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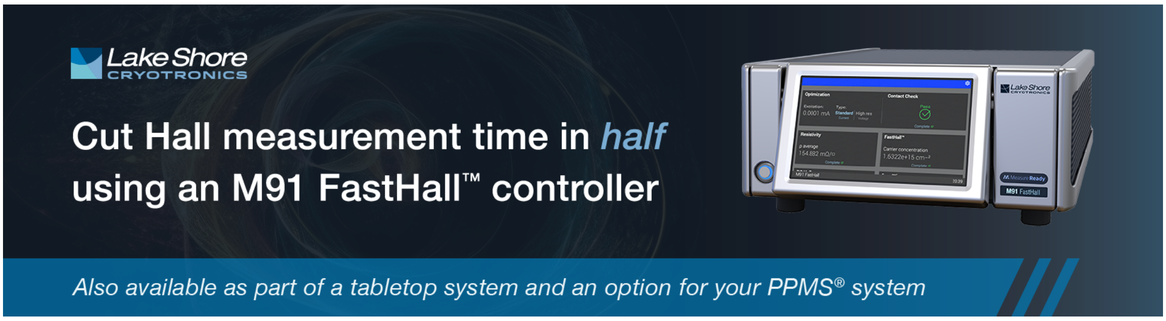

# Fire Behaviour of Wood and Wood-Based Composite Panels Towards the Development of Fire-Resistant Multilayer Systems

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**Abstract.** The use of sustainable natural resources has been practiced by the construction sector as a means to reduce energy demand and increase the efficiency of buildings. In this sense, wood and wood-based materials are alternative and renewable material sources that can be effectively used in building elements, such as doors and partition walls, which are required to provide adequate thermal, acoustic, and fire resistance performance. Such elements play an important role in the fire compartmentation of buildings. Appropriate selection of materials with a reduced potential of ignition and enhanced fire behaviour may reduce the heat flux, and the passage of hot gases and smoke, thus minimizing fire hazards. In the case of wood products, the combustibility of wood usually limits its use in fire-resistant components. However, the fire performance of wooden assemblies can be improved by using engineered wood products and insulation materials, which can be assembled into multilayer systems. This work investigates the performance of wood and wood-based multilayer panels exposed to ISO 834 standard fire curve to improve the knowledge about their fire resistance in terms of insulation (I) and integrity (E) criteria. The study considers pinewood, OSB (oriented strand board), and moisture-resistant MDF (medium-density fibreboard) of different thicknesses. Rockwool with a thickness of 27 mm was also used as a core material. The multilayer systems have a dimension of 580×580 mm, fixed to a wood frame and mounted to a wall made of refractory bricks and mortar. The composite panels were tested in a small-scale furnace. During each test, temperatures were measured using type k thermocouples attached between layers and to the panel's surfaces and wood frame. The specimens were considered to have failed when the insulation and integrity criteria were met according to EN 1363-1. The results showed that a 1-hour insulation fire resistance was achieved when using 16 mm-thick MDF panels on both sides and rockwool as a core material. Similar assemblies using 6 mm-thick and 10 mm-thick MDF panels reached 30 min., and 40 min., respectively. The specimen with 20 mm-thick pinewood on both sides and rockwool core had an insulation fire resistance of 41 min. but had one of the highest superficial masses and highest total thickness amongst tested specimens. Pinewood has been tested as a core material sandwiched between two 10 mm- thick MDF panels, and its insulation fire resistance was 30 min. The assembly with 15 mm-thick OSB placed between two 10 mm-thick MDF boards had the smallest insulation fire resistance of around 27 min. The fall-off of the exposed panel and warping of the edges of the panels greatly influenced the integrity behaviour of the samples. The insulation performance was mostly affected by the type of material and its thickness, as well as by the relative position of the layer in the composite assembly. The results provide important data regarding heat transmission effects and integrity issues related to the exposure of wood and wood-based composite multilayer systems under fire.

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## INTRODUCTION

The construction, use, and renovation of buildings require significant amounts of energy and mineral resources, accounting for 40 % of the energy consumed in Europe [1]. To reduce these significant impacts, sustainable strategies, such as the use of natural resources, have been practiced by the building construction sector following the basic requirements of the European Construction Products Regulation (CPR) [2]. In this context, the versatility, durability, and environmental attributes of minimally processed or highly engineered wood and wood-based materials are features that enable their use in the construction sector in various applications.

