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INNOVATIVE COMPOSITIONS OF STRUCTURAL ELEMENTS AND THEIR ESTIMATED FIRE RESISTANCE

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ABSTRACT

The paper is focused on the investigation of innovative compositions of structural elements suitable mainly for use in timber constructions, with respect to determining their expected fire resistance. The examined compositions of structural elements meet several requirements that contribute to both the energy efficiency and fire safety of buildings. The tested structures consisted of magnesium oxide boards forming the sheathing of the samples, combined with various types of thermal insulation cores (PUR foam, paper honeycomb, and straw mixed with MgO mortar). The expected fire resistance was determined by conducting medium-scale fire tests simulating the progression of a fully developed compartment fire. The samples were exposed to radiant heat from a radiation panel with an output of 20 $kW \cdot m^{-2}$. The best results were achieved by the sample containing the straw and MgO mortar mixture, which reached an estimated fire resistance of 90 to 120 minutes, confirming the suitability of this material combination in the composition of the structural element. The sample with the honeycomb core achieved an assumed fire resistance of 30 to 45 minutes, while the sample with PUR thermal insulation had the lowest, at 15 minutes.

Keywords: structural element; magnesium oxide board; thermal insulation core; expected fire resistance; medium-scale test.

INTRODUCTION

Modern construction is characterised by increasing demands for sustainability, rapid building processes, and energy efficiency. Timber structures have excellent potential to meet these requirements; however, these must also be reconciled with the need for fire safety. It can be achieved by using appropriate materials and suitable layer compositions in the structural elements of wooden buildings. An example of an innovative material is the magnesium oxide (MgO) board, also known as a magnesia board, which is composed primarily of magnesium oxide (MgO). In the structural elements of timber buildings, MgO boards can replace large-format materials such as particleboard, fibreboard, OSB, CETRIS boards, fire-resistant plasterboard, Fermacell boards, and other fireproof claddings. They can be applied to both the interior and exterior. MgO boards are characterised by good thermal and acoustic insulation properties, non-combustibility, and resistance to surface flame spread.

At present, the worldwide production of magnesium oxide boards comes almost exclusively from China (Iqra *et al.,* 2025). However, Slovakia is one of the leading countries in magnesite mining (Dubecký *et al.,* 2017). Magnesite ($MgCO_3$) is the most essential mineral of magnesium and occurs in crystalline and cryptocrystalline (massive) forms (Fig. 1). The massive form may also be of sedimentary origin. It contains admixtures of CaO, Fe_2O_3, MnO, Al_2O_3, SiO_2, and others that influence the raw material's quality. A substance is generally considered magnesite if it contains at least 40% MgO and no more than 4% CaO. Magnesite is primarily used to produce caustic sinter, which serves as a base for refractory materials, insulations, and special cement formulations resistant to acids and oils. Dead-burned magnesite (periclase) is produced exclusively from crystalline magnesite and is used for refractory linings in metallurgical furnaces and converters, cement kilns, and sulphuric acid production equipment (Baláž, 2008). MgO has been a component of various natural building materials used since ancient times and has proven its durability over centuries (Voroncov *et al.,* 2008).

Fig. 1 Crystalline magnesite, Lubeník locality (Baláž, 2008).

Today, relatively little attention is given to environmentally friendly building materials. Achieving environmentally sound construction is impossible without ecological materials and products featuring a low carbon footprint, low emissions of hazardous substances, and high biological stability. A unique property of magnesium oxide boards is their ability to absorb CO_2 from the air throughout their entire life cycle, thereby actively purifying and improving indoor air quality. MgO boards can be used in almost all building applications, i. e. ceilings, partitions, fireplaces, all types of internal and external wall claddings, ventilated façades, decorative ceilings, and anywhere that requires protection from fire, rot, or mould (Jandačka and Holubčík, 2020)

The MgO board generally consists of five layers (Fig. 2). Surface layer No. 1 is smooth and suitable for painting. Layer No. 5 usually has a rough texture, making it suitable for applying plaster or adhesive. Layers No. 2 and No. 4 are made of fibreglass mesh, which serves as reinforcement. Layer No. 3 forms the core of the MgO board (Dubecký *et al.,* 2017).

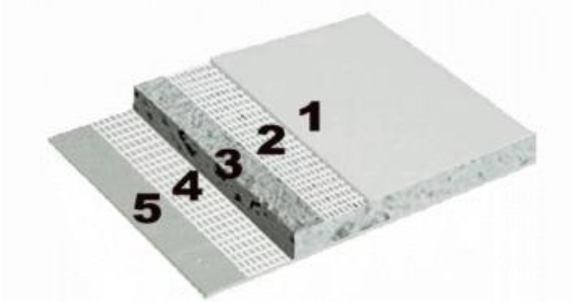

Fig. 2 The structure of the MgO board (Dubecký et al, 2017)
1 – surface layer, 2 – fiberglass mesh, 3 – core, 4 – fiberglass mesh, 5 – surface layer.

