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Enhancing Fire Resistance of Bio-Composite (Wood Based) for Interior Applications: A Review & Future Directions

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ABSTRACT

Wood-based bio-composites are gaining widespread use in interior applications due to their sustainability, lightweight structure, and aesthetic appeal; however, their inherent flammability poses a significant fire hazard. This review examines the latest advancements in enhancing the fire resistance of wood-based bio-composites through the incorporation of eco-friendly additives and structural modifications. The study highlights several promising flame-retardant strategies, including the use of alginate-based composites, phytic acid formulations, biosilica epoxy systems, and nano-silica–reinforced jute hybrids. Comparative analysis of key fire performance parameters—such as Limiting Oxygen Index (LOI), Peak Heat Release Rate (PHRR), and Smoke Production Rate (SPR)—reveals that additives like magnesium hydroxide (MDH) and aluminum hydroxide (ATH) considerably enhance fire resistance while maintaining mechanical integrity. The integration of nanomaterials and bio-derived flame retardants further improves thermal stability and smoke suppression efficiency. This review concludes that optimizing additive selection and dispersion can yield safer, more sustainable wood composites suitable for interior applications, contributing to improved building safety and environmental protection. Future research should focus on hybrid additive systems, cost-effective processing, and life-cycle assessment to ensure practical scalability and regulatory compliance.

Keywords: Bio-composites, Fire resistance, Interior materials, Sustainability, Material characterization

1. Introduction

A growing number of industries are adopting environmentally friendly, renewable materials to replace fossil-based resources due to environmental concerns, resource depletion, and stricter regulations. As a result, natural fibers are increasingly used to produce biobased composites, though their variable properties often cause inconsistencies in final products [1], [2]. Biofiber-reinforced biopolymers are low-cost, biodegradable, recyclable, and eco-friendly but suffer from drawbacks such as moisture sensitivity and poor fire resistance. These limitations can be addressed through chemical or structural modification and the use of flame-retardant additives (FRAs) [3]. The Biobased Industries (BBI) program projects that by 2030, 30% of fossil-based materials will be replaced by bio-based alternatives, and renewable resources will supply two-thirds of global chemical demand by 2100 [4], [5]. Recently, multifunctional textile fibers have gained significant attention, with flame resistance being one of the most critical requirements for both civilian and defense applications. Textile fibers such as cotton, hemp, silk, wool, and synthetic materials like nylon and polyester can be modified for flame resistance [6]. Recent developments have also produced low-cost, fire-resistant composites from household waste for construction applications [7]. However, natural fibers still face challenges such as high moisture absorption, weak fiber–matrix adhesion, and low flame resistance [8]. Despite these drawbacks, they are widely used due to their low cost, biodegradability, and environmental benefits [9]. Nanotechnology further enhances flame retardancy in polymer composites, though nanoparticle safety must be carefully managed [10].

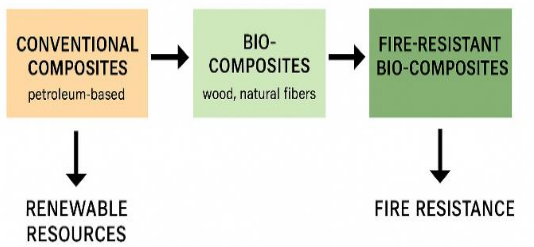

Fig.1: Transition from Petroleum-based synthetic composites to eco-friendly, flame-retardant bio-composites for interior applications

Overall, natural fiber–reinforced composites such as jute, kenaf, and flax offer strong, lightweight, and sustainable alternatives to synthetic materials [11].

2. Enhancement Of Wood Composites

As the wood composites are widely used in shopping malls, shops, hospitals for interior design, enhancement of fire resistance of its composite is a critical aspect in building design. The process of mixing some selected additives in different forms can be a useful solution. Such types of additives that can enhance the fire resistance of wood composites are discussed.