Due to its major influence on the energy efficiency of buildings, the components of the building envelope and interior environment, such as walls, facade systems and floors, have been greatly studied regarding their thermal behaviour, selection of materials and definition of multilayer systems and dimensions [3–5], including systems using wood and wood-based materials [6–8]. Yet, these components are also required to provide sufficient fire resistance and improving fire performance of wood-based materials is still challenging [9].

Moreover, the fire reaction properties of wood [10,11], engineered wood [12–16] and other innovative biobased materials used in multilayer systems [17–19] are available in the literature. However, information is lacking regarding the fire resistance of arrangements of multilayer systems using wood and wood-based materials as primary components. The performance of a particleboard panel under standard fire exposure was studied by Cueff et al. [20] who also developed a thermal degradation model. Similarly, the insulation behaviour of particleboard, MDF and plywood boards subjected to ISO 834 [21] fire was investigated by Harada et all. [22], who concluded that the insulation fire resistance of the panels was linearly correlated with their apparent density, being higher for denser boards. Nevertheless, these studies only considered single-layer panels and the performance at elevated temperatures of wood and wood-based multilayer systems is poorly understood.

Thus, this study aims to conduct experimental tests regarding the fire behaviour of wood and wood-based multilayer systems subjected to ISO 834 [21] standard fire, providing useful and practical information to support the design of innovative construction systems and expand their use in the construction industry. Different configurations are considered by combining pinewood, medium-density-fibreboard, oriented strand board and rockwool as an insulation layer.



## EXPERIMENTAL TESTS

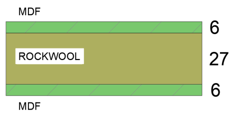
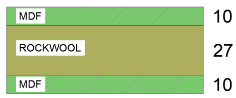
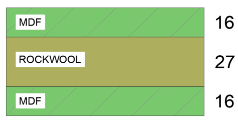
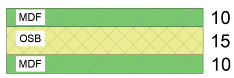
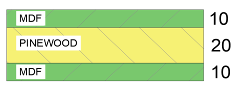
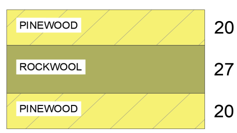
The materials tested included panels of moisture-resistant medium density fibreboard (MDF), oriented strand board (OSB), solid pinewood (PN) and rockwool insulation (RW). The panels had a surface area of 580 × 580 mm, with varying thicknesses, see Table 1. Before testing, the panels were conditioned at room temperature with a relative humidity of 65 %. The superficial mass was estimated based on density values provided by product datasheets.

The panels were assembled into symmetrical multilayer systems, see Table 1, which were then tested in a medium-scale gas-fired furnace with an internal volume of 1 × 1 × 1 m. The furnace is equipped with four burners of 90 kW each, and the temperature inside was calibrated according to ISO 834 [21] fire curve and controlled by a plate thermocouple installed at mid-height of the furnace and at a distance of 100 ± 50 mm from the exposed surface of the specimen. The data acquisition frequency was 1 Hz.

As seen in Figure 1a, the specimens were fixed on their edges to a pinewood frame using flat head screws. The dimensions of the frame were 610 x 610 mm with a cross-section of 80 x 40 mm, see Figure 2. The set was mounted to a 1000 x 1000 x 100 mm rigid supporting construction wall made of refractory bricks and mortar, see Figure 1b, in a way that the exposed surface of the specimen was levelled with the supporting construction, see Figure 1c. On the exposed side, the gaps between the edges of the panel and the supporting construction were filled with ceramic fibre since the frame was simply fitted into the opening of the supporting construction, see Figure 1c.

The set-up of the thermocouples on the unexposed side was based on EN 1634-1 [23]. The temperature of the unexposed surface of the panel and frame was measured using copper disk thermocouples (DT) with 10 mm in diameter welded to type K thermocouple wires protected with 30 x 30 mm calcium silicate pads. As for the exposed side, twisted type K thermocouple wires protected with thermal putty (BT) were used. Except for the specimen MDF-10_RW-27, the temperature at the centre of the interface between the core layer and the exposed (P_EXP) and unexposed (P_UNEXP) layers was also measured with type K twisted thermocouple wires. The data acquisition frequency was 2 Hz. The position of the thermocouples is shown in Figure 2.

