2014 standard and then analyzed and compared with each other. The obtained results indicate the incorporation of gypsum plasterboards provides a gain of 45 min of resistance to fire, compared to the system it only contains cement board, positively influencing gypsum in the stability and property of the thermal insulation of the panels. Likewise, it was found that intumescent coatings application effectively helps to give the SIP greater protection against fire.

Key Words: EPS, Fire resistance, intumescent coating, SIP, gypsum plasterboard.

1. INTRODUCTION

The first humans sensed that fire could be a useful tool when they began to recognize their benefits, but at the same time, they also observed fire would become a threat to their safety so it is important to develop studies on flame retardants that can improve material properties [1], [2], [3]. Building fires represent a significant part of fire-related deaths, for example, we can mention: Torch Tower in Dubai (2017 and 2015), Grenfell Tower in London (2017) [4]. Likewise, some statistics obtained from the MAPFRE Foundation during 2018 showed, 71% of fires occur in buildings, of which 33.3% happens in rooms, 21.9% in the bedroom, 5.2% in the kitchen, 2.1% in the living room, 2.1% in the garage, 35.4% do not know the starting point, adding 13% in common areas, 10% in shops, for the occupancy rate and 5% in industrial zones [5]. One of the consequences of this is the use of highly combustible building materials [4], [6], [7].

Notwithstanding, there is information about fires that remains unknown, the reason for this is the multitude of phenomena and causes that can cause them [8], [9]. This situation leads to consider a new scenario, most of the materials degrade when exposed to high temperatures, producing toxic components that severely threatened the environment, to mitigate this impact, flame retardant intumescent coatings are being developed to facilitate protection passive fire-fighting in large-scale buildings, this type of epoxy resins (EP) have highly fire-safe components and are smoke suppressants due to their components such as carbon sources, ammonium polyphosphate and a blowing agent (melamine) offering a fire-retardant effect and effectively protecting, also the characteristics of concrete as it is a non-combustible material [10], [9], [11], [12], [13] .However, in some cases high-performance concrete (HPC) different behaviors have been found at high temperatures, tending to be more susceptible owing to their low permeability, which produces an explosive rupture, technically known as spalling [14], [15].

In addition to the growing global awareness of energy consumption and environmental impact, the construction industry has promoted the development of new tools, systems, and construction methods, capable of optimizing fire behavior from physical and chemical phenomena that occurs in fires [16], [17], [18] .One of these is (SIP), which has the following functions: thermal or acoustic insulation, closing or compartmentalization properties [17], resistance to deflections, applied loads, and stress cutting [19]. Thanks to its mechanical capacity it makes the panel self-supporting, reducing the weight of the structure [20], [21].

Therefore, SIP not only resides in external properties but also internally, since it is composed of two external faces of small thickness (less than 120 mm), a thick core, and an adhesive element that helps to connect the system among each other [20]. The panels are fixed to the structure using mechanical components such as screws, staples, plates, etc. [22]. This construction element can have different materials such as polyurethane (PUR) and polyisocyanurate (PIR), expanded polystyrene (EPS), or extruded polystyrene (XPS). The protective faces can be metallic (sheet steel or aluminum) or plastic (PVC or plastic reinforced with fiberglass) [23], [24].

By incorporating the EPS system, the structural stability of the system improves, it also has a high thermal resistance; on account of its thermoplastic components, among which we can highlight Silicon Oxide (SiO_2) and Iron Oxide (Fe_2O_3) it prevents flame propagation, this foam contains 3 to 6 million independent closed cells per cubic meter of volume and more than 98% air, creating a barrier that expands its volume when is exposed to high temperatures, generating an air-penetrable cellular structure that does not allow the passage of smoke [25], [26], [27].. Furthermore, its nucleus has mechanical properties, resistance to humidity and chemicals [16].
However, the application of EPS is restricted without the incorporation of another material like cement boards since when they are combined with structural insulating panels, they increase the mechanical resistance, stability, flexibility, and humidity of the system, preventing it from breaking and gaining an 8% space, it can be used for load-bearing walls and dividing walls in buildings due to its materials such as cement, silicon and some additives [28]. Also, because of its reticulated structure, it is ideal

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for structural components to reduce weight, they do not need beams or columns [29], [24]. One of the advantages of these plates is their excellent acoustic insulation of soundproofing higher than 45dB, being a favorable response to the needs of current work [30], [24].

Analyzing the different components of SIP, it is necessary to mention the importance of gypsum plasterboards which thanks to their water tightness, rigidity, and thermal insulation properties reduces the transfer of heat through their porous structure, forming a thermal barrier [31]. The main reason for the high resistance of fire propagation through plasterboard is the dehydration phenomenon: an endothermic chemical reaction that occurs in the range of ≈90 ° C to 250 ° C, the contained water in the structure is released as vapor, causing considerable temperature lag. Consequently, the time available to evacuate the building is extended [32], [18].

