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FIRE BEHAVIOR IN CORNER TESTS OF INTERIOR FINISH MATERIALS UNDER NATURAL CONDITIONS

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Abstract: *In order to make a more accurate prediction of fire behavior under natural conditions, there were performed tests, using a corner configuration, the analyzed materials being wood chipboard, gypsum board, decorative polystyrene and polyvinyl chloride (wallpaper). The test space simulates the SBI (Single Burning Item) Test under modified conditions of geometry, ventilation and burner. Thus, data on flame spread use of a thermal vision camera were analyzed. It was found that, in the case of experimental tests performed with wood chipboard and polystyrene panels, the spread of flames and recorded temperatures have higher values unlike tests performed with polyvinyl chloride (wallpaper) and gypsum board, in which are recorded the lowest values.*

Key words: *Flame spread, corner configuration, Single Burning Item Test.*

1. INTRODUCTION

Corner fires are known to spread faster than simple wall fires [1]. Therefore, in the European concept of testing and classification of construction products in terms of fire reaction, the corner test (SBI method [2]) plays a key role. The reference scenario for the SBI method takes into account the development of the fire that can reach the flashover, and is simulated by a single burning product located in a corner of the test room, which generates a heat flux on adjacent surfaces. Evaluation of fire reaction performance measures the ability of the material to contribute to the spread of fire. This feature is specific to the beginning of the fire growth phase, when temperatures are relatively low. The SBI method is an intermediate scale test and was developed to allow the harmonization of the classification in terms of fire reaction in Europe [3] with the assessment of fire hazard in other countries [4]. Therefore, the main objective developed was that the ranking of products in the SBI should be as closely correlated as possible with the classification obtained in the ISO room corner test [5] [6].

In this article, are presented the results obtained after performing several experimental tests, under identical conditions, using commonly used materials from a commercial point of view, made of polystyrene, polyvinyl chloride, gypsum board and wood chipboard. Thus, in order to predict the fire behavior under normal conditions for most final uses of construction materials, in this paper is analyzed the development of fire in a corner configuration, performing experiments that simulate the SBI test, but with various conditions of ventilation and air currents development (**fig. 1**). The value of the mixing speed of the fire effluents with the ambient air in a corner flame is lower than that in the case of a free fire flame, which leads to higher values of both height and flame temperature. This makes the walls heat up more intensely in a corner fire configuration [1].

From the literature it has been found that in SBI tests the height of flames increases in direct

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proportion to the HRR value [1, 7, 8]. In order to increase fire safety by using materials with flame retardant properties were performed experimental tests specific to corner fire configurations [9, 10, 11]. This article analyzes, at the level of the two panels in the corner configuration, the spread of the flame and the evolution of the temperature measured with both K-type thermocouples (in several characteristic points, located on three levels, namely at 1.9 m, 1.6 m and 1.3 m from the floor), as well as by using a thermal vision camera.

2. DESCRIPTION OF THE TESTING PROCEDURE

2.1. Characteristics of the test room

The test room was designed taking into account the fact that both the surface dimensions of the ventilation openings and the thermal properties characteristics of the materials used to insulate the walls have a great influence on the evolution of a fire in an enclosed space. These conclusions resulted from simulating a fire in the test room, using the B-RISK software [12].

The test room specially designed for this research was fire protected with basalt wool, fire-resistant gypsum board (120 min) for the ceiling and non-combustible calcium silicate (SiCa) plates for the walls - **fig. 1.**

Fig. 1. Interior design (fire protection) of the test room, which simulates SBI test conditions

Following this arrangement, the test room has the next interior dimensions: length 5.2 m, width 2.9 m and height 1.9 m with three openings: two doors with a total opening of 2.4 m x 1.9 m, a single door (0.9 m x 1.9 m) and a window (1.3 m x 0.9 m), as can be seen in the sketch presented in **fig. 2.**