**TABLE 1.** Description of the test specimens and fire resistance results (measurements in mm).

| Specimen | Cross-Section | Total Thickness [mm] | Superficial Mass [kg/m²] | Fire Resistance, $T_{ave}$ (I) [min] | Fire Resistance, $T_{max}$ (I) [min] | Fire Resistance (E) [min] |
|---|---|---|---|---|---|---|
| MDF-6_RW-27 |   | 39 | 12.7 | 30.7 | 35.9 | 43 |
| MDF-10_RW-27 |   | 47 | 17.9 | 42.2 | 44.7 | 43 |
| MDF-16_RW-27 |   | 59 | 26.3 | 64.9 | 63.8 | 62 |
| MDF-10_OSB-15 |   | 35 | 23.9 | 27.7 | 27.5 | 26 |
| MDF-10_PN-20 |   | 40 | 26.5 | 31.4 | 31.3 | 28 |
| PN-20_RW-27 |   | 67 | 25.3 | 47.6[a] | 41.5[a] | 50 |

[a] The fire resistance was determined based on Infrared measurements following malfunction of the thermocouples on the unexposed surface of the panel.

(a) (b) (c)

**FIGURE 1.** Detail of the attachment of the specimen on the pinewood frame (a); Position of the set in the supporting construction (b); Insulation of the edges of the specimen on the exposed side (c).

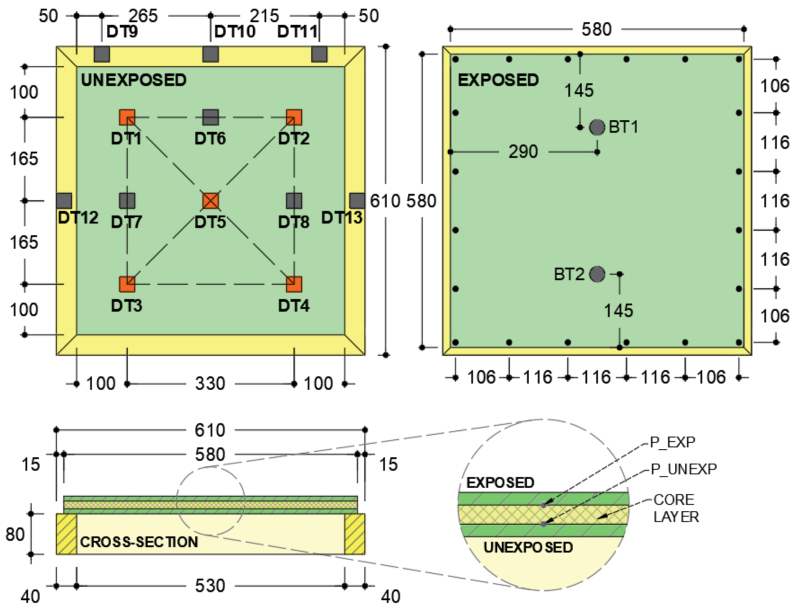



**FIGURE 2.** Fixing positions and set-up of the thermocouples on the unexposed and exposed side of the specimens.

Additionally, the average and maximum temperatures on the unexposed side were evaluated using an FLIR BT Series T365 Infrared camera, installed at 2.15 m distance from the unexposed surface of the specimen. The data were collected with an acquisition frequency of 1.25 Hz with a maximum temperature threshold of 350 ºC. The emissivity of the unexposed surface was set to 0.8, whilst ambient temperature was set to 20 ºC.