One of the key factors that makes MgO boards an excellent choice for fire safety is their high melting point. Magnesium oxide has an exceptionally high melting temperature, meaning the board can withstand elevated temperatures for a relatively long time before beginning to decompose. This property provides a significant advantage in the event of a fire, as it allows the board to resist flames and prevent their rapid spread. The surface of the MgO board contains a protective layer that acts as a barrier, reducing heat transfer to the opposite side. Therefore, if an interior MgO board is used as a fire-rated wall, it can help to contain the fire on one side and protect adjacent areas for a specific period of time (Chen, 2025).

Another important aspect is the low smoke emission of MgO boards during fire exposure. Smoke is often one of the most significant hazards in a fire because it can cause breathing difficulties and reduce visibility, hindering evacuation. Interior MgO boards produce only a minimal amount of smoke when exposed to fire, which is a significant contribution to the overall fire safety of occupants in a building (Chen, 2025).)

In addition to their fire-resistant properties, interior MgO boards also possess sound thermal insulation. It means they help to prevent heat from a fire from penetrating through the board into other parts of the building. It is important not only for preventing the spread of fire but also for maintaining the structural integrity of the building (Chen, 2025). The coefficient of thermal conductivity of MgO boards is 0.216 $W \cdot m^{-1} \cdot K^{-1}$. The MgO boards, therefore, have a clear justification and potential for broader use, both in terms of cost and due to their superior technical parameters compared with commonly used materials in timber constructions, such as plasterboard, CETRIS boards, OSB boards, or plywood (Mokrenko and Kozlovská, 2020).

At present, we are surrounded by a wide range of materials and material combinations used in manufactured products. In most industrial production processes, raw materials are transformed into semi-finished goods, many of which pose potential hazards. Therefore, it is essential to understand the material composition and nature of the raw materials used in industrial sectors, as only through suitable modifications can the undesirable effects of materials be minimised (Morais *et al.,* 2024).

The aim of the paper is to experimentally determine the assumed fire resistance of selected innovative compositions of structural elements using MgO boards, in combination with insulating materials: PUR, paper honeycomb, and MgO mortar mixed with straw, and based on the results of the behavior of individual compositions under fire conditions, to recommend possibilities for their use in current timber constructions.

MATERIALS AND METHODS

The test samples used for the experiment were provided by the Department of Technology and Innovation in Construction at the Faculty of Civil Engineering, Technical University of Košice, where experiments on the production of MgO boards were carried out, including tests of their tensile and flexural strength. The department also designed assemblies of structural elements comprising MgO boards and various core materials, which were subsequently submitted for fire resistance testing.

Three types of structural element compositions were tested, with two samples of each type (sample A and sample B). Sample No. 1 consisted of MgO boards combined with polyurethane thermal insulation (PUR), sample No. 2 consisted of MgO boards with a paper honeycomb insulation core, and sample No. 3 used MgO boards combined with a straw-based filling. Thus, both natural and synthetic materials were used as infill components.

For each composition, two test specimens were evaluated. The temperature deviation between replicate samples did not exceed ±5 °C at comparable exposure times, confirming the reliability of the results.

Sample No. 1: A panel with PUR insulation (MgO–PUR) was composed of MgO boards with a thickness of 12 mm and PUR foam insulation 90 mm thick.

Sample No. 2: A panel with a honeycomb insulation core (MgO–honeycomb). For the production of the MgO–honeycomb panel, MgO boards of 12 mm thickness were combined with a paper honeycomb core 90 mm thick.

Honeycomb panels were produced from high-quality kraft paper by lamination. They are available in various thicknesses and dimensions. Their compressive strength depends on the surface paper and the honeycomb cell size. The honeycomb is a lightweight, hexagonal filler material that provides excellent thermal insulation and mechanical strength. Paper honeycombs are suitable as core materials for sandwich constructions (www.vostina.com).

Sample No. 3: A straw-based panel (MgO–straw) was made from 12 mm-thick MgO boards and a thermal insulation core consisting of straw mixed with MgO mortar. The straw–MgO mortar mixture was prepared by a weight ratio of 3 parts straw : 2 parts MgO mortar. The binder was mixed with a 10 % magnesium chloride solution to achieve a workable consistency. After blending, samples were cured under laboratory conditions (20 ± 2 °C, RH = 60 %) for 7 days before testing. Wheat straw with a bulk density of 469 ($kg \cdot m^{-3}$) was used. Straw, as a building material, deserves particular attention in sustainable construction due to its natural, energy-efficient, and environmentally friendly properties (Džidić and Miličić, 2017). The MgO mortar consisted of caustic magnesite, magnesium chloride, potassium dihydrogen phosphate, and calcium chloride. Caustic magnesite (calcined magnesite) is produced by firing magnesite at temperatures up to approximately 1000 °C and is ideal for manufacturing refractory boards, lightweight partition boards, magnesium sulphate, paper production, and desulphurisation processes (sk.magnesium-fertilizer.com).