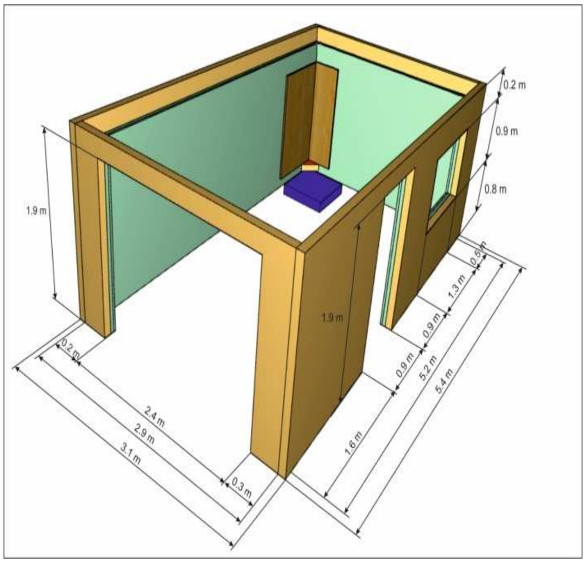

Fig. 2. Schematic representation of the test room with the highlight of the ventilation openings dimensions (doors and windows)

2.2. Characteristics of the materials used

Two panels (test boards) are placed vertically and perpendicular to each other to form a corner. The long panel is 1.5 m high and 1.0 m wide, and the short panel is 1.5 m high and 0.5 m wide (**fig. 3**).

Fig. 3. Test plates dimensions

A triangular burner with ethanol, made of refractory steel, with a lateral dimension of 0.25 m is located next to the panels (**fig. 4**).

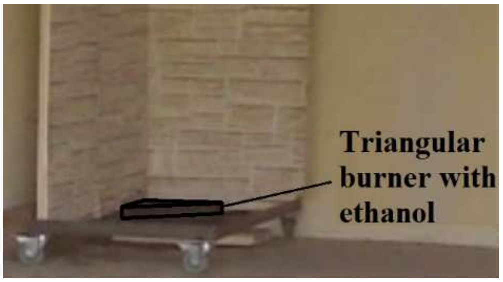

Fig. 4. The location of the triangular burner with ethanol

The burner with ethanol, with a purity of 99.3% (1 liter), is the source of fire, being positioned in the lower corner of the panels, similar to the SBI tests. The heat released by the burner (HRR) has the value of 12.56 kW for 20 min. To determine the evolution of a fire, commercial materials with the following thicknesses were used: polystyrene (16 mm), polyvinyl chloride (wallpaper - 0.5 mm), gypsum board (12.5 mm) and chipboard (12 mm).

Currently, there are data in the literature on the fire behavior of materials often used in construction (except for interior decorative polystyrene), the results of SBI inter-laboratory tests [13-17] for the materials in this study being presented in *Table 1*.

Table 1

Inter-laboratory results obtained from SBI tests performed for the materials in this study

Product	Depth [mm]	Density [kg/m^3]	Time to flashover [sec]	Peak HRR [kW]	Fire reaction class
Gypsum board	13	700	-	394.35	≥B
Wallpaper on gypsum board	13	700	-	394.7	≥B
Polyvinyl chloride wall finish on gypsum board	13	Plaster: 700	675	2312	C
Chipboard	12	700	155	2221	D

The construction products can be classified into fire reaction performance classes without the need to be tested on the basis of the European Reference Standard for the product: gypsum board [18], wallpaper [19] and chipboard [20]. For the interior decorative polystyrene, there has not been identified the reference standard for inclusion in Euro-classes. The materials used to determine the evolution of a fire, in this study, are shown in **fig. 5**.

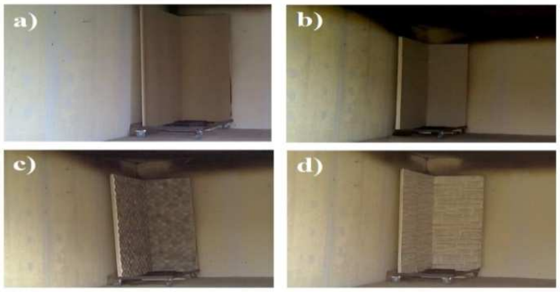

Fig. 5. Materials used to determine the evolution of a fire in this study: a) chipboard; b) gypsum board, c) polystyrene; d) polyvinyl chloride (wallpaper);

The plate / panel materials were mounted according to the manufacturers' instructions, according to end-use conditions, directly on the non-combustible material (SiCa). The polyvinyl chloride wallpaper was applied on a gypsum board.