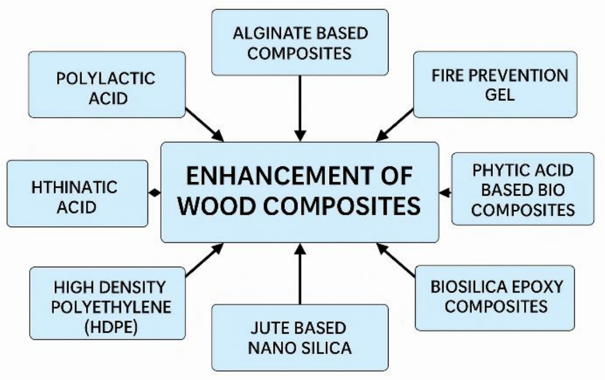

Fig.2: Enhancement of Different Wood Components

2.1. Alginate Based Composites

Lin Weng and Xiaolin Zhang discovered that a recycled composite made from calcium alginate and discarded polyester fiber achieved a flame retardancy index of a > 26, earning a UL94 V-2 rating for fire resistance. This composite also reduced smoke emissions by 27% and produced fewer harmful emissions when burned [12]. The ultimate decomposition temperatures of Alg-wv and Alg-wc composite felts were found to be 740 °C and 700 °C, respectively, indicating their suitability as flame-retardant materials. Thermogravimetric (TG) analysis revealed that Alg-wv felt exhibited weight loss at temperatures up to 330 °C and 500 °C, while Alg-wc felt lost weight at lower temperatures of 300 °C and 470 °C. These findings were further corroborated by 3D FTIR spectra [13]. Additionally, nano-calcium borate (CAB) demonstrated a limiting oxygen index (LOI) greater than 60 and a maximum-rate breakdown temperature of 410 °C, which surpassed that of calcium alginate (CA) at 275 °C. In cone calorimetry (CONE), the residual mass of CAB (35.3%) after 360 seconds was greater than that of CA (33.1%) [14].

2.2 Fire Prevention Gel

A novel self-healing fire prevention (FP) gel, composed of polyvinyl alcohol (PVA), borax, cellulose nanofibrils (CNF) derived from peanut shells, and expanded graphite (EG), has been developed. In a distilled aqueous solution, the PVA-Borax-CNF/EG gel exhibits an impressive water absorption capacity of 435 times its weight. Thermogravimetric (TG-DTG) analysis indicates a maximum mass loss of approximately 37.7% within the temperature range of 269 °C to 458 °C, with a peak heat release rate (HRR) of about 138 kW/m² [15]. Furthermore, the aerogels showcase remarkable fire resistance, achieving a limiting oxygen index (LOI) value of up to 63%, a Young's modulus of up to 4.5 MPa, and thermal conductivities below 38.2 $mW \cdot m^{-1} \cdot K^{-1}$ [16].

2.3 Phytic Acid Based Bio Composites

Phytic acid–tyramine salt (PATA) used with ammonium polyphosphate (APP) provides strong synergistic flame retardancy in wood–plastic composites (WPCs), achieving a V-0 rating, a 31% increase in LOI, and reductions in smoke density, total heat release, and peak heat release rate by 22%, 15%, and 49%, respectively [17]. Functional polypropylene (PP) also shows enhanced fire resistance, with 22 wt% PaArg giving an LOI of 26.0% and a V-0 rating, while PaLys performs even better; adding 25 wt% PaLys to PP reduces peak heat release rate by 70.7% and fire growth by 86.9% compared to standard PP [18]. Additionally, flame-retardant treatment of wood particles using phytic acid and sodium silicate significantly increases LOI and decreases HRR, THR, SPR, and TSP in hot-pressed composites [19].

2.4 Biosilica Epoxy Composites

Epoxy–silica nanocomposites are widely studied for use in protective coatings, bonding, wrapping, and electronics, with Near-Infrared Spectroscopy (NIR) used to monitor epoxy conversion at the 4530 cm^{-1} peak [20]. These composites show improved fire performance, as adding 2% bio-silica reduces flame propagation speed to 7.37 mm/min [21], making them suitable for lightweight and eco-friendly infrastructure applications such as manhole covers, gratings, handrails, and septic tanks. With 5 vol.% bio-silica, they achieve a V-0 fire rating without dripping or cotton ignition, with a flame propagation speed of 8.45 mm/min [22]. Their durability and high load-bearing capacity also make them useful in automotive, military, and domestic applications [23], [24].

2.5 Jute Based Nano Silica

Natural fiber-based nanocomposites are gaining prominence in construction and transportation due to their excellent lightness and high strength-to-weight ratio. These materials exhibit superior fire resistance, with a combustion rate of 17 mm/min and 29% char residue. XRD analysis shows that 6% SiO_2 nanoparticles have limited exfoliation (d-spacing 39.01 nm, correlation 23.41%), indicating room for improved dispersion [25]. Hybrid composites using woven jute fiber and micro-silica powder offer exceptional strength and lightness, making them ideal for engineering applications [26]. Mechanical tests confirm that nanosilica-reinforced jute and jute–HTPET hybrids provide durability and adaptability for structural use [27]. Rice straw–jute composites reinforced with silica are suitable for wall panels, bags, and furniture, valued for being low-cost, recyclable, and eco-friendly [28]. These nanocomposites also meet automobile standards, especially for interior panels using jute/kenaf materials [29], and jute shows vast potential in nanocellulose production, carbon processing, catalysis, energy storage, and biotechnological applications [30].