Figures 3 to 5 illustrate the test samples, and Table 1 lists the principal technical parameters of the materials used:

a) b) c)

Fig. 3 Sample No. 1: MgO–PUR
a) unexposed side, b) exposed side, c) panel composition.

a) b) c)

Fig. 4 Sample No. 2: MgO–Honeycomb
a) unexposed side, b) exposed side, c) panel composition.

a) b) c)

Fig. 5 Sample No. 3: MgO–Straw
a) unexposed side, b) exposed side, c) panel composition.

Tab. 1 Technical parameters of materials used in the sample composition.

Material	Density (kg·m^{-3})	Surface mass (g/m^2)	Thermal conductivity λ (W·m^{-1}·K^{-1})	Reaction-to-fire class (STN EN 13501-1: 2019)
MgO board	950 – 1000 ± 25*	–	0.216	A1**
PUR	30	–	0.036	E – F**
Honeycomb	–	120 – 150	0.0313	D**
MgO mortar	1800 – 2100	–	0.6	A1**

* Values represent average ± SD,
** source: (Jensen, 2000), (Maršál *et al.*, 2016).

A medium-scale test was carried out in a testing chamber with internal dimensions of 1670 mm × 550 mm × 2010 mm (width × depth × height), as shown in Fig. 6. The source of radiant heat was a radiation panel with a size of 500 × 300 mm. Automatic gas regulation ensured a constant burner power of 20 kW·m^{-2}.

The surface temperature of the radiation panel reached approximately 1,000 °C, corresponding to the maximum temperatures of a fully developed compartment fire. The samples were placed inside the testing chamber 20 minutes after the equipment was switched on, once the radiation panel had reached the required operating parameters. The distance between the samples and the radiant panel surface was 150 mm. The duration of each test depended on the behaviour of the individual samples when exposed to radiant heat, with exposure times of 15, 30, 60, and 90 minutes.

To measure the temperature profile, Ni–Cr thermocouples were used, placed in the centre of the sample in sequence T1–T4. The first thermocouple (T1) was located on the heated surface of the sample; T2 and T3 were positioned at the interfaces of the individual layers; and T4 was situated on the unheated surface. The temperatures were recorded every second using an Almemo 710 data logger (Fig. 7) and stored in a computer. Smoke extraction was provided by an exhaust unit located at the top of the testing chamber (Ø 250 mm).

Fig. 6 Testing chamber.

Fig. 7 Datalogger Almemo 710.

Prior to each test, all Ni–Cr thermocouples were calibrated using a furnace reference point to ensure accuracy within ±2 °C across the measurement range.

RESULTS AND DISCUSSION

The measured results were evaluated based on recorded temperatures and the behaviour of the samples during testing. The expected fire resistance of the proposed structural element compositions was determined based on temperatures measured on the unexposed surfaces. In accordance with the testing standard STN EN 1363-1 (2021), this temperature must not rise by more than 140 °C above the initial average surface temperature at the start of the test, and not more than 180 °C at any single point on the unexposed surface.

Sample No. 1 (MgO–PUR) was assessed as having a fire resistance of approximately 15 minutes. The results from sample 1b were considered representative. The test of sample 1a was terminated after 13 minutes due to an automatic shutdown of the radiation panel caused by improper placement within the test chamber. Fig. 8 shows the temperature development over the 13-minute duration of this test.

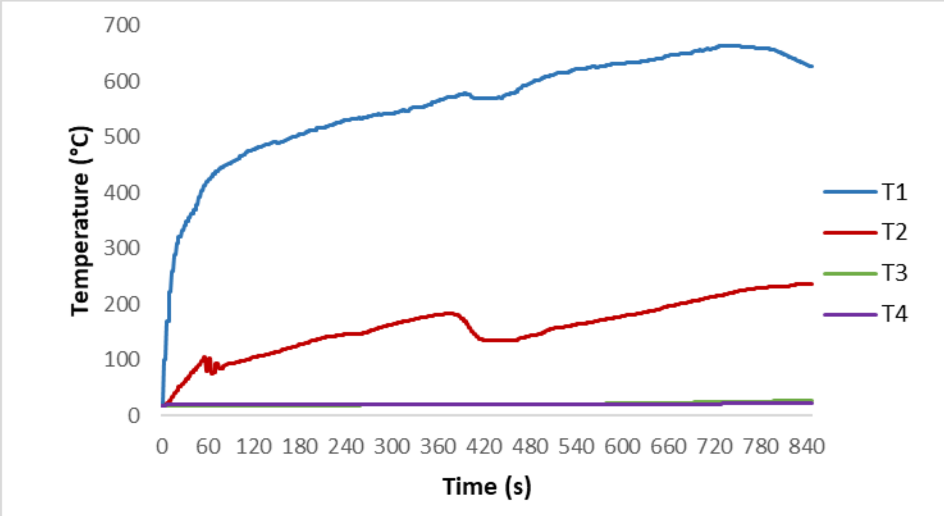

Fig. 8 Temperature profile of Sample 1a (MgO–PUR).

