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Citation:

OJEDOKUN, Olalekan and O'FLAHERTY, Fin (2026). A Review of Mycelium-Based Composites as a High Fire-Rated Construction Material. Key Engineering Materials, 1046, 75-81. [Article]

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A Review of Mycelium-Based Composites as a High Fire-Rated Construction Material

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Keywords: Mycelium-based composites, Fire retardancy, Bio-based materials, Char formation, Sustainable construction, SDG 9, SDG 11, SDG 12, SDG 13.

Abstract. Recent studies have aimed to develop sustainable bio-based fire-resistant building materials to replace the conventional building materials. Traditional fire retardants such as halogenated compounds rely on toxic chemicals that pose environmental and health risks. Mycelium-Based Composites (MBCs), produced from fungal mycelia cultured from agricultural byproducts, offer a promising eco-friendly alternative with inherent fire-retardant properties. Addressing fire safety in buildings is vital for enhancing resilience, reducing casualties and economic losses, and aligning buildings with development goals. MBCs contribute to circular economies by repurposing waste and making it key to climate-adaptive construction. This study provides a review of MBCs' fire-retardant properties from various studies. The high char formation of MBCs (up to 48% at 600°C) at low heating rates (as low as 33 kW/m²), delayed ignition, and minimal smoke production outperformed those of their synthetic counterparts. This study identifies key research gaps and provides actionable solutions, such as tripartite studies, to disentangle mycelium, substrate, and additive effects.

Introduction

Statistics show 38,189 building fire incidents in England, accounting for 63% of all primary fires [1]. This highlights that fire is a key threat to structural safety. The 2017 Grenfell Tower disaster revealed that polyethylene-core aluminium composite panels (ACPs), though rated “non-combustible”, can still ignite and propagate flames, exposing gaps in regulations and material performance [2]. Furthermore, climate-driven wildfires dominate large-scale infrastructure fires [3]. A typical example is the 2025 Los Angeles wildfire disaster report, which emphasised the need for fire-resistant eco-friendly construction materials that minimise ignitability [4]. Although halogenated compounds, organophosphates, and mineral fillers reduce fire risks, they also pose environmental and health hazards [5,6].

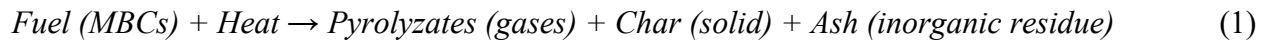
Emerging research has suggested the use of bio-based materials and nanocomposites as sustainable fire-resistant alternatives [7,8]. Mycelium-based composites (MBCs) produced from fungal mycelia grown on agricultural waste [9] are nontoxic, biodegradable, and naturally have low flammability [10,11]. Studies have reported that MBCs delay ignition, reduce heat release rates (HRR), and form protective char layers that preserve structural integrity and slow fire spread [12,13,14]. The char layer in MBCs preserves structural integrity during fire outbreaks. Unlike conventional insulants, such as polystyrene, polyurethane, and mineral wool which are flammable, produce toxic fumes, and are energy-intensive [15], MBCs are eco-friendly, lightweight, formaldehyde-free, and circular-economy compliant [16,17]. Although thermal insulation and fire resistance are distinct, they work together to improve safety, slow heat transfer, delay ignition, and limit the spread of fires [18]. This review addresses the limited data on MBC fire performance by analysing metrics such as flame resistance, ignition behaviour, and fire test outcomes. This highlights their potential for sustainable, fire-resilient, and climate-adaptive designs. Quantitative experimental data on the fire performance (for example, Limiting Oxygen Index (LOI), HRR, and microscale calorimetry) and thermal conductivity of MCB's

are presented in this paper. Recent experimental studies were selected for discussion, ensuring a focused synthesis of the current evidence on the fire retardancy properties of mycelium composites.

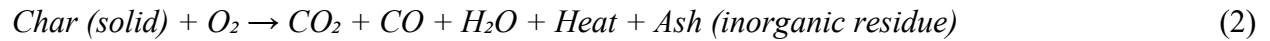
Fire Retardancy Mechanisms in MBCs

The fire resistance of MBCs stems from chitin-rich fungal hyphae interactions and thermal degradation combustion pathways which are discussed in this section. Fig. 1 adapts zone-based fire models [19, 20] to illustrate the interplay between the condensed, smouldering, and gas-phase mechanisms in MBCs.