2.6 High Density Polyethylene (HDPE)

Bifunctional silyl ethers (BSEs) are employed to develop chemically deconstructable derivatives of high-density polyethylene (HDPE) that enable recycling through Si–O bond exchange. HDPE, widely used in bottles, packaging, and supermarket bags, accounts for about 60% of municipal plastic waste [31]. Eco-friendly HDPE nanocomposites are produced using polybutylene succinate (PBS) and calcium carbonate (NPCC) nanoparticles via injection molding [32]. Co-pyrolysis of HDPE with sugarcane bagasse (SCB) yields high-calorific-value oil (42.41 MJ/kg), comparable to commercial diesel, indicating favorable combustion properties [33]. FTIR and XRD analyses confirm that both PLA and HDPE maintain structural integrity post-irradiation, showing increased crystallinity due to chain scission under oxidative conditions [34]. Although polystyrene (PS) rigid plastics yield a 14% internal rate of return, mixed polyolefins show negative profitability, underscoring the need for policy support to enhance the economic feasibility of recycled materials [35].

2.7 Polylactic Acid

The fire resistance of particleboards improves notably with bio-polyester incorporation, which reduces MAHRE, THR, and PHRR while maintaining thermal stability, as confirmed by TGA-FTIR analysis. The phosphorylated bio-polyester performs comparably to ammonium polyphosphate as a flame retardant [36]. Polylactic acid (PLA), a renewable and biodegradable polymer, is widely used in agriculture, automotive, and packaging industries for its mechanical strength and sustainability [37]. In biomedicine, PLA serves in slow-degrading implants and pharmaceuticals produced through additive manufacturing [38]. It also replaces petrochemical polymers in food packaging, enhancing safety and shelf life [39]. As a leading biopolymer, PLA is being reinforced with natural fibers for advanced composites [40], and its high calorific value (20.949 $MJ \cdot kg^{-1}$) enables energy recovery from 3D printing waste [41]. Cost-effective PLA production using carbohydrate-rich food waste further improves its sustainability and scalability [42].

Table.1: Latest additives used in wood composite

Substance	LOI (%)	Peak HRR (kW/m²)	Smoke Production Rate (m²/s)	Ref
Untreated Wood Composite	20–22	200-400	0.10–0.40	[43]
Ammonium Polyphosphate	28–35	100-180	0.05–0.20	[44] [45]
Magnesium Hydroxide (MDH)	33–36	90–150	0.02–0.10	[46]
Boron Compounds	27–30	120–220	0.02–0.10	[47]
Melamine Compounds	28–32	100–180	0.10–0.30	[48]
Aluminum Hydroxide (ATH)	30–35	80–160	0.03–0.15	[49]

3. Discussion on Fire Performance

Table.1 summarizes the effects of various flame-retardant additives on the fire performance of wood composites, showing significant improvements in LOI, reduced Peak HRR, and lower Smoke Production Rates compared to untreated samples.

A higher Limiting Oxygen Index (LOI) indicates better fire resistance, and Figure 1 shows that the addition of additives increases the LOI of wood composites, enhancing their flame retardancy. Similarly, a high peak Heat Release Rate (HRR) signifies rapid fire spread and poor fire resistance; however, Figure 2 demonstrates that additives significantly reduce the peak HRR, confirming improved fire performance. Furthermore, excessive smoke generation increases fire hazards, while Figure 3 shows that additives lower the smoke production rate of wood composites, making them safer for building applications.