For sample 1b, the radiation panel was positioned outside the chamber, at the boundary of the testing enclosure, allowing better air access to the burner (as illustrated in Figure 6). The distance between the sample and the radiant surface was adjusted from 100 mm to 150 mm. The temperature curve for sample 1b is shown in Fig. 9.

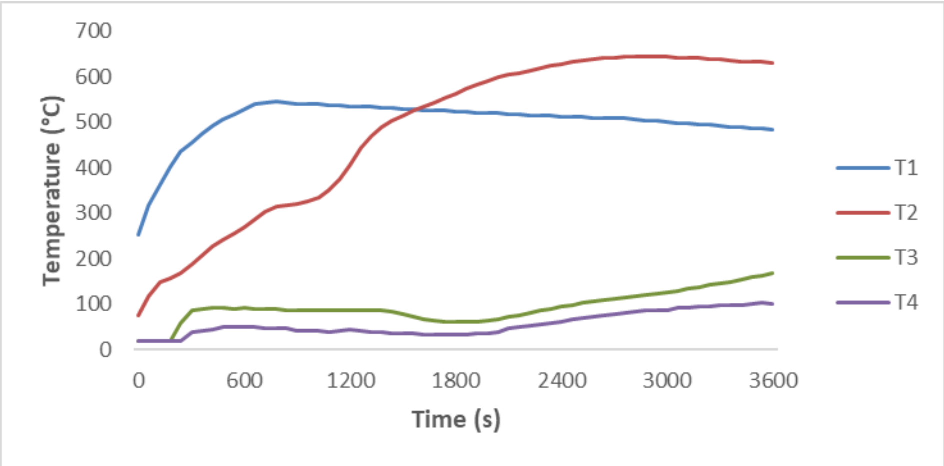

Fig. 9 Temperature profile of Sample 1b (Mgo–PUR).

During the test of sample 1a, thermocouple T2 malfunctioned (Fig. 8), and the test lasted 13 minutes. The maximum temperature at T1 after 13 minutes was 666.7 °C, and at T4 (on the unexposed surface) 22.2 °C. In sample 1b, smoke was observed from the inner part after approximately 15 minutes, accompanied by exposure of the fibreglass mesh on the MgO board. Around the 15th minute, the T1 thermocouple detached from the heated surface, resulting in a measurement interruption. Until that point, the temperature showed a rising trend (max. T1 = 547.8 °C), followed by a decline after reattachment.

The difference in maximum temperatures between samples 1a and 1b was due to their differing distances from the radiant panel (100 mm vs 150 mm). The temperature curve for sample 1b (Figure 9) shows a sharp inflection at the 25th minute, when the temperature at T2 exceeded that at T1, indicating the onset of internal heat penetration. On the unexposed surface (T4), the temperature after 60 minutes was 104.2 °C.

Fig. 10 illustrates sample 1b during and after testing. After around 20 minutes, significant bulging of the MgO board occurred due to thermal degradation of the PUR core, followed by heavy smoke emission from the sides and interior of the sample. After cooling, complete charring of the PUR insulation was observed, with the MgO board disintegrating in the thermally stressed region (Fig. 10c). For comparison, Figure 10d shows sample 1a after its early termination, where the MgO board and PUR insulation had already severely degraded after just 13 minutes.

a) b) c) d)

Fig. 10 Sample 1b (MgO–PUR) during and after testing
a) 20 min – bulging of the sample, b) 55 min – degradation of PUR and exposed fibreglass mesh of the MgO board, c) PUR insulation after sample cooling, d) sample 1a after 13 minutes of testing.

The results indicate that the PUR insulation completely degraded, leaving only a brittle black shell. Similar behaviour of sandwich panels with polyurethane cores has been reported by Tereňová (2024), in which the internal layer was almost entirely burned out, reducing the thickness from 60 mm to 7 mm. During testing, an unpleasant acrid odour was noted, causing eye and respiratory irritation. The critical temperature for the MgO–PUR sample was reached after 25 minutes, when rapid internal heating and thermal degradation of the PUR insulation occurred. The estimated fire resistance of the assembly was 15 minutes.