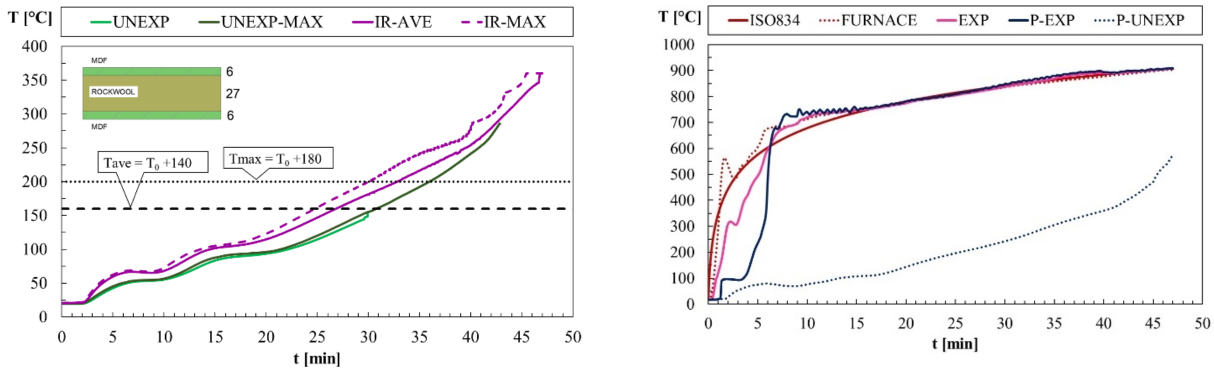
## RESULTS AND DISCUSSION

This section presents the temperature history in specific regions of the test specimens. The average unexposed surface temperature (UNEXP) was determined based on the readings of DT1 through DT5, whereas the maximum unexposed surface temperature (UNEXP-MAX) was calculated using the readings of DT1 through DT13. The average (IR-AVE) and maximum (IR-MAX) temperatures measured by the Infrared camera are also presented, as well as the temperature history of the furnace (FURNACE), exposed side (EXP), and interface between the core layer and the exposed (P-EXP) and unexposed (P-UNEXP) panels. The initial average temperature ($T_0$) was 20 ºC, and according to EN 1363-1 [24], the specimens were considered to have failed, by insulation, when the average ($T_{ave}$) or the maximum ($T_{max}$) temperature on the unexposed side reached 160 ºC or 200 ºC, respectively. The integrity failure was reached when sustained flame or visible flame though gaps on the unexposed side occurred, see Table 1.

Due to moisture migration and roughness of the panel's surface, detachment of the thermocouples on the unexposed surface was a common observation towards the end of the fire tests. After this malfunction, the measurements of these thermocouples were not considered to determine maximum and average temperatures. Also, for all specimens, it was verified that the maximum temperature on the unexposed side was always that of the thermocouples located on the board's surface and not those located on the frame.

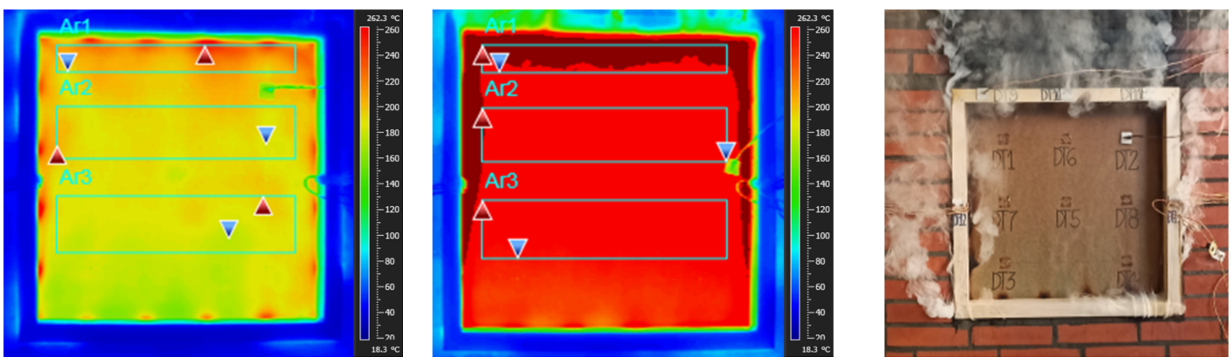
Figure 3 shows the temperature history of MDF-6_RW-27. From Figure 3b, P-EXP rises rapidly after 2 min. of fire exposure due to cracking and shrinking of the exposed board, which falls off 3 min. later. As seen in Figure 3a, slight temperature plateaux are noticed around 50 °C and 100 ºC when free water starts to gradually evaporate from the exposed and unexposed MDF layers, respectively. However, the small thickness of the MDF boards limits the extension of these plateaux, and temperatures rise at a quick heating rate after 100 ºC. Also, the combustion and fall-off of the exposed layer led to a sudden rise in the furnace temperature, requiring manual adjustments of the burners to verify agreement with ISO 834 [21] fire curve. As the rockwool layer remains in place after being directly exposed, temperatures rise uniformly until the end of the fire test. The difference between UNEXP and UNEXP-MAX is fairly small during most part of the test duration, meaning that the temperature distribution is relatively uniform. This can also be observed in the Infrared images shown in Figures 4a and 4b. From Figure 3a, after 30 min., UNEXP and UNEXP-MAX match. This is due to the fact that after that time, only one thermocouple (DT2) was available to assess the evolution of the average and maximum temperatures on the unexposed board's surface.

Furthermore, since the temperature readings of the Infrared camera include eventual hot spots, such as cracks, warping of the edges, smoke and flames, the temperatures measured by the Infrared camera are higher than those measured by thermocouples throughout the entire test time. Figure 4c shows that a dense smoke is produced prior to the ignition of the unexposed MDF board.