The plaster-coated walls help to resist buckling. They also allow derivations and compositions, proportional to the need for resistance to humidity and acoustic insulation or fixing in large spans [33]. Gypsum laminate boards are industrially manufactured and consist of a mixture of gypsum, water, and additives, coated on both sides with cardboard sheets, which gives them resistance to traction and bending [34].
Moreover, an effective way to give greater protection to the panels is by applying intumescent coatings which expands from their original thickness when subjected to a fire situation, as a result, it protects any structural element against fire. Passive coatings have low thermal conductivity [35]. Because of their water-based chemicals and volatile organic compound (VOC), they help to prevent fires more effectively [36].

In this study, there were use experimental techniques to evaluate the behavior of (SIP) with core (EPS) with or without laminated gypsum board, taking into account these lightweight systems fulfill functions as structural and dividing walls, the main objective of this research is to determine the resistance and behavior of fire through the parameters of stability, thermal insulation and integrity of the systems, studying this is important to achieve reducing fire times and at the same time providing results to expand the information to through experimental tests, contributing to possible new studies in the scientific community.

2. EXPERIMENTAL PROCEDURES

For this experimenting procedure, the fire resistance behavior of two structural insulated panels with EPS foam core, one with cement board and the other with cement board and plasterboard (both painted with an intumescent coating), was evaluated, analyzed, and compared to each other.
The main objective of this test on both panels is to determine the fire resistance of the systems when exposed to thermal attack, resulting in the fire resistance time (FRT), checking the test parameters according to the norm [34]: structural stability, integrity, and thermal insulation.

2.1 Panels

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In this experiment, two panels were tested and compared with each other. The primary consideration was the fire resistance behavior of construction products when exposed to high temperatures. The tests were carried out under the determination of two standards. For the first system (sample 1), attributed to its very nature, its procedure was established for dividing walls without structural function UNE EN 1364-1, while for the second system (sample 2), also ascribed to its properties, the described procedure for structural components of the building was used UNE EN 13381-1 [37].

Both systems consisted of an EPS foam core covered by cement board on both sides, their joints between the sealing plates were treated with intumescent paint on their external faces. The only difference between the two systems was the inclusion of additional gypsum plasterboard for sample 2.

For the system analysis, both samples had dimensions of 3150x3000 mm and at their ends contained metallic profiles with a thickness of 600 mm. The composition of the samples is shown in Figure 1.

Sample 1 consists of a vertical dividing system, composed of a core of black EPS type F5 with a density of 20 kg/m³ and approximately 80 mm thick, covered on both sides by a 10 mm thick cement board. The gaskets between the sealing plates were treated with cementitious pastes, and fire sealant CKC-INSS 2460. The system was finally coated with intumescent paint of reference CKC-333 manufactured by CKC Ltda. This selection is due to being the national reference and market leader offering products certified, recognized, and accepted by the firefighters and regulatory bodies in Brazil. Also, because it is an international reference in the use of a low toxicity product due to the low content of VOC (Volatile Organic Compound) [38]. Finally, two coats were applied on the face exposed to the fire and one hand on the non-exposed one.

Sample 2 (panel with structural function) shared the same characteristics as sample 1. The only exception on both superimposed sides to the cement board was the insulation of a fire-resistant gypsum with a thickness of 12.5 mm. This thickness was chosen due to being generally the most used and standard commercially, suitable for coating internal surfaces such as walls and ceiling when you need fire protection. Avoiding detachment of the two faces between the cement board and the gypsum plasterboards, they were treated with ceramic and cementitious mass. Finally, the same intumescent paint reference used for sample 1 was applied to the gypsum plasterboard, applying two coats to the face would be directly exposed to the fire and one hand to the unexposed face.
The characteristics of the systems components are summarized in the Table 1.

2.2 Methods

All tests were performed in a standardized and calibrated manner as prescribed by UNE EN [37]. The purpose of the test is to determine the fire resistance time of the samples when subjected to high temperatures. In both cases, the samples are classified as firewalls or flame arresters, for a period that meets the requirements for thermal insulation, integrity, and structural stability.

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Both tests were carried out in a standardized and calibrated vertical furnace at the Technological Institute for Civil Construction Performance of the Unisonous University (itt Performance). The furnace was heated with four liquefied petroleum gas burners and controlled by differential pressure. Two burners were installed on the sidewalls of the kiln and then calibrated to increase the temperature according to the standard temperature-time curve established by the ISO 834 [39] and EN 1991-1-2: 2002 standards, given by the equation 1 [37]. The total heat output of the oven was 65,400 kcal / h, a procedure previously adopted in other studies [40], [41], [42].

$$\theta g = 20 + 345\ Log10\ (\ 8t + 1\ ) \qquad (1)$$

Where θg is the temperature of the gas in the fire compartment (°C) and t is the time (min).

The tests were assisted using 5 thermocouples, they were continuously monitored with a diameter of 0.59 inches (1.5 mm) on the fire-exposed surface and 6 other thermocouples with a diameter of 0.27 inches (0.7 mm) on its non-fire-exposed surface. The position and numbering of both internal thermocouples (face exposed to high temperatures) and external thermocouples (face not exposed to high temperatures) are shown in Figure 2. The thermocouples 6 to 10 (external) coincide with the position of the thermocouples 1 to 5 (internal) and obey the location precepts of the standard [43]. It is worth noting for sample 2 an additional thermocouple was installed on the external face (number 11) located right in one of the joints between the plates of the system to evaluate the temperature at this point. However, it is important to clarify that this fact does not alter the test results.