Condensed-phase Mechanisms. The early condensed phase occurs between 130–280 °C [10] [15], where the thermal softening and decomposition of organic constituents begin. This stage involves the breakdown of low-stability organics and initiation of active pyrolysis. The active pyrolysis phase, occurring between 234–465 °C [8, 12], involves the degradation of fungal cell wall components such as chitin, β -glucans, and lipids. The chemical pathway for this process is represented by Eq. 1.



Smouldering Combustion in the MBCs. Smouldering combustion occurs as the primary char undergoes oxidative degradation, leading to ~10% mass loss between 465 °C and 600 °C. At 600–810 °C, the primary char transforms into a carbon-rich secondary char, reaching a stable residual char content of ~26% at 850 °C [12]. Extensive char formation in MBCs usually redirects combustion to a slower, flameless smouldering mode (Fig. 1). This transition reduces both the heat release and flame spread, which are central to the fire-retardant performance [11, 12].



Gas-Phase Interactions. In typical combustible materials, the gas phase is dominated by the release of pyrolytic volatiles that sustain the flaming combustion [21]. However, in MBCs, this phase is either significantly suppressed or absent owing to the limited generation of flammable gases [15]. Consequently, MBCs rarely exhibit sustained flaming, and combustion proceeds predominantly via smouldering and condensed-phase oxidation [10,12,13].

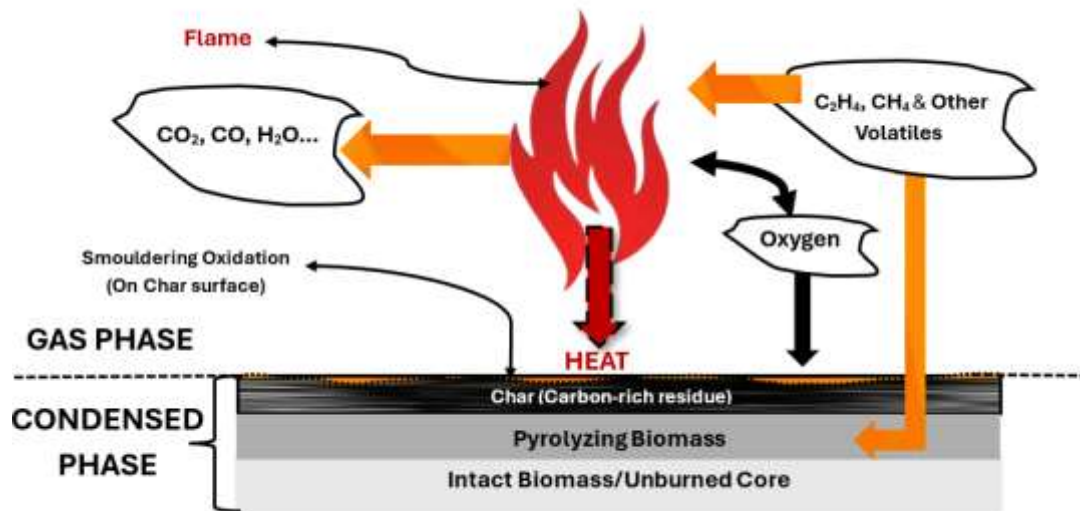
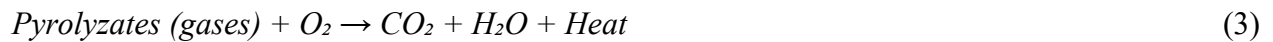


Fig. 1. Flame Retardant Mechanisms During Combustion of MBCs

Fire Performance Metrics and Standard Tests for MBCs

MBCs are lightweight bio-based materials with promising applications in sustainable cladding [22]. As novel cladding materials become more prevalent, existing fire testing protocols designed initially for traditional materials require reassessment, owing to the rising fire risks associated with flammable exterior cladding [23].

Standard tests like EN 13501 (reaction to fire classification) and ISO 4589 (limiting oxygen index) mainly focus on conventional polymers or building materials and may not adequately reflect the fire behaviour of MBCs [24,25,26]. Therefore, tailored fire safety protocols are required to provide flexible and comprehensive evaluation of these novel composites. Small-scale fire tests are increasingly employed to assess the fire performance of bio-based materials.

Small-scale fire test measures reaction-to-fire properties including ignitibility, flammability, fire spread, heat release, and smoke production [23]. Examples include ignition and fire spread tests, limiting oxygen index (LOI) tests, thermogravimetric analysis (TGA), Pyrolysis Combustion Flow Calorimetry, and Cone Calorimetry. Cone Calorimetry is widely used in MBCs because of its cost-effectiveness and ease of replication [27]. Cone Calorimetry in accordance with ISO 5660 [28] tests prism specimens ($100 \times 100 \times 20$ mm) under a controlled heat flux (50 kW/m^2). It measures heat release rate (HRR, calculated via oxygen consumption), peak HRR (PHRR), total heat release (THR), time to ignition (TTI), flameout time (TOF), effective heat of combustion (EHC), mass loss, CO/CO₂ production, and total smoke release (TSR) [8,23,29].