(a) (b)

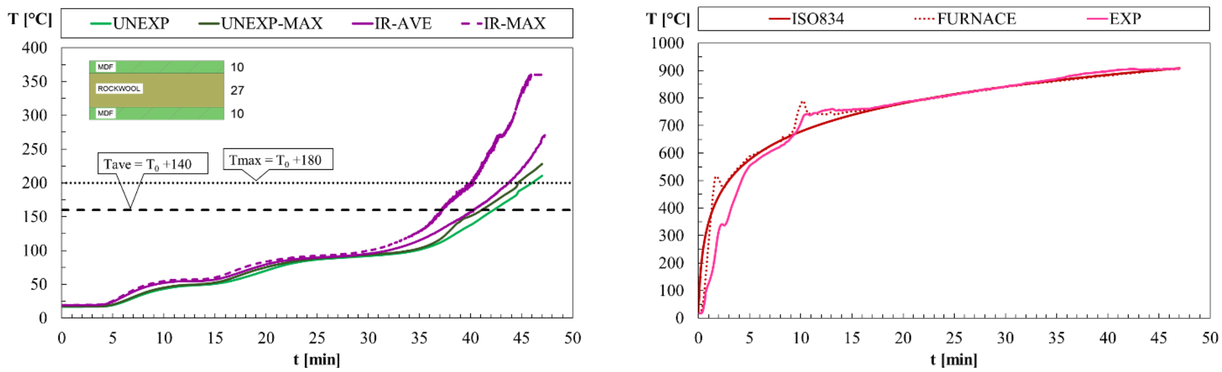
**FIGURE 3.** Temperature history on the unexposed side (a), and on the exposed side and between layers (b) of specimen MDF-6_RW-27.




(a) (b) (c)

**FIGURE 4.** Temperature distribution on the unexposed side of specimen MDF-6_RW-27 as read by the Infrared camera after 35 min. (a) and 45 min. (b) of fire exposure. The selected measurement areas are identified as Ar1, Ar2 and Ar3; Smoke production during testing of specimen MDF-6_RW-27 (c).

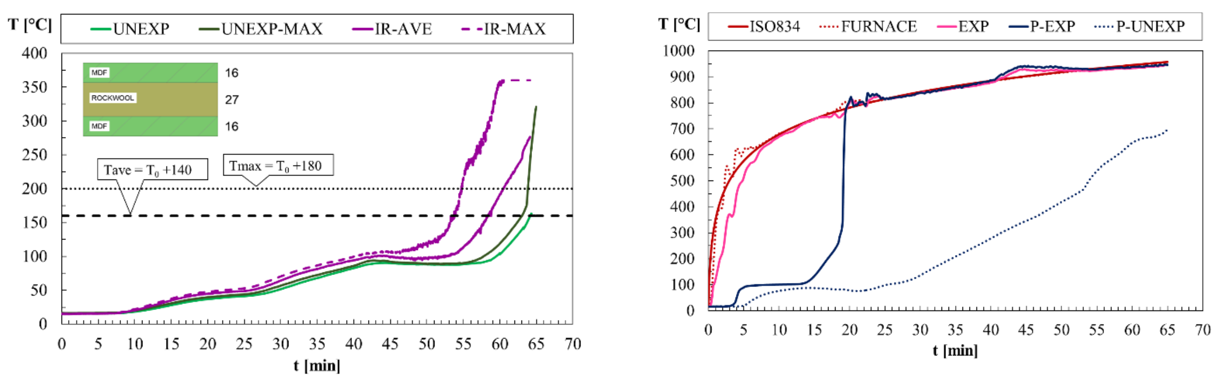
Figures 5a and 5b present the results for specimen MDF-10_RW-27. As seen in Figure 5a, the heating rate of the average and maximum temperatures is smaller when compared with specimen MDF-6_RW-27. Also, larger temperature plateaux at 50 °C and 100 °C are noticed, with temperatures rising significantly after 35 min. Such effects are attributed to the higher thickness of the MDF boards. Moreover, fall-off of the exposed board occurred after 10 min. of fire exposure, when the temperature inside the furnace rises rapidly, see Figure 5b.