Temperatures were recorded every 30 seconds during testing and with an accuracy of ± 1.5%. In addition, a thermal imaging camera, a stopwatch, and laser tape were used to carry out the control tasks.

On the other hand, a thermographic camera and a laser tape were also used to monitor and measure horizontal displacement. All results were finally visually inspected throughout the procedure. Table 2 shows the technical description of the equipment used in this study.

During the test, the load capacity, integrity, and thermal insulation of the systems were checked. Load-bearing capacity is defined as the load element´s ability to withstand its test load without exceeding the specified deformation of the panels. For this experiment, the load capacity was checked, applying a load of 5Ton/m. According to the UNE EN [43]**.** standard for both systems, the load must be applied before the start of the thermal program, it must be maintained throughout the test period, and then reapplied 24 hours later, as long as it can be applied to the systems.

Integrity refers to the ability of a separating element when exposed to fire on one side, to prevent the appearance or passage of flames and hot gases on the non-fire exposed side in the construction of a building [39], [10]. Finally, thermal insulation is the ability of a partition element when exposed to fire on one side, to restrict the

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temperature rise of the non-fire exposed face in the construction of a building to below-specified levels [39], [10].

3. RESULTS AND DISCUSSION

The test for sample 1 had 29 min, with an initial temperature of 25 °C, from the respective start. After 4 minutes, heating on the panel was observed and the release of smoke began in the upper part. After 20 minutes, the release of dark smoke began, and the system presented a transverse displacement. However, it had a stable behavior until minute 25 where flames were shown on the cementitious plate. Finally, at minute 29, the system had an inflammation-causing it to lose the tightness test, which resulted in losing the integrity of the system.
The test for sample 2 lasted 82 minutes with an initial temperature of 18ºC. After 18 minutes of being exposed to fire, the system began to show cracks in the joint´s upper corner. Between minutes 25 and 28, the smoke release began in the center and on the right side of the sample. At 50 minutes, there was a transverse displacement of the system. However, the system presented a stable behavior without collapsing or losing its stability and integrity. Finally, at minute 81, the cementitious plate appeared burned, finishing the test 1-minute passes. It is also the system showed the bubbles on the surface of the face not exposed to fire, as evidenced in Figure 4.
For a better representation, Table 3 presents the main events recorded in the tests carried out for both samples.

3.1 Load bearing capacity

For sample 1, displacement suffered by the sample during exposure to the fire were evidenced at each instant. Still, after 10 minutes, greater displacements began to be noticed, occurring the maximum deformation (16 mm) 20 minutes after starting the test, which indicates an unstable behavior compromising its mechanical resistance. Sample 1 reached a fire resistance time (FRT) of 20 min. Figure 5, shows the horizontal displacement of sample 1 every 10 minutes throughout the test.

For sample 2 was subjected to a representative load of the incident load on the walls of a conventional building, producing forces of the same nature and order of magnitude as those observed in the building in use, as established by the standard [43]. During the test, arrows, deformations, or signs of instability characterize the loss of mechanical resistance were verified. The load was applied before starting the thermal program and was maintained throughout the test period and was reapplied 24 hours after the end of the test. The horizontal displacement suffered by sample 2, verifies a maximum deformation presented of 9 mm after 50 minutes from the start of the test, as shown in Figure 5.

Sample 2 had an internal temperature during the 972.06 °C with a total duration of 82 minutes, reaching a fire resistance time (FRT) of 65 minutes. Considering the loss of its stability, it was not possible to apply the load 24 hours after the end of the test, so

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the fire resistance time of the sample is considered 80% of the time in the requirements of the thermal service program, according to the norm [43].

3.2 Integrity

The tightness of the systems consisted of verifying the passage of gases and fumes outside the furnace and was evaluated employing the ignition of a cotton bearing located at a distance of 1 to 3 cm from the deflagrated cracks of the sample for 10 seconds. For this parameter of the fire resistance tests, the samples tested had different reactions. For sample 1, the cotton inflammation was verified, and the system was characterized by the loss of integrity and tightness at 29 minutes. While, for the other system, despite crack openings were verified at 18 minutes and at the time of conducting the tightness test the system had been testing for 59 minutes, no ignition of the cotton pad was detected, the sample being characterized as a seal against the passage of hot gases and smoke throughout the test period, as shown in Figure 6.

3.3 Thermal Insulation

The verification of the thermal insulation consists of an analysis of the high temperatures registered at the external face of the sample (not directly exposed to fire). For it, the standard [39] specifies the average temperature (the arithmetic mean of the 5 thermocouples located on the outer face) measured by the thermocouples cannot exceed 140 °C, and the temperature of none of the punctual thermocouples cannot exceed 180 °C.

As is shown in Figure 7, for sample 1, the point temperatures and the average of the face´s measurements not exposed to fire reached a test start temperature of 25 °C, values of 161 °C and 201 °C, respectively. In such a way, it was found the average temperature and point limits were not reached during the first 29 min of the test. For this reason, the system did not cause any loss of thermal insulation during the test.