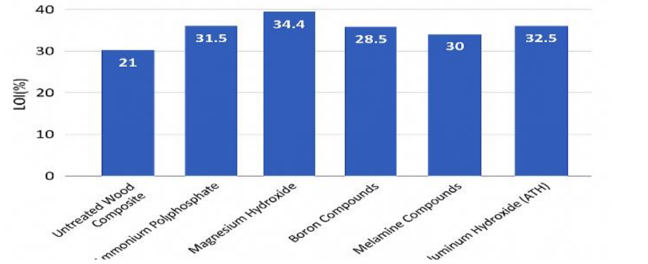

Fig1: LOI Enhancement of wood composite with the addition of additives

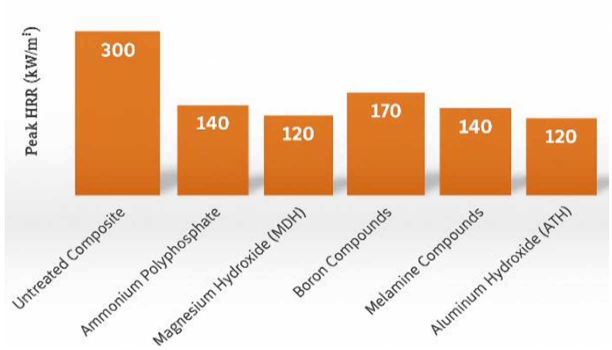

Fig.2: Changes of Peak Heat Release Rate of wood composite with addition of additives

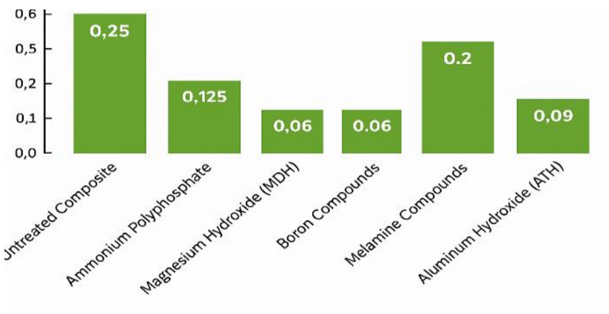

Fig.3: changes of Smoke Production Rate of wood composite with addition of additives

4. Recommendations

- **Develop multifunctional flame-retardant systems** combining bio-based and nanomaterial additives to enhance fire resistance while maintaining structural integrity.
- **Improve additive dispersion and fiber–matrix bonding** to achieve uniform thermal and mechanical performance across wood-based bio-composites.
- **Conduct life-cycle and techno-economic assessments (LCA–TEA)** to evaluate cost-effectiveness, recyclability, and environmental impact at industrial scale.
- **Establish standardized testing protocols** for evaluating Limiting Oxygen Index (LOI), Peak Heat Release Rate (PHRR), and Smoke Production Rate (SPR) for better cross-study comparability.
- **Promote collaboration** among researchers, manufacturers, and policymakers to develop cost-efficient fabrication methods and recycling frameworks.
- **Incorporate advanced analytical tools** such as TGA-FTIR, cone calorimetry, and microstructural imaging for deeper insights into composite behavior under thermal stress.

- **Focus on sustainable material design** to create eco-friendly, fire-safe composites suitable for interior and structural applications that align with global sustainability goals.

5. Cost Analysis

A rough cost analysis has been done by considering the additive based composite with 75% of base material (wood) and 25% of the selected additives. From Table.2, it is clearly visible that melamine compounds increase the cost a lot; thus, their use is very expensive, while ATH increases only 25% of the total price. However, according to need, the composition's additive ratio can be changed, which can make the composite more cost-effective.

Table.2: Cost Analysis

Additive	Additive Cost (৳/kg)	Treated Material Cost (৳/kg)	% Increase vs Untreated	Ref
Untreated Composite	-	60	-	-
Ammonium Polyphosphate (APP)	240	(0.75×60) + (0.25×240) = ৳ 105	+75%	[50]
Magnesium Hydroxide (MDH)	180	45 + 45 = ৳ 90	+50%	[51]
Boron Compounds	144	45 + 36 = ৳ 81	+35%	[52]
Melamine Compounds	360	45 + 90 = ৳ 135	+125%	[53]
Aluminum Hydroxide (ATH)	120	45 + 30 = ৳ 75	+25%	[54]

6. Conclusion

Wood-based bio-composites have emerged as sustainable alternatives to conventional synthetic materials, offering advantages such as renewability, biodegradability, and cost-effectiveness. However, their high flammability remains a critical limitation for interior applications. This review highlighted various strategies to improve the fire resistance of bio-composites through the incorporation of flame-retardant additives, such as ammonium polyphosphate, magnesium hydroxide (MDH), aluminum hydroxide (ATH), boron, and melamine compounds. Comparative analysis revealed that these additives significantly increase the Limiting Oxygen Index (LOI), while reducing the Peak Heat Release Rate (PHRR) and Smoke Production Rate (SPR), thereby enhancing safety and survivability during fire incidents. Among the studied materials, MDH-based composites exhibited the highest LOI and superior smoke suppression properties. The integration of nanomaterials, bio-based retardants, and hybrid systems demonstrates strong potential for achieving high-performance, eco-friendly fire-resistant composites. Future research should focus on optimizing additive dispersion, improving interfacial bonding, and evaluating the long-term durability and recyclability of treated composites. A life-cycle and cost-benefit assessment will also be essential to ensure large-scale adoption of these sustainable fire-safe materials in modern construction and interior applications.