(a) (b)

**FIGURE 5.** Temperature history on the unexposed (a) and exposed side (b) of specimen MDF-10_RW-27.

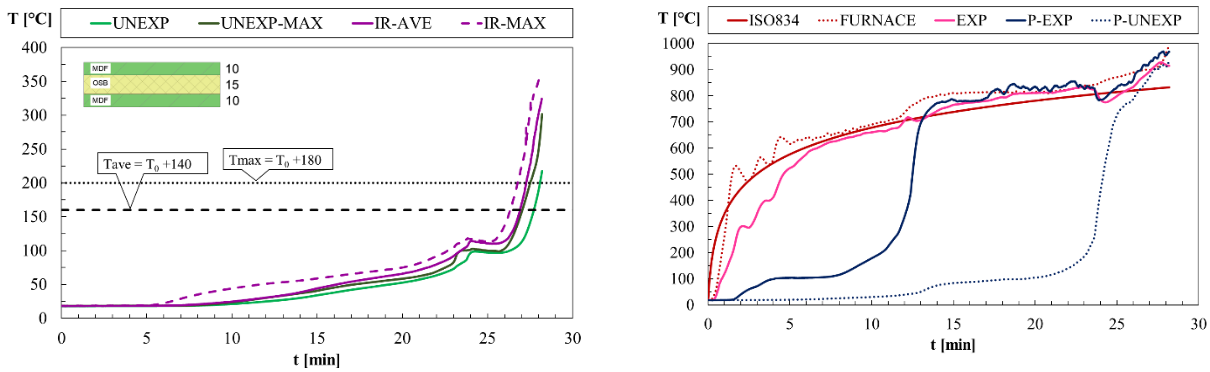
A similar behaviour is observed for the specimen with two 16 mm thick MDF boards and rockwool insulation (MDF-16_RW-27), see Figures 6a and 6b. From Figure 6b, P-EXP remains flat from 5 to 15 min. as the MDF board on the exposed side goes through dehydration. Figure 6a shows that the beginning of the temperature plateau at 100 ºC on the unexposed side was significantly delayed, remaining almost flat for nearly 15 min. Also, P-EXP quickly increases after 19 min., when the exposed layer fell off completely.




(a) (b)

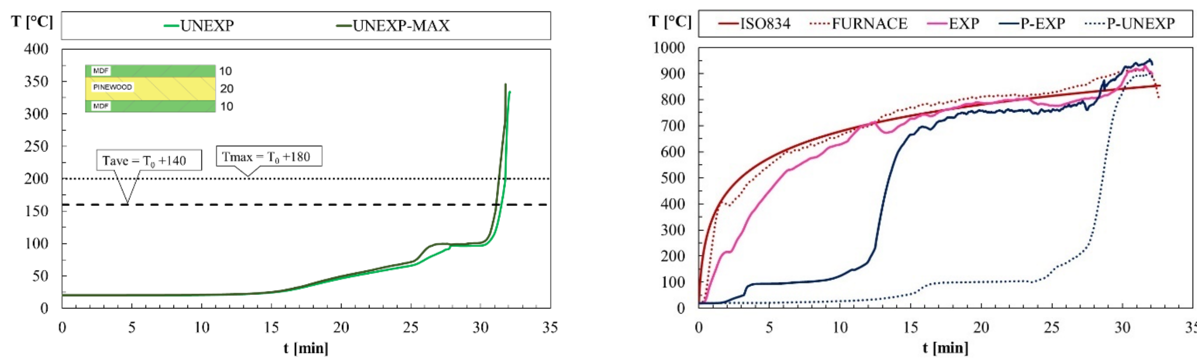
**FIGURE 6.** Temperature history on the unexposed side (a), and on the exposed side and between layers (b) of specimen MDF-16_RW-27.

As for the specimens with OSB (MDF-10_OSB-15) and pinewood core (MDF-10_PN-20) with MDF protection, the fire resistance of the assemblies was significantly reduced when compared with the specimens with rockwool insulation, see Figures 7a and 8a. This was expected as a result of the fast ignition and combustion of the OSB and solid pinewood. As seen in Figures 7b and 8b, the exposed MDF panel detached from the frame after 12 min. of fire exposure and fall-off of the OSB and pinewood boards occurred at 23 min. and 25 min., respectively. In Figures 7a and 8a, the characteristic temperature plateau at 100 ºC is noticed towards the end of the fire tests as the OSB and pinewood boards also go through dehydration. In the case of MDF-10_PN-20, due to malfunctioning of the software, it was not possible to obtain Infrared temperature measurements.