2.3. Comparisons with other experimental methods specific to corner configurations

There are two experimental methods specific to corner configurations: the SBI method and the Room Corner Test method.

The SBI method is used to classify building materials into the European Class System. This method involves burning a single object in a corner of a room. The material analyzed is arranged in the form of two vertical panels, measuring 1 m × 1.5 m and 0.5 m × 1.5 m, and the burner, located between the two panels, has a triangular shape, with a side length of 250 mm, being fueled with propane. The HRR (en: heat released rate) of the burner has the value of 30 kW for 21 min, the recorded results being analyzed only for the first 20 min. The test room is provided with a floor, but not with a ceiling, the effluents resulting from the burning of the material being collected through a hood. The analyzed parameters are HRR, the flame spread laterally, on the panel with the larger surface, the production of smoke and the burning particles / drops. Following the results obtained, there are calculated the fire growth rate and the smoke production rate [3]. The Room Corner Test method involves, according to ISO 9705, a test room with the following dimensions L = 3.6 m, l = 2.4 m, h = 2.4 m, characterized by the fact that three interior walls and the ceiling are covered with the analyzed material. The door of the room is open, so that smoke and hot gases are collected at the top, through a hood and an exhaust system, and fresh air is introduced inside at the bottom. The ignition source consists of a gas burner, located in a corner of the room. The HRR of the burner is 100 kW for the first 10 minutes and 300 kW for the next 10 minutes. The analyzed parameters are HRR and the smoke production rate, these being measured continuously [5].

It is known from the literature [21] that there are good correlations between the results from the SBI method and the Room Corner Test method in terms of fire growth rate.

The test method used in this article is very similar to the SBI method, with the difference that the substance used in the burner is ethanol, but also by the fact that the both front doors of the test room are open, which ensures a natural spread of fire effluents. The analyzed materials were arranged on two panels that form a corner configuration, as follows: gypsum board, chipboard and polystyrene were applied directly on the incombustible material (SiCa), and the polyvinyl chloride wallpaper was applied on a gypsum board. Similar to the Room Corner Test method, in which the door of the room is open, in the method applied in the experiment conducted for this article, the ventilation openings are represented by two doors and a window. The analyzed parameters in the tests are the flames spread (common element of the SBI and Room Corner Test methods), respectively, the temperatures measured both with K-type thermocouples (located on three levels, at different heights from the floor) and with a thermal vision camera.

2.4. The characteristics of measuring equipment

Real-scale tests were performed in the space specially designed to determine the evolution of a fire using commercial materials made of polystyrene, polyvinyl chloride, gypsum board and chipboard. During the experiments, 27 K-type thermocouples (cromel-alumel) were used with a measuring range up to 1200 ℃, for monitoring the temperatures on 3 layers in the space that was set on fire.

In fig. 6, the 1st layer of thermocouples is presented, located at approximately 1.9 m from the floor.

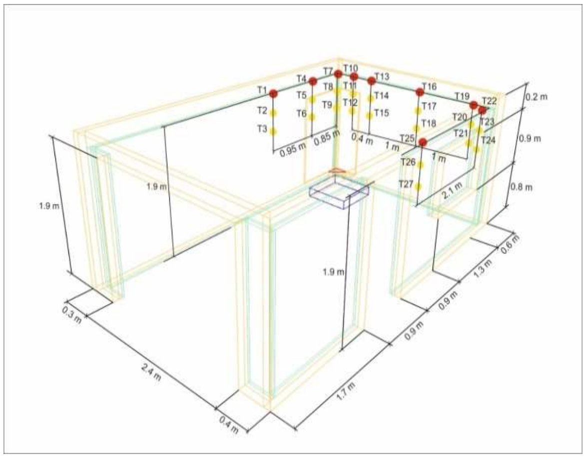

Fig. 6. Location of layer 1 of thermocouples

In fig. 7 is presented the 2nd layer of thermocouples, located at about 1.6 m from the floor.