Concerning sample 2, unlike sample 1, the initial test temperature of 18 °C on the face not exposed to fire reached an average temperature limit of the thermocouple of 158 ° C and the temperature limit of each thermocouple of 198 °C, it should be noted that the temperature limits were not exceeded in the course of the test, obtaining 65 minutes. It is also important to highlight time gain compared to sample 1 when it had already reached its maximum point, just from this moment on, as soon as system 2 began to present behaviors, showing this as shown in Figure 8.

Another aspect to highlight is the thermocouple 11 did not present an increased temperature higher expected, and its behavior was stable. Therefore, sample 2 can be considered as a thermal insulator for the entire test period. A curious fact to mention is this thermocouple reaching even lower temperature values than the thermocouple located in the geometric center of the sample (thermocouple 8). This may be the result of joints treatment o with intumescent paint used for both samples tested in this experimental program.
In a complementary way, Figures 9 and 10 show some thermographic images recorded at different moments during the fire resistance test for samples 1 and 2,

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respectively.

3.4 Final appearance

Once the test was finished, and after each of the systems had cooled independently, the furnace structure was dismantled to better inspect the results obtained, finding signs of changes in their structures such as chipping on the face exposed to the fire, for both sample 1 and sample 2. Details of the final aspects obtained for each system are explained below. Figure 11 shows the initial and final appearance of the faces exposed to fire.
In sample 1, the system changed even on the face not exposed to the fire; the cement plate presented flaking, it was completely consumed, and its internal components showed high decomposition.

In sample 2, the system did not suffer excessive changes on the face not exposed to the fire, or bubbles were observed in the upper part of the unexposed one. It should be noted for both systems, when subjected to high temperatures, the panels suffered great damage to their internal structures upon consumption of EPS core.

3.5 Discussions

Despite the importance of studies that helps to mitigate structural fires that occur daily, claiming many people's lives, the behavior of construction systems in fires is still acknowledged as largely unknown, being considered a field is not much investigated. Thus, in this study, the fire behavior of 2 samples of structural insulated panels with EPS core was analyzed, one with the cementitious board as internal material and the other one covered with gypsum board, both coated with intumescent paint. Attempted to find relevant differences or the impact and its influence of gypsum plasterboard has to improve the fire performance of this type of panels.

The systems were characterized by having the same structure and composition, differentiating sample 2 with the inclusion of additional plasterboard. In this experimental investigation, it was possible to demonstrate the structural stability presents these constructive systems, despite the occurrence of millimeter displacements both samples suffered. Sample 1 reached a maximum displacement of 16 mm measured at 20 min showing a stable behavior, while for sample 2, its maximum displacement was 9 mm, estimated at 50 min. Although after 60 minutes of exposure to fire, it did not affect lateral displacement.

It should be noted both have high bending and compression strength so the structural capacity may influence these results, which can meet the requirements of walls with and without load, but when exposed to high temperatures, their behaviors vary. The difference between the results can be supported by the differentiating component materials' internal characteristics and chemical compositions (cement board versus gypsum board). For sample 1, the cementitious plates worked as an ideal insulator for the EPS core, helping both from reaching thermal equilibrium, affecting each other more slowly. However, by presenting the cementitious plate's movement, it is also relevant to mention this system does not have joint protection, so the flames reached the EPS core more quickly. While for sample 2, having

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gypsum board incorporated could have helped protect the second plate (cement plate) and cement joints, which caused the reduction of expansion or dilation and avoiding thermal movements in the elements. This could also be explained as an increase in each material's internal particles' temperature, causing a greater distance or separation between them.

Very significant findings were also manifested in the samples integrity parameter, considering the sample1 presented openings or fissures in the system from the first 15 minutes, for which it achieved a shorter fire resistance time. Conversely, sample 2 behaved better, avoiding the passage of flames outward. However, the load condition acted as a determining factor with the resistance of the panels because the system was not subjected to the load test showed better sealing behavior and maintained its stable structure throughout the test, unlike the other one which was loaded.

Another important aspect was the temperature reached on the face not exposed to the fire, showing a slight reduction in the external temperature with the inclusion of gypsum. The average temperature reached for the system with the cementitious plates only was 161 °C. In comparison, the plasterboard system reported an average temperature of 158 °C, demonstrating the benefits of thermal insulation of this material.

In general terms, both systems presented a good behavior in relationship with fire resistance, being classified in the firewall categories FW-20 and FW-60 the system of sample 1 and 2 respectively, according to the standards [43], permitting the gypsum a four-fold increase in the fire resistance time for sample 2. This contribution can be attributed to the increase in the insolation coat and the joint treatment for this second system, highlighting how important joint treatment is. A similar result had been already observed from previous studies where EPS was covered with plaster to address its behavior against fire, categorized as "difficult to ignite" [44], [45] also indicated the emission of smoke production was minimum, it does not represent toxic gases affects people's quality of life. The reason for this is the low thermal conductivity of EPS of 0.036 W/Mk [44], providing a positive response for the application suitable as a thermally insulating material.