Sample No. 2 (MgO–honeycomb) exhibited an estimated fire resistance of 30 to 45 minutes. Around the 5th minute, sample 2a began to brown in the centre, and by the 10th minute, smoke appeared at the interface between the MgO board and the honeycomb core. After 15 minutes, a grey circle formed on the surface of the MgO board, followed by smoke emissions that gradually intensified. By the 30th minute, noticeable bulging of the MgO surface occurred, along with exposure of the mesh, heavy smoke release, and a distinct odour.

The temperature development for sample 2a (Fig. 11) shows that the temperature at T2 (572.8 °C) surpassed that at T1 (571.4 °C) after 43 minutes, indicating heat transfer through the honeycomb structure. At that time, the unexposed surface temperature (T4) was only 16.9 °C. By the 55th minute, smoke was observed escaping from the rear interface between the honeycomb and MgO board, and the test was concluded at 60 minutes. Sample 2b showed similar behaviour. Fig. 12 presents its temperature development, but the data from sample 2a were considered more representative, as during sample 2b testing, thermocouple T1 detached from the MgO surface at the 6th minute, delaying the temperature increase and altering the crossover point between T1 and T2.

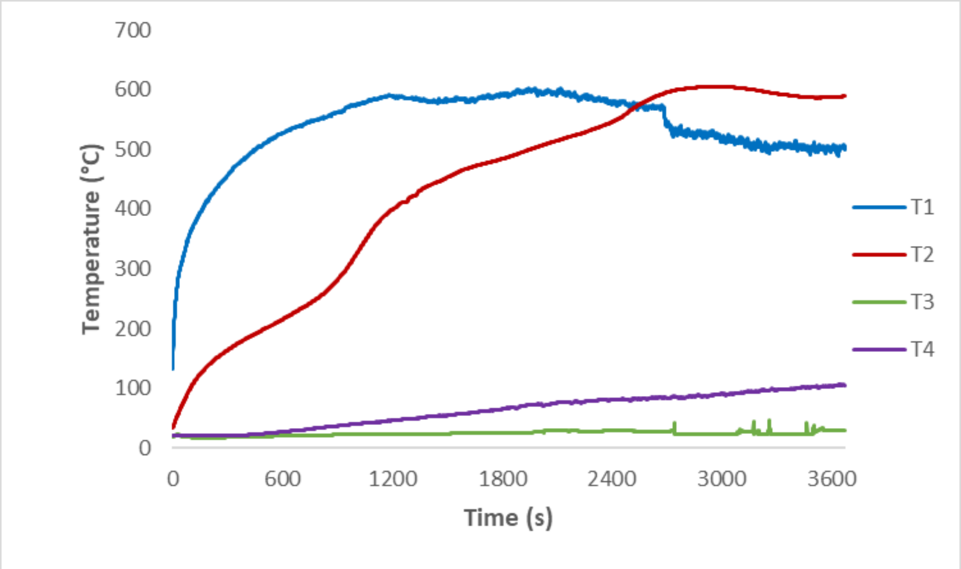

Fig. 11 Temperature profile Sample 2a (MgO–Honeycomb).

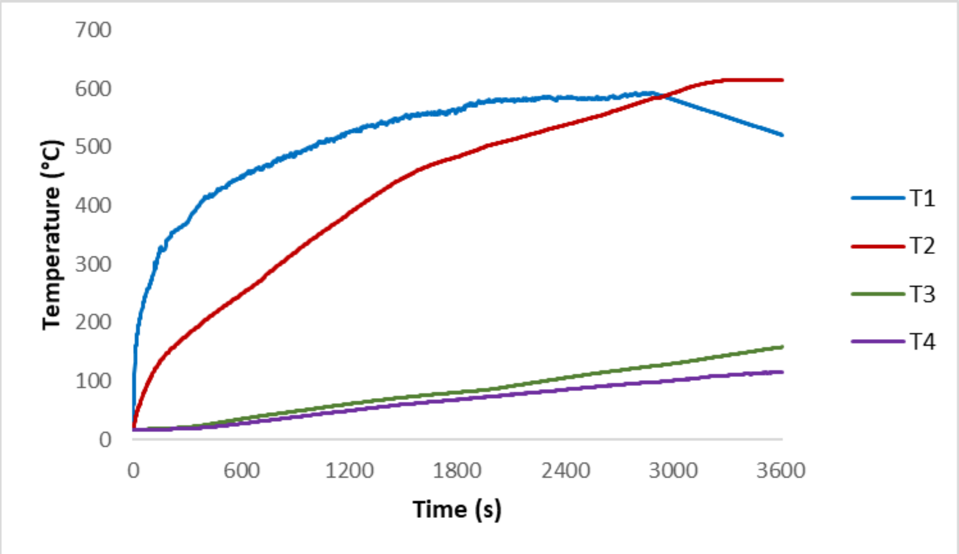

Fig. 12 Temperature profile Sample 2b (MgO–Honeycomb).