7. References

[1] A. Karimah *et al.*, "A review on natural fibers for development of eco-friendly bio-composite: characteristics, and utilizations," *Journal of Materials Research and Technology*, vol. 13, pp. 2442–2458, Jul. 2021, doi: 10.1016/J.JMRT.2021.06.014.

[2] E. W. Madyaratri *et al.*, "Recent Advances in the Development of Fire-Resistant Biocomposites—A Review," *Polymers 2022, Vol. 14, Page 362*, vol. 14, no. 3, p. 362, Jan. 2022, doi: 10.3390/POLYM14030362.

[3] M. E. Mngomezulu, M. J. John, V. Jacobs, and A. S. Luyt, "Review on flammability of biofibres and biocomposites," *Carbohydr Polym*, vol. 111, pp. 149–182, Oct. 2014, doi: 10.1016/J.CARBPOL.2014.03.071.

[4] Brett C. Suddell and William J. Evans, "Natural Fibers, Biopolymers, and Biocomposites: An Introduction," *Natural Fibers, Biopolymers, and Biocomposites*, pp. 17–51, Apr. 2005, doi: 10.1201/9780203508206-9.

[5] S. RameshKumar, P. Shaiju, K. E. O'Connor, and R. B. P, "Bio-based and biodegradable polymers - State-of-the-art, challenges and emerging trends," *Curr Opin Green Sustain Chem*, vol. 21, pp. 75–81, Feb. 2020, doi: 10.1016/J.COGSC.2019.12.005.

[6] M. Yusuf, "A Review on Flame Retardant Textile Finishing: Current and Future Trends," *Current Smart Materials*, vol. 3, no. 2, pp. 99–108, Jul. 2018, doi: 10.2174/2405465803666180703110858.

[7] N. Surtiyeni, R. Rahmadani, N. Kurniasih, Khairurrijal, and M. Abdullah, "A Fire-Retardant Composite Made from Domestic Waste and PVA," *Advances in Materials Science and Engineering*, vol. 2016, no. 1, p. 7516278, Jan. 2016, doi: 10.1155/2016/7516278.

[8] A. Ari, M. Karahan, H. A. M. Ahmed, O. Babiker, and R. M. A. Dehşet, "A Review of Cellulosic Natural Fibers' Properties and Their Suitability as Reinforcing Materials for Composite Panels and Applications," *https://doi.org/10.1177/24723444221147365*, vol. 10, no. 3, pp. 163–183, Feb. 2023, doi: 10.1177/24723444221147365.

[9] S. Kumar, A. Manna, and R. Dang, "A review on applications of natural Fiber-Reinforced composites (NFRCs)," *Mater Today Proc*, vol. 50, pp. 1632–1636, Jan. 2022, doi: 10.1016/J.MATPR.2021.09.131.

[10] A. Rabajczyk, M. Zielecka, T. Popielarczyk, and T. Sowa, "Nanotechnology in Fire Protection—Application and Requirements," *Materials 2021, Vol. 14, Page 7849*, vol. 14, no. 24, p. 7849, Dec. 2021, doi: 10.3390/MA14247849.

[11] K. N. Keya, N. A. Kona, F. A. Koly, K. M. Maraz, Md. N. Islam, and R. A. Khan, "Natural fiber reinforced polymer composites: history, types, advantages and applications," *Materials Engineering Research*, vol. 1, no. 2, pp. 69–85, Jun. 2019, doi: 10.25082/MER.2019.02.006.

[12] L. Weng and X. Zhang, "Recycling polyester fiber with bio-based alginate fiber into fire-safety composite," *Polym Degrad Stab*, vol. 217, p. 110519, Nov. 2023, doi: 10.1016/J.POLYMDEGRADSTAB.2023.110519.

[13] L. Weng and X. Zhang, "Fully bio-based fire-safety composite from cotton/viscose wastes and alginate fiber as furniture materials," *Waste Management*, vol. 168, pp. 137–145, Aug. 2023, doi: 10.1016/J.WASMAN.2023.05.047.

[14] Z. Liu, Z. Li, X. Zhao, L. Zhang, and Q. Li, "Highly Efficient Flame Retardant Hybrid Composites Based on Calcium Alginate/Nano-Calcium Borate," *Polymers 2018, Vol. 10, Page 625*, vol. 10, no. 6, p. 625, Jun. 2018, doi: 10.3390/POLYM10060625.