When comparing the cement plates behavior with gypsum boards, considering they both perform as non-combustible materials and can be used as coatings for panels, it was found that the flash time of plasterboards is much longer. It is unlikely to ignite spontaneously when subjected to fire, as well as being a good insulator to fire, being the opposite for cementitious plates its ignition time is shorter. One of the main reasons why the fire resistance behavior through plasterboards is better is derived from the fact which possesses amounts of water in its molecular structure, and when they are heated to more than 100 °C, the water begins to evaporate while the heat destroys the system, it undergoes a dehydration process, or an endothermic reaction begins at 90 °C. This is also for the presence of rocks such as limestone and phosphorite as a consequence of their non-combustible characteristics, helping lower the temperature during more extended periods [46].

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This fact is also supported by the use of cardboard gypsum board helps as a determinant for the propagation of the fire; its coefficient of thermal conductivity is 0.28 W/m.K [47] being lower than the cementitious of 0.35 W/m.K [48], affirming the gypsum boards function as a retardant to the propagation of fire. This was evident in sample 2 that includes gypsum when reflecting a useful behavior, being the cementitious board and the expanded polystyrene fireproof material to incorporate the cardboard gypsum boards.

Additionally, it is worth noting the inclusion of plasterboard in this type of panels contributed to the improvement of the thermal insulation factor but also the structural rigidity. This can be evidenced by comparing the deformations measured for each of the tested, sample 2 yielded lower maximum values (9 mm) than sample 1 (16 mm), as is shown in the comparative graph represented in Figure 5.

According to the literature, through studies in which fire experiments have been developed in panels SIP with a PIR core, satisfactory results have been obtained and indicated the temperature of the side not exposed to the fire is lower. However, when these systems are exposed to high temperatures, the PIR core creates space between the joints. this indicates the join´s temperature has risen much more than the panel temperature, being considered a point of failure of some systems [49]. Nonetheless, when reducing these spaces to be treated, the panel systems' insulation would improve, reaching much higher fire classification standards [50].

Subsequently, the structural insulated panels also have excellent results as thermal insulation and mechanical resistance properties to be used for structural walls and can be formed by various coatings appears weak separately but when joined. In large-scale fire tests for domestic homes in which they have been built with EPS core and clad with plasterboard, have indicated good performance resulting in passive fire protectors and very stable structures [51], [52].

Ratifying the results above, studies have been found on the properties of gypsum boards in light construction systems demonstrating the efficiency of this material against fire. The transfer of heat from the fire-exposed surface of the gypsum board to the unexposed surface is strongly delayed during the initial stage of the fire, causing a considerable delay in the temperature increase in the plasterboard [53]. For all this, it can be said gypsum boards offer significant benefits in delaying a fire and facilitating the evacuation of people in any fire situation [53], [54].

It can also be inferred the joint protection and the intumescent paint used in the samples tested in this experiment acted as fire retardants, preventing the transfer of heat directly to the core (EPS) of both systems. Still, even so, it is considered that probably the fire resistance behavior of these types of panels could be improved either utilizing the inclusion of prefabricated pieces, fiber cement board, or glass fibers that tend to have fire-resistant properties.

On the other hand, the significant advances in fire safety carry out permanent studies in expanding polystyrene foam (EPS), especially used as an interior or exterior wall for thermal insulation in buildings, like the Caliskan and Alpala survey [55]. These studies recommend applying an effective flame retardant composed of resin as phenolic epoxy, which makes up a surface coating equivalent to a protective "shield". Some tests also prove the importance of EPS and its efficiency to lower heat and extend ignition time by 70 percent [56].

Finally, considering the Structural Insulated Panels (SIP) with expanded polystyrene (EPS) core present good behavior against fire-as long as it is protected from flames-, the authors considering these materials altogether offer a good system for construction and is a valid and attractive option for interior construction applications in homes with lower fire risk, reducing construction times and costs.

4. CONCLUSIONS

The fire resistance behavior of two panels of dimensions 3150 mm x 3000 mm with expanded polystyrene foam core covered by a cement board treated with an intumescent coating was evaluated and analyzed according to the UNE EN standards, to later be compared with each other. The following findings were obtained:

1. Sample 1 reached an FRT of 29 min showing a stable behavior, characterizing the loss of intensity, although the system met the stability requirements and thermal, being categorized as FW-20.

2. Sample 2 achieved a FRT of 82 minutes, but it had a failure in its stability, so it was classified as FW-60.

According to the results obtained in this experimental and comparative study, it could be verified that both panels have a considerable fire resistance behavior, and the application of the intumescent coating effectively works to give the panels greater protection against fire. It is important to highlight that the panel coated with gypsum board obtained better results (increasing the classification category 4 times), compared to coated with cement board, also positively influenced as thermal insulation and protection against passing gases.

On the other hand, and despite the obtained results, it is recommended to study and analyze the panels with EPS core with the same structure, under addition of fire-resistant materials for a better understanding of the behavior to fire and mainly considering the analysis of chemical aspects. Likewise, it is recommended for future works to analyze the sound insulation effect of this type of panel, as well as the performance of the other parameters.