Photographs in Fig. 13 depict the sequence of changes during and after testing of sample 2a. The MgO surface began to brown at the start (Fig. 13a), deformed significantly by 30 minutes (Fig. 13b), emitted smoke from the rear interface at 55 minutes (Fig. 13c), and displayed degraded honeycomb material after removing the MgO board (Fig. 13d).

Fig. 13 Sample 2a (MgO–Honeycomb) during and after testing
a) browning of MgO at the beginning of the test, b) bulging of MgO at 30 min, c) 55 min – smoke emission from the rear gap, d) exposed mesh on MgO board, e) degraded honeycomb after removal of the MgO board.

The test of sample 3a was unsuccessful due to a failure in the automatic oxygen supply to the burner, which caused the radiation panel to shut down after 23 minutes and 52 seconds. The test of sample 3b proceeded correctly and was completed after 90 minutes. The temperature profiles for both samples (Figs. 14 and 15) revealed similar trends, suggesting that the results of sample 3a would have been comparable if the test had been completed. At the time of termination of the 3a test (23:52 min), the temperature at T1 was 518.7 °C, while the corresponding temperature for sample 3b was 569.5 °C. This difference was likely caused by inhomogeneities in the manually prepared mixture of MgO mortar and straw. The maximum temperature at T1 for sample 3b (586.4 °C) was reached after 39 minutes, while the unexposed surface (T4) temperature at that time was 32.1 °C. At the end of the 90-minute test, the T4 temperature reached only 57.8 °C. Throughout the test, the temperature at T2 never exceeded that at T1, demonstrating that the thermal barrier was maintained within the structure. The recorded temperature pattern suggested a fire resistance of 90 to 120 minutes.

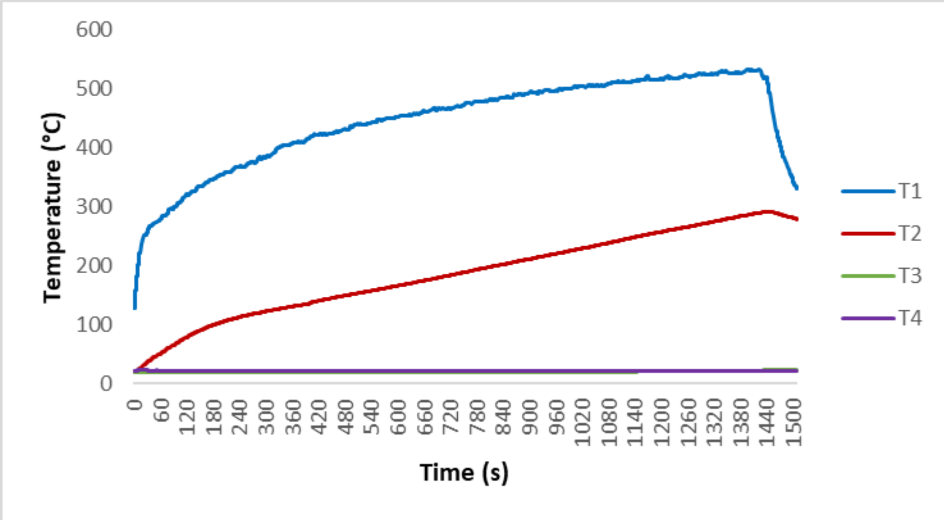

Fig. 14 Temperature profile Sample 3a (MgO–straw).

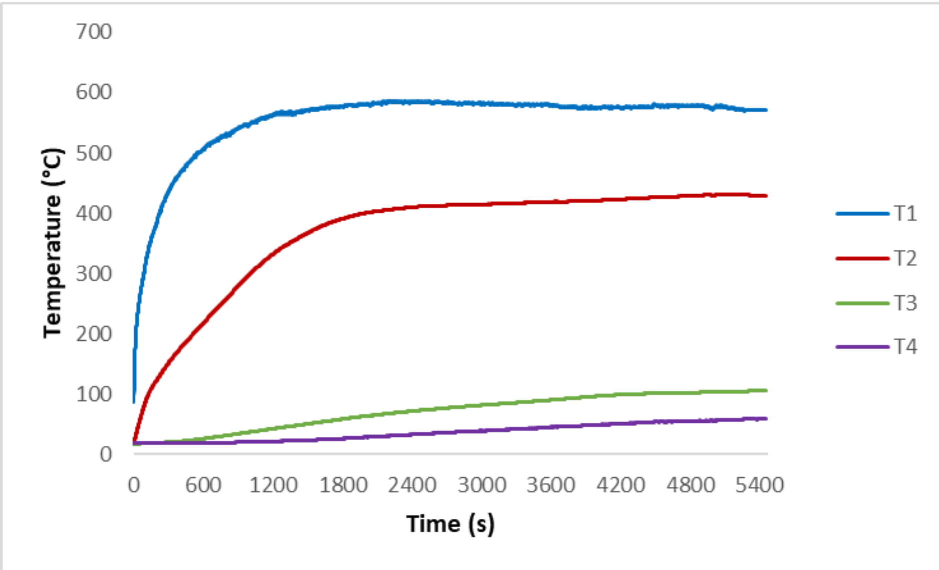

Fig. 15 Temperature profile Sample 3b (MgO–straw).