(a) (b)

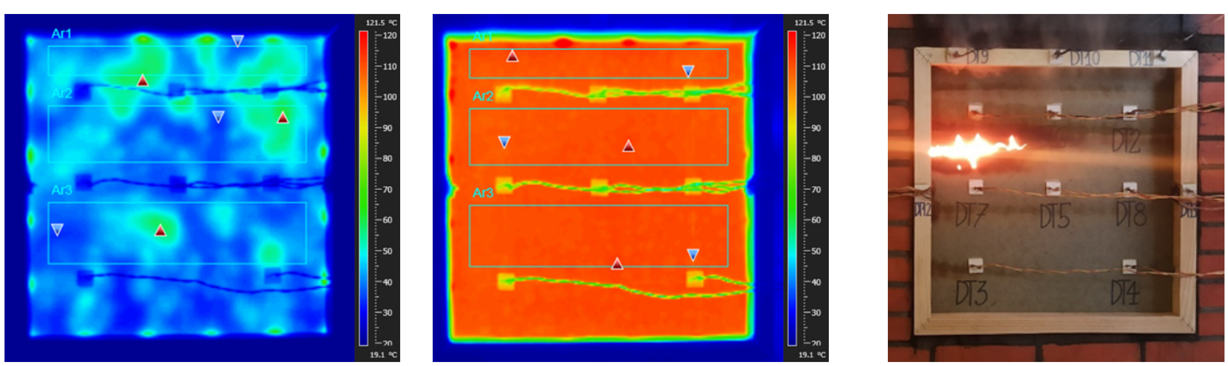
**FIGURE 7.** Temperature history on the unexposed side (a), and on the exposed side and between layers (b) of specimen MDF-10_OSB-15.




(a) (b)

**FIGURE 8.** Temperature history on the unexposed side (a), and on the exposed side and between layers (b) of specimen MDF-10_PN-15.

The temperature distribution of the unexposed surface of the specimen with OSB core is shown in Figure 9a, at 15 min., after fall-off of the exposed MDF layer, and Figure 9b at 25 min., right after fall-off of the OSB board. Figure 9c shows the unexposed surface of specimen MDF-10_PN-20 after integrity failure, when the flame inside the furnace becomes visible given that the pinewood core was no longer in place.

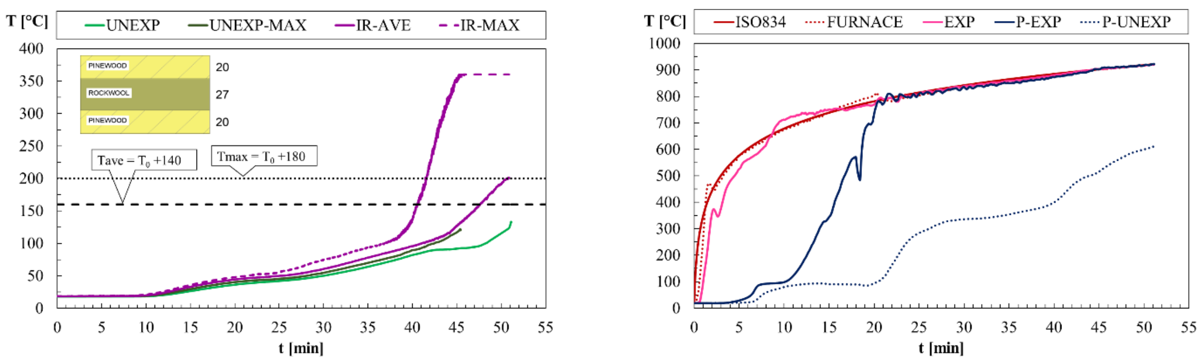



(a) (b) (c)

**FIGURE 9.** Temperature distribution on the unexposed side of specimen MDF-10_OSB-15 as read by the Infrared camera after 15 min. (a) 25 min. (b) of fire exposure. The selected measurement areas are identified as Ar1, Ar2 and Ar3; Interior flame is visible from the unexposed side of specimen MDF-10_PN-20 (c).