[15] G. Zhou *et al.*, "Preparation and properties of bio-based self-healing fire prevention gel reinforced with expanded graphite ligand," *Journal of Building Engineering*, vol. 66, p. 105845, May 2023, doi: 10.1016/J.JOBE.2023.105845.

[16] A. Varamesh *et al.*, "Fully biobased thermal insulating aerogels with superior fire-retardant and mechanical properties," *Chemical Engineering Journal*, vol. 495, p. 153587, Sep. 2024, doi: 10.1016/J.CEJ.2024.153587.

[17] Y. M. Leng, X. Zhao, T. Fu, X. L. Wang, and Y. Z. Wang, "Bio-Based Flame-Retardant and Smoke-Suppressing Wood Plastic Composites Enabled by Phytic Acid Tyramine Salt," *ACS Sustain Chem Eng*, vol. 10, no. 15, pp. 5055–5066, Apr.

2022, doi: 10.1021/ACSSUSCHEMENG.2C00848/SUPPL_FILE/SC2C00848_SI_001.PDF.

[18] C. F. Lin *et al.*, "Phytic Acid-Silica System for Imparting Fire Retardancy in Wood Composites," *Forests 2023, Vol. 14, Page 1021*, vol. 14, no. 5, p. 1021, May 2023, doi: 10.3390/F14051021.

[19] C. F. Lin *et al.*, "Phytic Acid-Silica System for Imparting Fire Retardancy in Wood Composites," *Forests 2023, Vol. 14, Page 1021*, vol. 14, no. 5, p. 1021, May 2023, doi: 10.3390/F14051021.

[20] G. Garcia-Mejia, G. Saavedra-Intriago, A. Rigail-Cedeño, A. Rivas-Ferrín, and C. V. Tapia-Bastidas, "Effect of silica fume and rice husk silica in bio-epoxy composites," *Mater Today Proc*, vol. 33, pp. 2008–2012, Jan. 2020, doi: 10.1016/J.MATPR.2020.06.498.

[21] S. Dharmalingam and T. Sasikumar, "Mechanical, wear, and flammability properties of silanized cow dung biosilica-dispersed corn husk Fiber-reinforced epoxy composites," *Biomass Convers Biorefin*, pp. 1–11, Nov. 2023, doi: 10.1007/S13399-023-05082-Z/METRICS.

[22] T. M. Raj and T. P. Robert, "Effect of adding silanized cassava periderm biosilica on mechanical, V-notch rail shear, wear, and UL-94 flammability behavior of spinach stem fiber epoxy composite," *Biomass Convers Biorefin*, pp. 1–9, Jul. 2023, doi: 10.1007/S13399-023-04619-6/METRICS.

[23] S. Poomathi and S. S. S. Roji, "Experimental investigations on Palmyra sprout fiber and biosilica-toughened epoxy bio composite," *Biomass Convers Biorefin*, vol. 14, no. 8, pp. 9697–9705, Apr. 2024, doi: 10.1007/S13399-022-02867-6/METRICS.

[24] P. Neopolean and K. Karuppasamy, "Characterization of Silane Treated Opuntia Short Fibre and Bagasse Biosilica Toughened Epoxy Resin Composite," *Silicon*, vol. 14, no. 15, pp. 9331–9340, Oct. 2022, doi: 10.1007/S12633-021-01634-Y/METRICS.

[25] G. Velmurugan *et al.*, "Investigation of Nano SiO2 Filler Loading on Mechanical and Flammability Properties of Jute-Based Hybrid Polypropylene Composites," *Silicon*, vol. 15, no. 17, pp. 7247–7263, Nov. 2023, doi: 10.1007/S12633-023-02578-1/METRICS.

[26] G. Velmurugan *et al.*, "Investigation of Nano SiO2 Filler Loading on Mechanical and Flammability Properties of Jute-Based Hybrid Polypropylene Composites," *Silicon*, vol. 15, no. 17, pp. 7247–7263, Nov. 2023, doi: 10.1007/S12633-023-02578-1/METRICS.

[27] S. Kirubai, S. Padmavathy, N. Ganesh, and K. Rajaguru, "Study of mechanical behaviour on jute fiber and rice straw reinforced hybrid silica filled composite material," *Mater Today Proc*, vol. 69, pp. 1206–1212, Jan. 2022, doi: 10.1016/J.MATPR.2022.08.260.