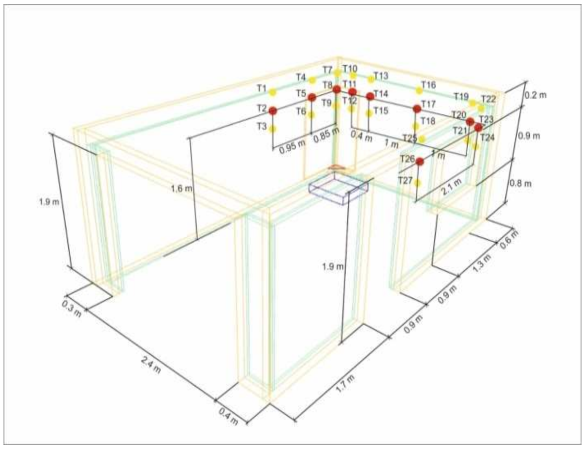

Fig. 7. Location of layer 2 of thermocouples

In fig. 8 is presented the 3rd layer of thermocouples located at about 1.3 m from the floor.

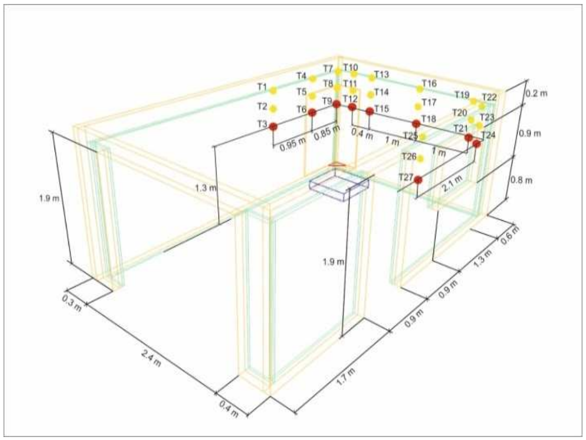

Fig. 8. Location of layer 3 of thermocouples

The equipment's for monitoring the parameters analyzed during the tests are: 27 K-type thermocouples, which were coupled to 8 data acquisition modules produced by Brain Child and a Flir-type thermal scanning camera Type FLUKE Ti 400 for measuring infrared temperature on solid surfaces (test corner) up to 1200 ℃, as shown schematically in fig. 9.

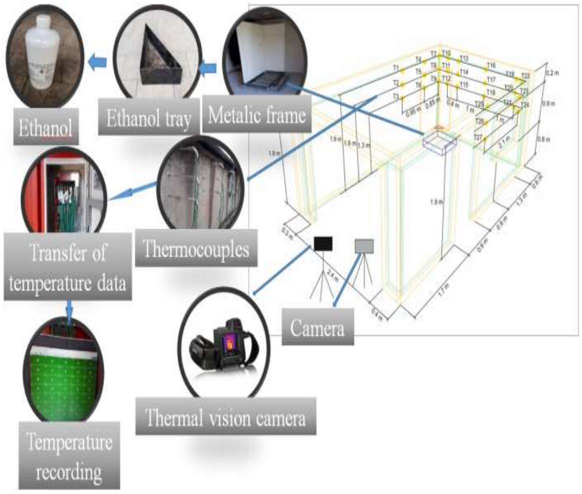

Fig. 9. Scheme of the location of the equipment used for fire testing related to the real-scale space

3. RESULTS AND DISCUSSIONS

The snapshots taken at the characteristic moments during the tests are shown in **fig. 10** and **fig. 11**, to illustrate the association between flame spread and temperature range measured with a thermal vision camera, which are shown in fig. 12**.** The comparative analysis on the four different materials of the temperatures measured with K-type thermocouples is presented on the three layers of their positioning in fig. 13 **- 15**. From this analysis can be determined the temperature fluctuations, useful in predicting the flashover phenomenon, based on the calculation of the permutation entropy [22, 23].