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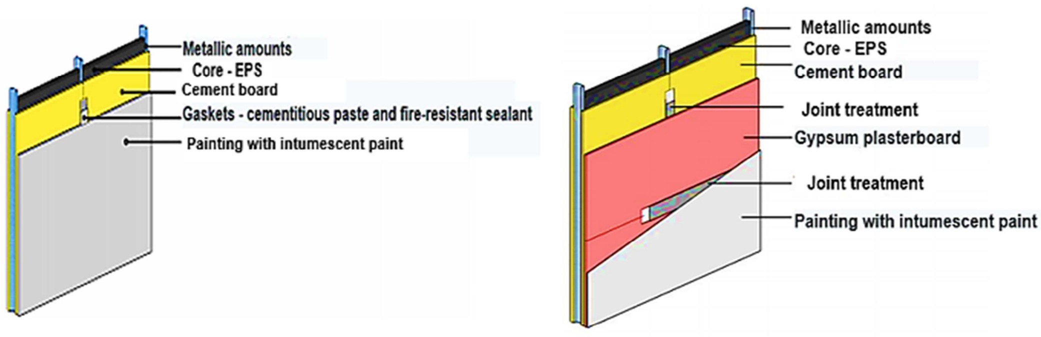
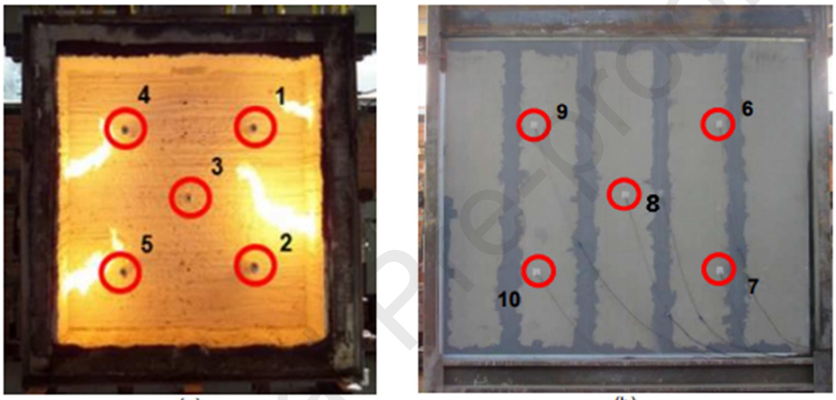
FIGURES



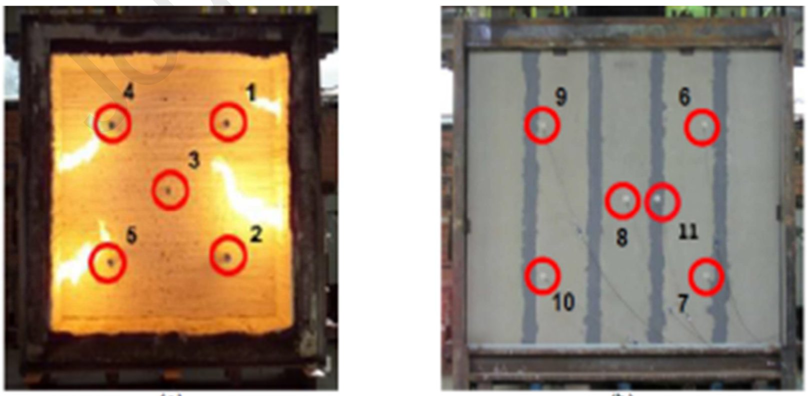
a) b)

Figure 1. Illustration of components in a) sample 1 and b) sample 2.



(a) (b)

Figure 2. The numbering of internal thermocouples (a) inside the furnace and external (b) on the face not exposed to fire for sample 1.



(a) (b)

Figure 3. The numbering of internal thermocouples (a) inside the furnace, and external (b) on the face not exposed to fire for sample 2.

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Figure 4. Bubble formation in sample 2, after being tested.

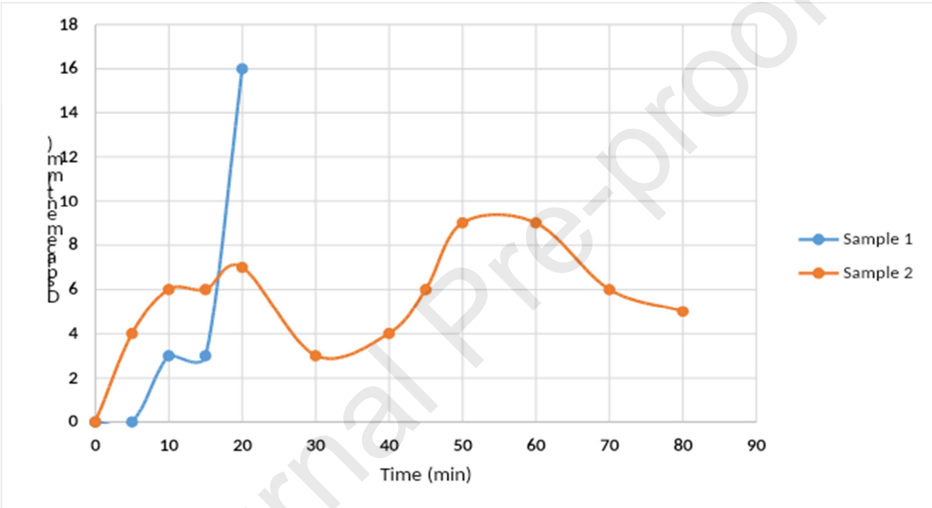

Figure 5. Displacement suffered by samples 1 and 2 tested during their fire testing times.

a) b)

Figure 6. The integrity test procedure for the a) sample 1 and for the b) sample 2.