During testing, a crack began forming between the MgO board and the straw layer at the 9th minute (Fig. 16a), gradually expanding as the test continued. By the 25th minute, the fibreglass mesh became visible on the MgO surface (Fig. 16b), and after 50 minutes, smoke started escaping through the crack (Fig. 16c). At 60 minutes, the mesh was clearly exposed (Fig. 16d). Despite this, no further degradation occurred, and the sample remained structurally stable until the end of the 90-minute test. After removal from the chamber, the panel remained intact (Fig. 16e). Once cooled, the MgO board was detached, and fragmentation was observed only in the most heat-exposed areas, while the MgO mortar mixed with straw remained solid and undamaged (Fig. 16f).

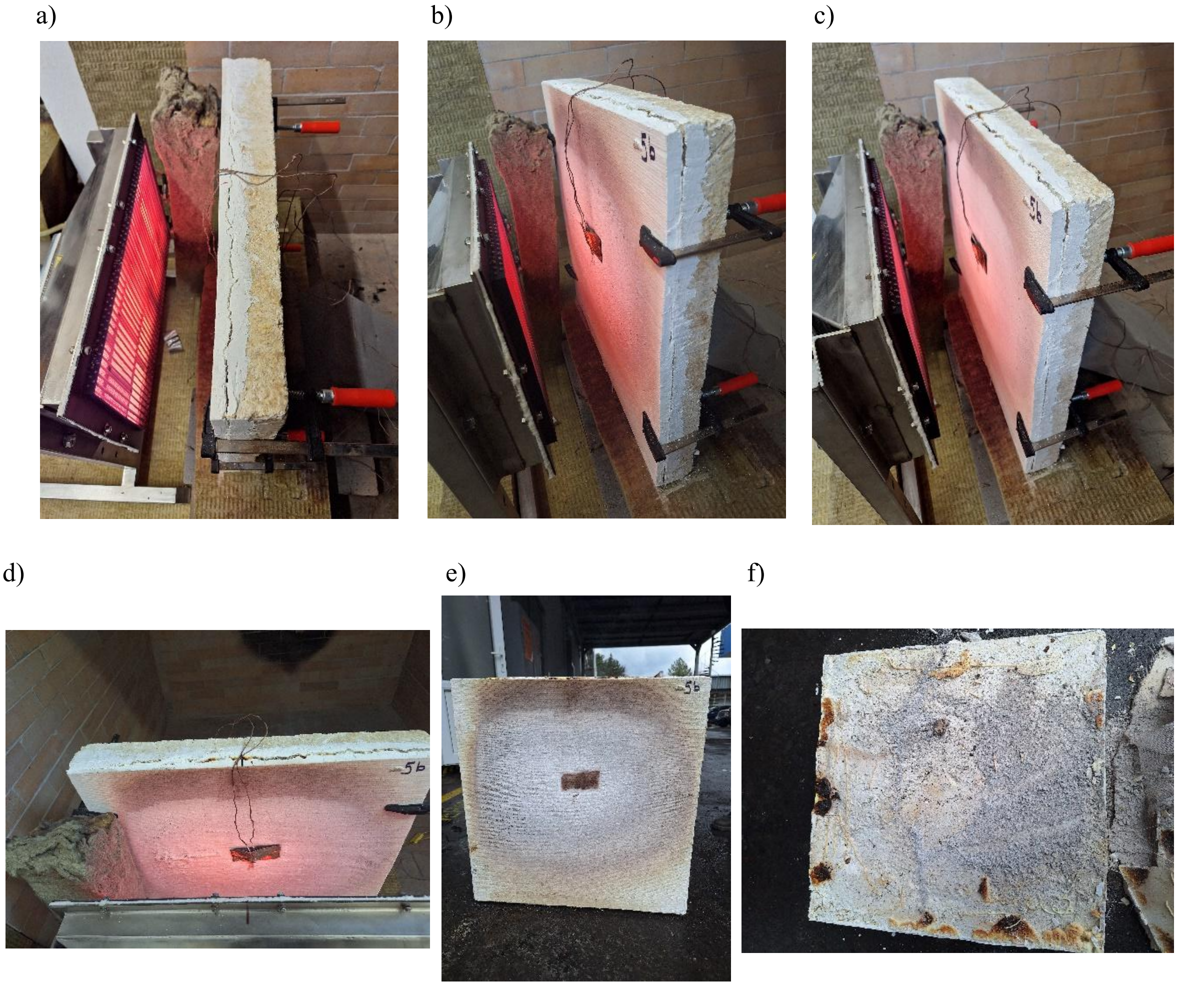

Fig. 16 Sample 3b (MgO–Straw) during and after testing
a) formation of a crack at 9 min, b) 25 min – beginning of mesh exposure, c) 50 min – smoke emission from the enlarged crack, d) 60 min – pronounced exposure of the mesh, e) sample after completion of the test, f) sample after removal of the MgO board.