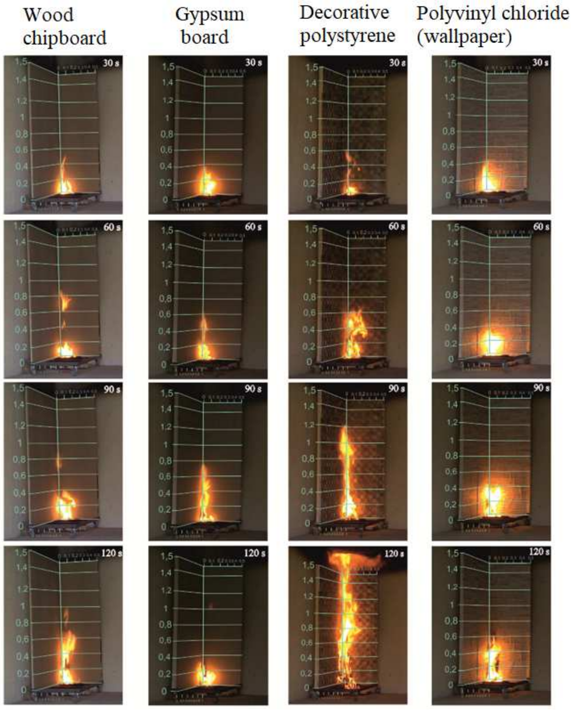

Fig. 10. Snapshots taken in characteristic moments (30 s, 60 s, 90 s and 120 s), showing the flame spread on the panels of: wood chipboard, gypsum board, decorative polystyrene and polyvinyl chloride (wallpaper).

In fig. 10 is presented a comparison between the evolution of the flame height in all tests, from the point of view (angle) oriented towards the long panel and the short panel. The geometry of the panels is graded with the distance units in meters. The initial values correspond to the flames produced by the burner itself (meaning 0.4 m). The highest values of flame height are obtained in the case of polystyrene (at 120 s exceeds 1.5 m), followed by the values obtained in the case of wood chipboard (at 120 s exceeds 1 m), and the lowest values of flame height are observed on gypsum board (at 90 s they exceed 0.8 m) and on polyvinyl chloride (wallpaper) (at 120 s they exceed 0.6 m).

Similarly, the lateral spread of the flame is more intense in the wood chipboard test and polystyrene panel test, and less pronounced in the gypsum board test (0.15 m on both sides) and the polyvinyl chloride (wallpaper) test (0.2 m short side and 0.15 long side).

The evolution of the flame height is recorded in the different moments in time: 150 s, 540 s, 870 s and 1200 s and is represented in **fig. 11**.

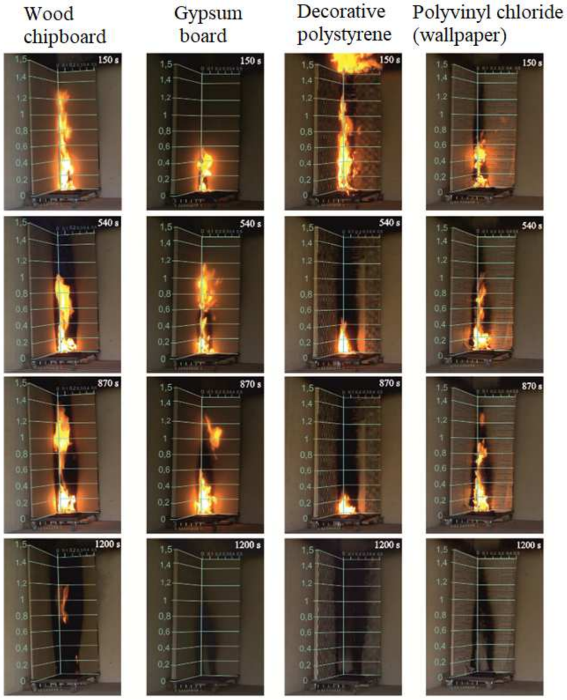

Fig. 11. Snapshots taken in characteristic moments (150 s, 540 s, 870 s and 1200 s), showing the flame spread on the panels of: wood chipboard, gypsum board, decorative polystyrene and polyvinyl chloride (wallpaper).