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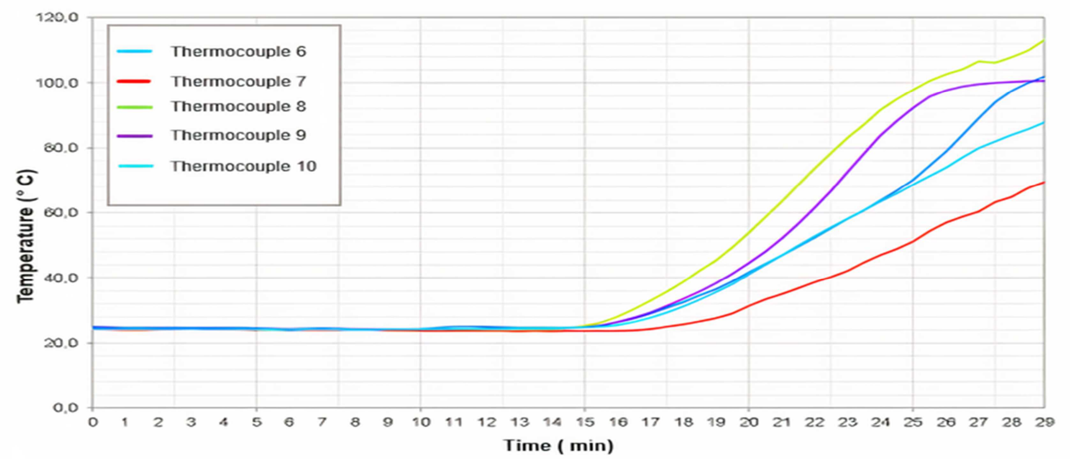

Figure 7. Temperature values were recorded by external thermocouples for sample 1.

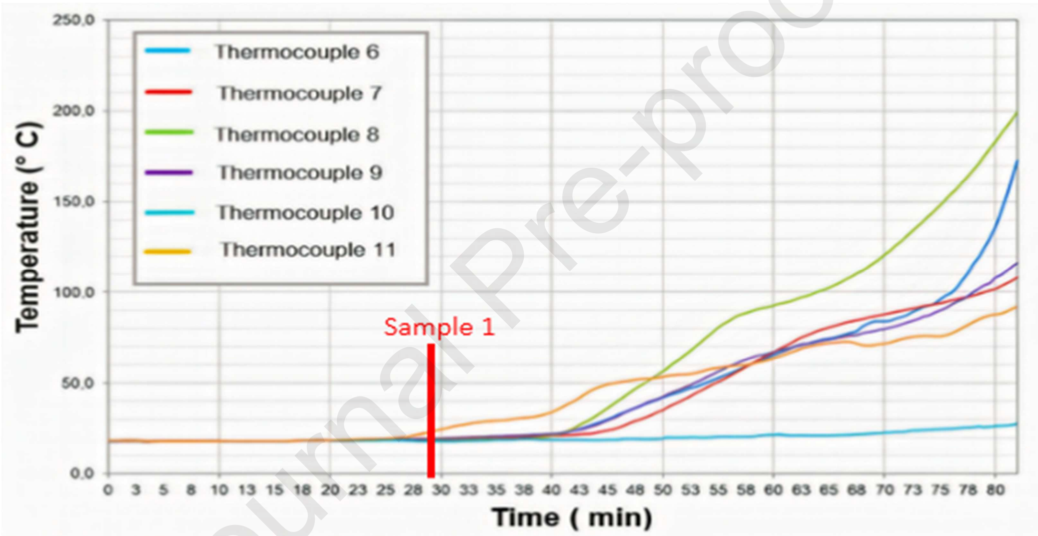

Figure 8. Temperature values were recorded by external thermocouples for sample 2.