Even after thermal exposure, the panel preserved structural integrity without delamination or complete disintegration. It suggests that the MgO–straw mixture not only prevents temperature breakthrough but also retains mechanical cohesion, an advantageous property for load-bearing wall assemblies.

The results demonstrate that the fire resistance of the tested assemblies strongly depended on the type of insulation core used. Although the thermal conductivity coefficients of the insulation materials were relatively similar (see Table 1), their behaviour under high temperatures differed significantly.

For Sample 1 (MgO–PUR), the PUR insulation was destroyed, leaving only a brittle carbonised shell. It aligns with previous findings by Tereňová (2024), who reported similar behaviour in sandwich panels with polyurethane cores, in which the inner layer was almost entirely burned away, resulting in a thickness reduction from 60 mm to 7 mm. The sample emitted a pungent odour throughout testing, causing eye and respiratory irritation. The critical temperature occurred approximately 25 minutes into the experiment, corresponding to rapid internal heating and the onset of PUR degradation. The estimated fire resistance was therefore 15 minutes.

In the case of Sample 2 (MgO–honeycomb), the improved fire resistance (30 to 45 minutes) was attributed to the unique geometry of the honeycomb core. Its dense structure delayed heat transfer and fire spread, contributing to greater stability of the MgO board during exposure. As Lee (2025) noted, suitable flame-retardant treatment of honeycomb materials can slow combustion and improve fire performance. The critical temperature for this sample was reached after 43 minutes, when gradual degradation of the honeycomb core began.

Sample 3, the MgO–straw mixture combining natural reinforcement with MgO mortar, showed clearly superior thermal and structural stability, achieving 90–120 minutes of fire resistance. It confirms its potential as an effective and sustainable core material for load-bearing timber assemblies, see also Abdul Motaleb et al. (2022) or Tlaiji et al. (2022).

Compared to the MgO–PUR and MgO–honeycomb panels, the MgO–straw composite reduced the temperature rise on the unexposed surface by approximately 45–60 %, and maintained stable internal temperature gradients throughout the 90-minute exposure.

The primary advantage of MgO-based boards lies in their resistance to high temperatures and flame. When used as cladding for structural components, they significantly enhance the overall fire resistance and safety of the construction. This finding aligns with the study by Švajlenka et al. (2021), who evaluated thermal parameters of wall assemblies with internal linings made of gypsum, MgO, and clay boards. Their results showed that wall variants using double MgO boards (2 × 12.5 mm) achieved some of the best thermal-technical performance and, based on our findings, are also expected to provide superior fire resistance.

In summary, the fire performance of MgO-based structural assemblies is primarily determined by the insulation material selected. The more susceptible the insulation is to thermal degradation, the more rapidly temperatures rise inside the structure, leading to loss of MgO board integrity. In contrast, the MgO–straw sample retained its structural cohesion even after 90 minutes of exposure, whereas the MgO–PUR and MgO–honeycomb samples showed visible deterioration and fragmentation of the MgO surface during and after the tests.

CONCLUSION

The results of the research demonstrate that magnesium oxide (MgO) boards are a suitable fire protection system for achieving the required fire resistance of building structures. The findings revealed that the behaviour of these materials under fire conditions is significantly influenced by the composition of the structural element and, above all, by the thermal insulation material used directly behind the MgO cladding.

Plastic-based materials, such as polyurethane (PUR), proved unsuitable because they degrade rapidly at high temperatures and cause a substantial increase in the structure's internal temperature, leading to a gradual loss of mechanical integrity of the MgO board. The combination of MgO board with a natural material, i., paper honeycomb, achieved improved fire resistance. The specific geometry and low thermal conductivity of the honeycomb core enhanced the durability and temperature stability of the MgO layer.

The best performance was obtained with MgO mortar mixed with straw, which proved to be the most suitable insulation material. During the entire 90-minute test, the temperature on the heated MgO surface remained higher than on subsequent thermocouples, indicating that no thermal degradation occurred within the inner layer. For further research, other eco-friendly materials such as mineral wool, wood fibre, straw panels, or natural wood-based composites are recommended as potential insulation cores.

MgO boards, when combined with an appropriate filler material within a structural assembly, are a promising solution for enhancing the fire resistance of load-bearing elements in multi-storey timber buildings.

The results presented confirm that appropriate combinations of MgO-based facings and natural insulation materials, such as straw–MgO mortar, can significantly enhance the fire safety and environmental performance of modern timber structures.

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