[28] S. Thanikodi, S. Rathinasamy, and J. A. Solairaju, "Developing a model to predict and optimize the flexural and impact properties of jute/kenaf fiber nano-composite using response surface methodology," *International Journal of Advanced Manufacturing Technology*, pp. 1–15, Jun. 2024, doi: 10.1007/S00170-024-13975-0/METRICS.

[29] S. Kirubai, S. Padmavathy, N. Ganesh, and K. Rajaguru, "Study of mechanical behaviour on jute fiber and rice straw reinforced hybrid silica filled composite material," *Mater Today Proc*, vol. 69, pp. 1206–1212, Jan. 2022, doi: 10.1016/J.MATPR.2022.08.260.

[30] S. S. Shah, M. N. Shaikh, M. Y. Khan, M. A. Alfasane, M. M. Rahman, and M. A. Aziz, "Present Status and Future Prospects of Jute in Nanotechnology: A Review," *The Chemical Record*, vol. 21, no. 7, pp. 1631–1665, Jul. 2021, doi: 10.1002/TCR.202100135.

[31] A. M. Johnson and J. A. Johnson, "Thermally Robust yet Deconstructable and Chemically Recyclable High-Density Polyethylene (HDPE)-Like Materials Based on Si−O Bonds," *Angewandte Chemie*, vol. 135, no. 51, p. e202315085, Dec. 2023, doi: 10.1002/ANGE.202315085.

[32] K. M. Abd El-Rahman, S. F. Abdellah Ali, A. I. Khalil, and S. Kandil, "Influence of poly(butylene succinate) and calcium carbonate nanoparticles on the biodegradability of high density-polyethylene nanocomposites," *Journal of Polymer Research*, vol. 27, no. 8, pp. 1–21, Aug. 2020, doi: 10.1007/S10965-020-02217-Y/METRICS.

[33] H. Hassan, B. H. Hameed, and J. K. Lim, "Co-pyrolysis of sugarcane bagasse and waste high-density polyethylene: Synergistic effect and product distributions," *Energy*, vol. 191, p. 116545, Jan. 2020, doi: 10.1016/J.ENERGY.2019.116545.

[34] A. Alsabbagh, R. Abu Saleem, R. Almasri, S. Aljarrah, and S. Awad, "Effects of gamma irradiation on 3D-printed polylactic acid (PLA) and high-density polyethylene (HDPE)," *Polymer Bulletin*, vol. 78, no. 9, pp. 4931–4945, Sep. 2021, doi: 10.1007/S00289-020-03349-3/METRICS.

[35] M. Larrain *et al.*, "Techno-economic assessment of mechanical recycling of challenging post-consumer plastic packaging waste," *Resour Conserv Recycl*, vol. 170, p. 105607, Jul. 2021, doi: 10.1016/J.RESCONREC.2021.105607.

[36] I. Svensson, A. Butron, M. Puyadena, A. González, L. Irusta, and A. Barrio, "Bio-Based Phosphate-Containing Polyester for Improvement of Fire Reaction in Wooden Particleboard," *Polymers (Basel)*, vol. 15, no. 5, p. 1093, Mar. 2023, doi: 10.3390/POLYM15051093/S1.

[37] N. A. A. B. Taib *et al.*, "A review on poly lactic acid (PLA) as a biodegradable polymer," *Polymer Bulletin*, vol. 80, no. 2, pp. 1179–1213, Feb. 2023, doi: 10.1007/S00289-022-04160-Y/METRICS.

[38] F. Ebrahimi and H. Ramezani Dana, "Poly lactic acid (PLA) polymers: from properties to biomedical applications," *International Journal of Polymeric Materials and Polymeric Biomaterials*, vol. 71, no. 15, pp. 1117–1130, Oct. 2022, doi: 10.1080/00914037.2021.1944140.

[39] T. A. Swetha *et al.*, "A comprehensive review on polylactic acid (PLA) – Synthesis, processing and application in food packaging," *Int J Biol Macromol*, vol. 234, p. 123715, Apr. 2023, doi: 10.1016/J.IJBIOMAC.2023.123715.

[40] R. A. Ilyas *et al.*, "Polylactic Acid (PLA) Biocomposite: Processing, Additive Manufacturing and Advanced Applications," *Polymers 2021, Vol. 13, Page 1326*, vol. 13, no. 8, p. 1326, Apr. 2021, doi: 10.3390/POLYM13081326.

[41] F. Zhang *et al.*, "Pyrolysis of 3D printed polylactic acid waste: A kinetic study via TG-FTIR/GC-MS analysis," *J Anal Appl Pyrolysis*, vol. 166, p. 105631, Sep. 2022, doi: 10.1016/J.JAAP.2022.105631.