The analysis of the temperature on the solid bodies (corner panel and wall), recorded by thermal vision camera at time t = 30 s, 60 s, 90 s and 120 s, is represented in fig. 12.

During the tests, the following maximum temperatures were recorded: 30 s after ignition (wood chipboard: 311.5 °C, gypsum board: 293.9 °C, decorative polystyrene: 260.2 °C and polyvinyl chloride (wallpaper): 342.6 °C) ; at 60 s from ignition (wood chipboard: 427.3 °C, gypsum board: 387.7 °C, decorative polystyrene: 429.1 °C, polyvinyl chloride (wallpaper): 474.2 °C); at 90 s from ignition (wood chipboard: 476.1 °C, gypsum board: 502.2 °C, decorative polystyrene: 524.4 °C, polyvinyl chloride (wallpaper): 539.3 °C), and at 120 s from ignition (wood chipboard: 490.1 °C, gypsum board: 522.3 °C, decorative polystyrene: 610.8 °C, polyvinyl chloride (wallpaper): 670.1 °C).

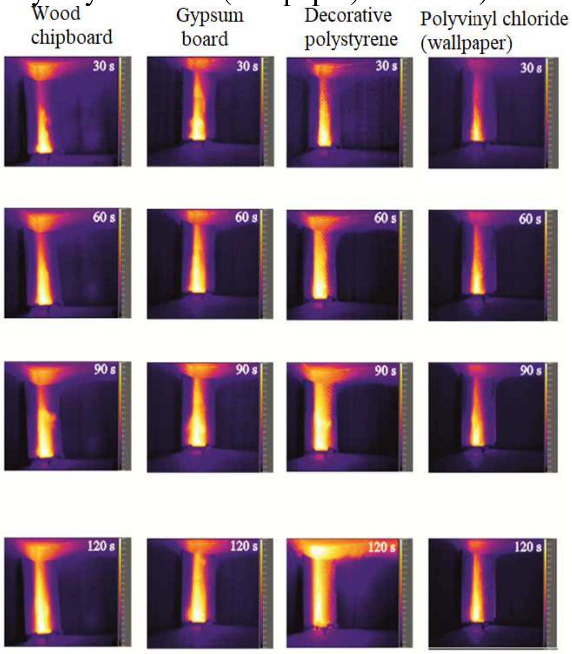

Fig. 12. Analysis of test temperature at time t = 30 s, 60 s, 90 s and 120 s

In fig. 13 are presented the graphs with the comparative temperatures on the four materials for the 1st layer of thermocouples, located almost at the limit of the ceiling, at 1.9 m.

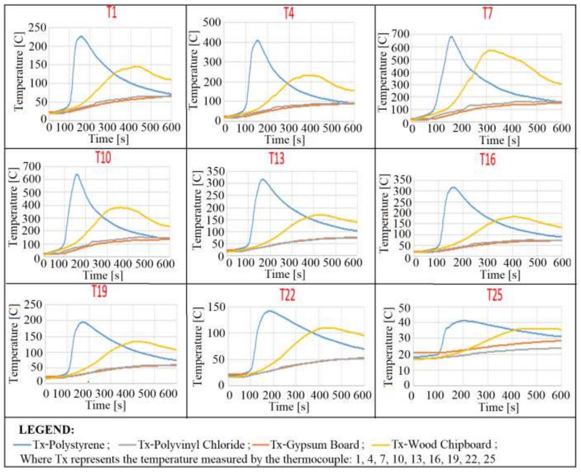

Fig. 13. Graphs with comparative temperatures on the four materials for layer 1 of thermocouples

In fig. 14. are presented the graphs with the comparative temperatures of the four materials for the 2nd layer of thermocouples located at 1.6 m from the floor.