Full-scale testing in accordance with the BS EN 13501-1 standard [25] is rarely used for MBCs owing to its high cost, complexity, and large sample size. A key exception is the study by Dias et al. [14], which evaluated mycelium-Miscanthus panels under EN 13501-2:2003 [26], achieving an EI 15 rating which indicated 15 min of fire resistance with maintained integrity (E) and insulation (I). This study represents a shift from reaction-to-fire testing to assessing structural fire resistance in MBC. Despite their promising characteristics and thermal stability, most MBC studies have focused on micro- and bench-scale fire tests.

Discussion

Table 1 shows the key findings from the literature, including the performance indicators and test values for the MBCs [8,11,12,13,14,30,31]. Performance indicators include char formation, heat release rate (HRR), time to ignition (TTI), limiting oxygen index (LOI), and thermal degradation, as discussed in this section.

Char formation is key to fire retardancy because it creates an insulating barrier that reduces gas release. MBCs exhibit high char yields; unmodified mycelia produce 36% char at 600°C , whereas deacetylated mycelia increase this to 48% [11,12]. Similarly, Jones et al., 2018 [8] reported 23% char for pure mycelium at 600°C , exceeding the negligible char of synthetic polymers, such as poly methyl methacrylate (PMMA) having 0% char yield and polylactic acid (PLA) having 0.6% char yield, when exposed to thermal loading [8]. Chulikavit et al., 2023 [11] stated that deacetylation promotes larger crystalline microparticles and a porous network, enhancing insulation (Table 1). Thus, optimising the char morphology that improves fire retardancy.

MBCs showed a lower heat release rate (HRR) than the synthetic materials. Rice husk-based composites had a peak HRR of 133 kW/m^2 , and wheat grain-based composites had a peak HRR of 185 kW/m^2 , both lower than extruded polystyrene XPS foam (503 kW/m^2) and particleboard (200 kW/m^2), as shown in Table 1 [13]. Furthermore, deacetylated mycelium laminates had HRR values below 50 kW/m^2 and 149 kW/m^2 for the unmodified mycelium laminates (Control-Lam). Both types of GFRP laminates reduced the peak HRR, with deacetylated mycelia achieving a 60% reduction in the first peak HRR compared with unprotected GFRP laminates [12].

Similarly, HRR performance varies depending on the substrate and treatment, with tail-treated cotton showing a 40% reduction in HRR [31].

Table 1. Key performance results of MBCs and their key findings

Performance Indicator	Mycelium Type/MBCs	Value/Result	Key Findings	Source
Char Formation	Deacetylated mycelium (2M/40°C/8h)	Unmodified (36%) vs 48% residue after treatment @ 600°C	↑ 33%; microporous crystalline structure enhances insulation	[11, 12]
	Rice husk mycelium composite	36–38% residue	Silica in rice husks boosts char stability	[30]
	Mycelium (pure)	23% residue at 600°C	Outperforms PMMA (0%) and PLA (0.6%)	[8]
Heat Release Rate (HRR)	Deacetylated mycelium laminate	Peak HRR: <50 kW/m ² (vs. 149 kW/m ² unmodified)	GFRP fireproofing reduce first peak HRR by 60%	[12]
	Rice hull composite + 50% glass fines	Avg HRR: 133 kW/m ² ; Peak HRR: 185 kW/m ²	↓70% avg HRR vs. XPS foam (114 kW/m ²)	[13]
	Turkey Tail-treated cotton	↓40% vs. untreated	Significant reduction across textiles	[31]
Time to Ignition (TTI)	GFRP + unmodified mycelium	↑55s vs. unprotected GFRP	Delays ignition via char barrier	[12]
	Wheat grain composite	12 s	Shorter TTI vs. particleboard (26 s) but slower fire growth	[13]
	Rice-hull composite	7 s		
Limiting Oxygen Index (LOI)	Rice husk/sawdust composites	25.5–32.7%	Self-extinguishing (LOI >21%)	[30]
	Turkey Tail-treated cotton	25% (vs. 17–20% untreated)	Fell below the 26% industry benchmark for flame-retardant textiles.	[31]
Smoke Production Combustion Behaviour	Turkey Tail-treated textiles	↓25–28%	Reduced smoke toxicity	[31]
	Mycelium-Miscanthus + render	EI15 fire rating (EN13501-2)	No combustion in 70-min test	[14]
Additional Metrics	FIGRA (GFRP + mycelium)	↓57–72%	Slows fire growth rate	[12]
	Time to flashover (rice hull composite)	311 s	5× longer than XPS foam (61 s)	[13]