[42] T. A. Swetha *et al.*, "A review on biodegradable polylactic acid (PLA) production from fermentative food waste - Its applications and degradation," *Int J Biol Macromol*, vol. 234, p. 123703, Apr. 2023, doi: 10.1016/J.IJBIOMAC.2023.123703.

[43] R. A. Mensah, L. Jiang, J. S. Renner, and Q. Xu, "Characterisation of the fire behaviour of wood: From pyrolysis to fire retardant mechanisms," *J Therm Anal Calorim*, vol. 148, no. 4, pp. 1407–1422, Feb. 2023, doi: 10.1007/S10973-022-11442-0/METRICS.

[44] W. Liu, D. Wang, Y. Zhang, T. Bai, and J. Li, "Flammability and flame-retardant mechanism of high density polyethylene/wood fiber/modified ammonium polyphosphate composite," *Polym Compos*, vol. 39, no. 4, pp. 1192–1199, Apr. 2018, doi: 10.1002/PC.24048.

[45] L. Zhang *et al.*, "Char formation and smoke suppression mechanism of montmorillonite modified by ammonium polyphosphate/silane towards fire safety enhancement for wood composites," *Wood Sci Technol*, vol. 58, no. 2, pp. 811–827, Mar. 2024, doi: 10.1007/S00226-024-01546-1/METRICS.

[46] F. Guo, Y. Zhang, L. Cai, and L. Li, "Functionalized graphene with Platelet-like magnesium hydroxide for enhancing fire safety, smoke suppression and toxicity reduction of Epoxy resin," *Appl Surf Sci*, vol. 578, p. 152052, Mar. 2022, doi: 10.1016/J.APSUSC.2021.152052.

[47] B. Tawiah *et al.*, “Highly efficient flame retardant and smoke suppression mechanism of boron modified graphene Oxide/Poly(Lactic acid) nanocomposites,” *Carbon N Y*, vol. 150, pp. 8–20, Sep. 2019, doi: 10.1016/J.CARBON.2019.05.002.

[48] A. Abdelkhalik, M. Mahmoud, M. A. Nour, M. A. Hassan, and E. R. Souaya, “Smoke suppression, flame retardancy, and fire toxicity of polypropylene containing melamine salt of pentaerythritol phosphate halloysite,” *Journal of Vinyl and Additive Technology*, vol. 29, no. 2, pp. 356–369, Mar. 2023, doi: 10.1002/VNL.21987.

[49] J. Yan *et al.*, “Flame Retardant and Smoke Suppression Performance of Intumescent Fire-Retardant Coating Modified by Aluminum Hydroxide and Montmorillonite,” *Nano Hybrids and Composites*, vol. 46, pp. 51–64, Jul. 2025, doi: 10.4028/P-RL8ITH.

[50] L. Meng, X. Li, M. Liu, C. Li, L. Meng, and S. Hou, “Modified Ammonium Polyphosphate and Its Application in Polypropylene Resins,” *Coatings 2022, Vol. 12, Page 1738*, vol. 12, no. 11, p. 1738, Nov. 2022, doi: 10.3390/COATINGS12111738.

[51] G. Li *et al.*, “A flame-retardant wood-based composite with magnesium–aluminium layered double hydroxides for efficient daytime radiative cooling,” *J Mater Chem A Mater*, vol. 12, no. 3, pp. 1609–1616, Jan. 2024, doi: 10.1039/D3TA06065A.

[52] L. Cai, H. Lim, N. C. Fitzkee, B. Cosovic, and D. Jeremic, “Feasibility of Manufacturing Strand-Based Wood Composite Treated with β-Cyclodextrin–Boric Acid for Fungal Decay Resistance,” *Polymers 2020, Vol. 12, Page 274*, vol. 12, no. 2, p. 274, Jan. 2020, doi: 10.3390/POLYM12020274.

[53] Z. Góral *et al.*, “Impact of melamine and its derivatives on the properties of poly(vinyl acetate)-based composite wood adhesive,” *European Journal of Wood and Wood Products*, vol. 79, no. 1, pp. 177–188, Jan. 2021, doi: 10.1007/S00107-020-01618-6/FIGURES/11.

[54] A. P. Basnayake, J. P. Hidalgo, and M. T. Heitzmann, “A flammability study of aluminium hydroxide (ATH) and ammonium polyphosphate (APP) used with hemp/epoxy composites,” *Constr Build Mater*, vol. 304, p. 124540, Oct. 2021, doi: 10.1016/J.CONBUILDMAT.2021.124540.