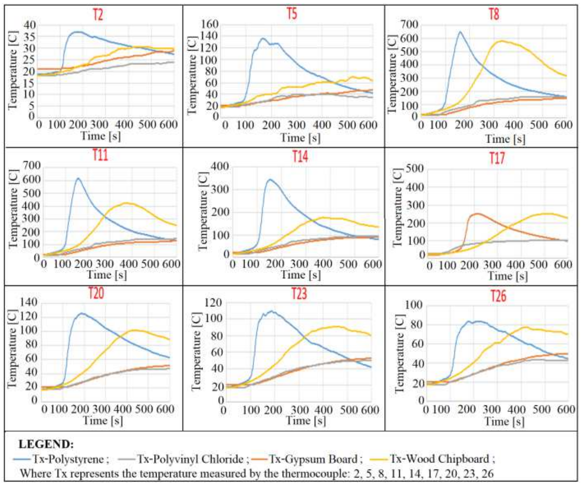

Fig. 14. Graphs with comparative temperatures of the four materials for layer 2 of thermocouples

In fig. 15 are presented the graphs with the comparative temperatures of the four materials for the 3rd layer of thermocouples located at 1.3 m from the floor.

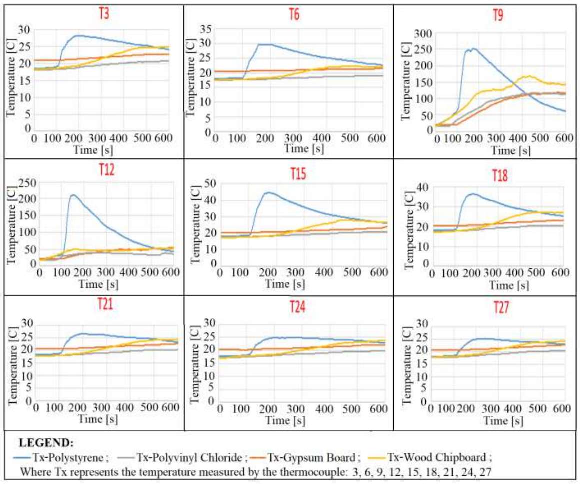

Fig. 15. Graphs with comparative temperatures of the four materials for the layer 3 of thermocouples

Graphical comparisons show that the highest temperatures were recorded at the burning of polystyrene, reaching 650℃, while the lowest temperatures were recorded at polyvinyl chloride (wallpaper) of 170℃. At wood chipboard the maximum temperature difference recorded during the test is 550℃, while at gypsum board are recorded temperatures of about 150℃.

4. CONCLUSIONS

From all the real-scale thermal analyzes it results that the flames spread and the recorded temperatures are more intense in the test with wood chipboard and polystyrene panels (the dangerous flashover phenomenon can occur), and in the case of polyvinyl chloride (wallpaper); in the case of gypsum board are registered the lowest temperatures and flames.

Analyzing the flame spread at different times, it is found a faster evolution to higher heights in the case of polystyrene (at 60 s, 90 s, 120 s and 150 s), followed by the values recorded in the case of wood chipboard (at 150 s, 540 s, 870 s), gypsum board (at 150s, 540 s, 870 s), the lowest values being recorded in the case of polyvinyl chloride (wallpaper).

Analyzing the temperatures recorded by the thermal vision camera, it is found that the highest values are obtained in the case of wood chipboard.

In the case of temperatures measured with K-type thermocouples, it is found that the highest temperatures were recorded when burning polystyrene, while the lowest temperatures were recorded for polyvinyl chloride (wallpaper).

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Comportamentul la foc în teste de colț al materialelor de finisaj interior în condiții naturale

În vederea realizării unei predicții cât mai exacte a comportamentului la foc în condiții naturale, au fost efectuate teste, utilizându-se o configurație de colț, iar ca materiale polistiren, PVC (tapet), ghips carton și PAL. Spațiul de testare simulează testul Single burning item în condiții modificate de geometrie, ventilare și de arzător. Astfel, au fost analizate date privind propagarea flăcărilor, temperaturile măsurate cu termocuple de tip K, respectiv temperaturile obținute în urma utilizării unei camere de termoviziune. S-a constatat că răspândirea flăcărilor, precum și temperaturile înregistrate sunt mai intense la testul cu panouri de PAL și cu panouri de polistiren, în schimb la PVC (tapet) și panouri de ghips carton se înregistrează cele mai mici temperaturi și flăcări.

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