A longer Time to ignition TTI indicates a better ignition resistance. Jones et al., 2018 [13] reported TTI values of 7 s for rice-hull-based and 12 s for wheat-grain-based composites, versus 26 s for particleboard (Table 1). This suggests that MBCs may ignite quickly, thereby limiting their application. Conversely, mycelium delayed ignition in GFRP laminates by 55 s (unmodified) and 28 s (deacetylated) [12]. The EI15 fire rating [26] for mycelium-Miscanthus composites indicates that the mycelium functions as a fireproofing layer rather than a standalone material [14]. This dual behaviour—quick ignition when standalone but effective as a protective barrier requires careful consideration in the application context.

The limiting oxygen index (LOI) measures minimum oxygen required for combustion. Materials with LOIs below 21% are flammable in air, whereas those with LOIs above 21% exhibit flame retardancy because they require higher oxygen than atmospheric levels for combustion [51]. Mbabali et al., 2024 [30] reported LOI values of 25.5–32.7% for rice husk and sawdust MBCs as shown in Table 1, classifying them as self-extinguishing. Karthikeyan et al., 2025 [31] found an LOI of 25% for Turkey Tail (*Trametes versicolor*)-treated cotton, improved from 17–20% in untreated cotton (Table 1). These results suggest that the MBCs can achieve LOI values, indicating good fire retardancy. The reduction in LOI stems from char formation, which traps volatile compounds and prevents smoke release. This is a key advantage over synthetic materials, which generate toxic smoke during combustion.

Thermal degradation studies revealed the heat behaviour of MBCs which is crucial for fire performance assessments. Jones et al., 2018 [8] found that mycelia decomposed at $\sim 225^{\circ}\text{C}$, with char formed at 500°C . Chulikavit et al., 2023 [12] observed that deacetylated mycelia showed improved thermal stability owing to the presence of chitosan. In epoxy composites, mycelia shifted the maximum mass loss temperature lower (from 418°C to $405\text{--}411^{\circ}\text{C}$) but increased char yields above 418°C . This increased char formation was attributed to the intrinsic char-forming ability of the mycelium and superior thermal stability of the deacetylated mycelium [12].

Conclusion

The increasing frequency of building fires and urban blazes highlights the pressing demand for sustainable materials that can resist fire. Mycelium-based composites (MBCs) have emerged as groundbreaking bio-based solutions that utilise fungal mycelia cultivated on agricultural waste to provide a nontoxic and biodegradable alternative to traditional fire retardants. This review highlights that MBCs exhibit exceptional fire-retardant properties attributed to their biochemical composition, including chitin, β -glucans, proteins, and microstructural porosity. These attributes allow MBCs to form a protective char layer when exposed to heat, which reduces the heat release rate (HRR), delays ignition (TTI), and promotes smouldering combustion during flaming. Furthermore, their low smoke production and potential self-extinguishing properties make them safer alternatives to synthetic materials, such as polystyrene and polyurethane, which often emit toxic fumes and are highly flammable. Standardised tests, such as Pyrolysis Combustion Flow Calorimetry (PCFC), Cone Calorimetry, Limiting Oxygen Index (LOI), and Thermogravimetric Analysis (TGA), have quantified the fire performance of MBCs, revealing char yields of up to 48%, LOI values exceeding 25%, and HRR as low as 33 kW/m^2 in optimised formulations. However, significant research gaps remain. The lack of a tripartite control framework comparing MBCs with binder-free substrates and resin-bound systems impedes our understanding of the specific contributions of mycelia to fire retardancy. Variability in substrates, treatments, and testing protocols further complicates performance assessments, whereas full-scale fire tests (e.g. BS EN 13501-1[25]) are rare and impede regulatory approval. Future research should prioritise tripartite studies to isolate the role of mycelia, explore molecular mechanisms such as chitin deacetylation, and develop standardised testing protocols. By addressing these gaps, MBCs can be optimised for fire-conscious applications, offering synergy between fire resistance, thermal insulation, and sustainability. With interdisciplinary innovation, MBCs can redefine construction standards and align with circular economic principles and climate-adaptive designs to enhance building safety worldwide.

Acknowledgements

The authors gratefully acknowledge the continuing support of School of Engineering and Built Environment, Sheffield Hallam University.

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