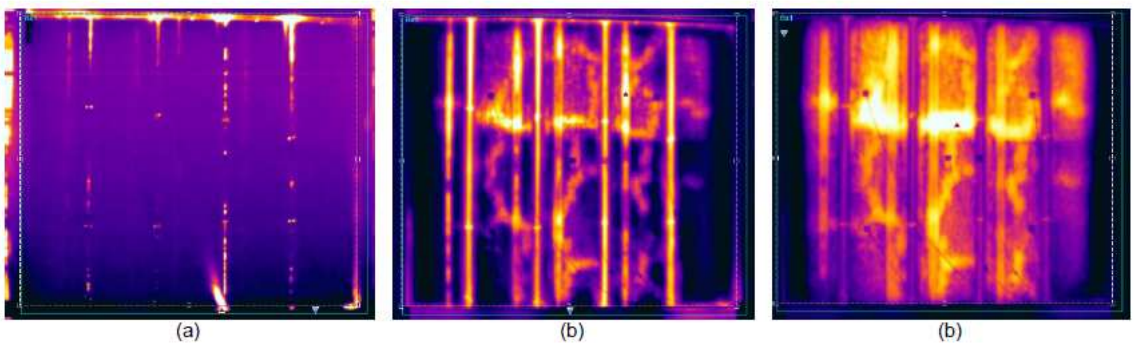

Figure 9. The temperature increased in sample 1 recorded by the thermographic camera at (a) 4 minutes, (b)15 minutes, and (c) 20 minutes.

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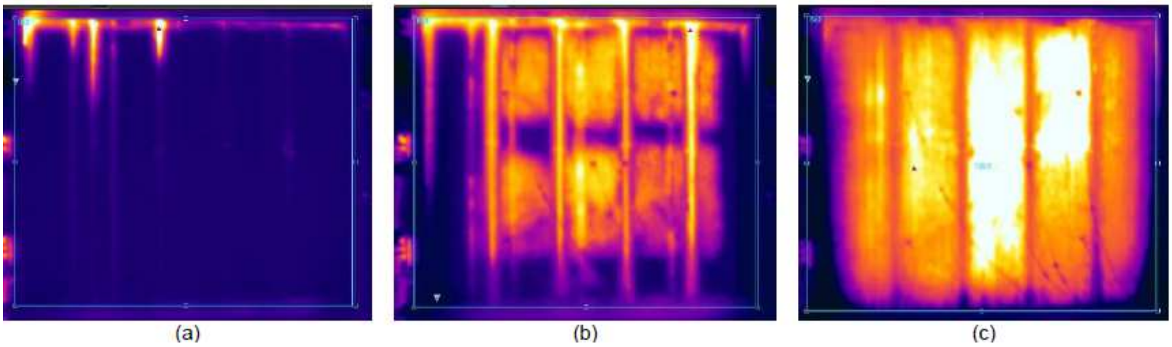

Figure 10. The temperature increase in sample 2 was recorded by the thermographic camera at (a) 15 minutes,(b) 50 minutes, and (c) 80 minutes.

	Before exposure to fire	After exposure to fire
Sample 1		
Sample 2		

Figure 11. Initial and final aspects of the external faces of the samples before and after being tested.

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TABLES

Component	Property	Sample 1	Sample 2
Structure	Description	Metallic amounts	
	Spacing	600 mm	
EPS Core	Description	Black EPS of type F5	
	Thickness	80 mm	
	Density	20 kg/m2	
Cement board	Thickness	10 mm	
Gypsum plasterboard	Thickness	-	12.5 mm
Joint treatment (both sides)	Description	Cementitious paste	
		Fire sealant CKC-INSS 2460 (CKC Ltda)	
Finish Coating	Description	Intumescent paint CKC-333 (CKC Ltda)	
	Application	Two coats	

Table 1. Characteristics of the component materials of the samples tested.

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Description	Manufacturer/ Model	Technical capacity
Thermal camera	FLIR / A325	Minimum capacity: 0°C Maximum capacity: 350°C Resolution: 1°C
Chronometer	Extech Instrument / 365535 (itt Performance – E050P)	Minimum capacity: 0:00':00"1s Maximum capacity: 9:00':99"9s Resolution: 1/100s
Fire resistance furnace	Grefortec / GFT 03276 FG (itt Performance – E054P)	Capacity: 1200°C Resolution: 0,01°C
Tren láser	Bosch / GLM 150 Professional (itt Performance – E051P)	Minimum capacity: 0m Maximum capacity: 150m Resolution: 1mm
Thermometer	Instrutemp ITMP 600 (itt Performance – E003P)	Minimum capacity: 10°C/20%/20dB(A)/0Lux Maximum capacity: 60°C/80%/130dB(A)/2000Lux Resolution: 0.1°C/0.1%RH/0.1dB(A)/1Lux

Table 2. Equipment used in the experiment.

Time (min)	Sample 1	Sample 2
0	Start of the thermal program	Start of the thermal program (charging and heating)
1	Smoke release begins	Smoke release at the top of the sample
4	The joints are heated and smoke is released at the top	-
10	Smoke release at the bottom ends	-
18	-	Smoke release from the gasket on the right side of the sample
20	Release of dark smoke	-
25	Flaming spots are observed on the cementitious slab	Smoke release from the joints in the center of the sample
28	Tightness test: no inflammation of the cotton pad	-
29	Tightness test: with inflammation of the cotton pad	-
29	End of rehearsal	-
31	-	Moisture release near the joint on the right side of the sample
38	-	Tightness test: no inflammation of the cotton pad
45	-	Smoke release with darker coloring
59	-	Tightness test: no inflammation of the cotton pad
72	-	Tightness test: no inflammation of the cotton pad
81	-	The cementitious slab looks burnt
82	-	End of rehearsal

Table 3. Summary of the main events recorded during the tests performed.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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