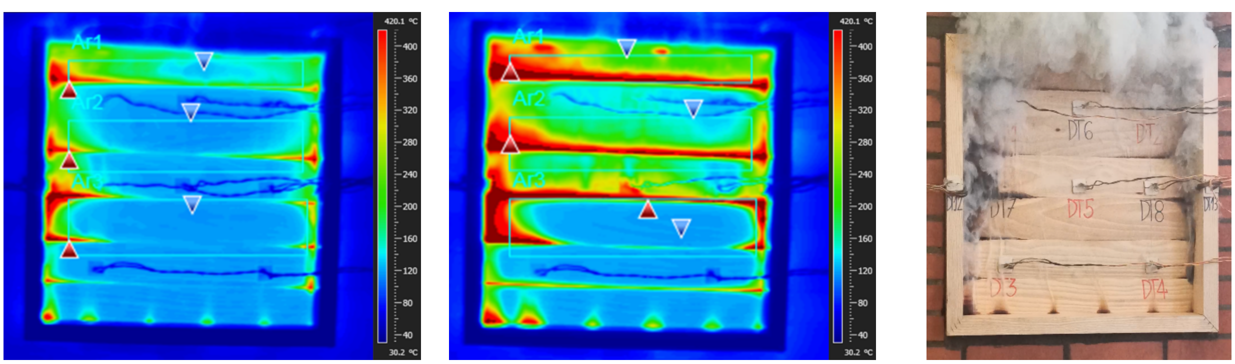
Figures 10a and 10b present the temperature history of the specimen with pinewood boards on both sides and rockwool core insulation. Regarding temperatures on the unexposed side, see Figure 10a, a temperature plateau is not clearly defined, but the heating rate of UNEXP decreases at 42 min., increasing again near the end of the test. The development of UNEXP-MAX rises continuously up to 45 min., when measurements are stopped. This is because the thermocouple that recorded the highest temperatures throughout the test (DT7) malfunctioned, and the temperature of the remaining thermocouples would not be representative of the maximum temperature evolution on the unexposed panel's surface.

Figure 10a shows that IR-MAX and IR-AVE differ significantly from thermocouple measurements after 38 min. This is because the pinewood boards were actually composed of bonded horizontal panels. These panels tend to warp around the junctions between them, see Figure 11c, allowing for the passage of smoke and flames. Thus, as shown in Figures 11a and 11b, the temperature of these hot spots is measured by the Infrared camera, but not by the thermocouples, which are placed on the surface of the individual panels and not at the junctions, see Figure 11c. Consequently, given that UNEXP and UNEXP-MAX did not reach 160 °C and 200 ºC, respectively, the fire resistance classification of the specimen PN-20_RW-27 was determined based on Infrared measurements.




(a) (b)

**FIGURE 10.** Temperature history on the unexposed side (a), and on the exposed side and between layers (b) of specimen PN-20_RW-27.



(a) (b) (c)

**FIGURE 11.** Temperature distribution on the unexposed side of specimen PN-20_RW-27 as read by the Infrared camera after 40 min. (a) 45 min. (b) of fire exposure. The selected measurement areas are identified as Ar1, Ar2 and Ar3; Smoke flow through the junctions between the panels of the pinewood board and at the interface between the frame and board (c).

Regarding the integrity performance of the specimens, the values shown in Table 1 indicate that, except for specimens MDF-6_RW-27 and PN-20_RW-27, the time to reach integrity failure tends to be smaller than those that characterize insulation failure. Warping of the edges between the panel and frame, followed by ignition of the unexposed panel was observed in all tested specimens. It is noteworthy that a full assessment of the integrity failure modes is necessary since in this research only the occurrence of sustained flame or visible flame through gaps on the unexposed side were considered.

## CONCLUSION

This study assessed the fire behaviour of different configurations of multilayer systems composed of wood, wood-based and insulation materials subjected to standard fire. Experimental tests were developed to determine the fire resistance of the specimens in terms of insulation and integrity performance.

Concerning the specimens with rockwool core insulation placed between MDF panels, it was verified that the fire resistance increases with the thickness of the outer layers. This is related to the free water evaporation in MDF, and also to the time it takes for the exposed board to fall off, which is higher for thicker MDF panels. However, increasing the thickness of the exposed and unexposed boards leads to an increase in the specimen's superficial mass. Furthermore, the improved fire resistance of these specimens is also linked to the insulating properties of rockwool. The rockwool batt remained in place throughout fire exposure even after fall-off of the exposed layer, slowing heat transmission through the remaining cross-section.

The samples with OSB and pinewood core protected with MDF boards had the smallest fire resistance amongst tested specimens. The quick ignition followed by fall-off of the OSB and pinewood boards were detrimental to the fire performance of these specimens. The specimen with rockwool core insulation placed between pinewood boards had an insulation fire resistance of 41 min. but had one of the highest estimated superficial masses and highest total thickness.

The results obtained provide useful information regarding the fire behaviour of wood and wood-based materials, and may be used to support the development, improvement, and optimization of fire-resistant multilayer systems.

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