Cureus Journal of Engineering

Open Access Original Article

The Impact of Glass Waste Filler on Density and Flame Retardancy in Sawdust-Reinforced Hybrid Composite Ceiling Boards

Received 04/27/2025
Review began 05/26/2025
Review ended 06/14/2025
Published 07/22/2025

DOI: https://doi.org/10.7759/s44388-025-05687-2

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Abstract

This study investigated the impact of glass waste filler on the density and flame retardancy of sawdust-reinforced unsaturated polyester resin (UPR) hybrid composite ceiling boards, with the aim to enhance material properties for construction applications. Four formulations were evaluated, including pure UPR control, sawdust/UPR, glass waste/UPR, and sawdust/glass waste/UPR hybrid composites. Density was measured in accordance with ASTM D792 while flame retardancy was assessed using ASTM D635 horizontal burning tests on 125 mm × 13 mm × 5 mm specimens, measuring extent of burning (mm) and ignition time (s). Results showed that density increased significantly with higher glass content ($r = +0.68$, $p < 0.01$), with the highest values recorded at 40% glass, attributed to the inherently higher density of glass compared to sawdust. Flame retardancy improved significantly with moderate glass content of 20%-33% ($r = -0.72$, $p < 0.01$), but deteriorated at 40% glass despite increased density. The optimal flame resistivity was observed in hybrid composites such as 13/27/60 wt.% and 20/20/60 wt.%, balancing fire safety and mechanical properties. Specifically, the 13/27/60 wt.% sample achieved the best performance, with a minimal burning extent of 3.34 mm and a corresponding density of 1.41 g/cm³. In contrast, the pure UPR control exhibited poor flame resistance (16.15 mm burning extent) and a lower density of 1.11 g/cm³. The findings emphasize that a balanced composition of sawdust, glass, and resin is essential for optimizing both mechanical strength and fire safety. A glass waste content of approximately 20%-33% is recommended for high-performance composite ceiling boards, while formulations with zero or excessively high glass content should be avoided in safety-critical applications.

Categories: Advanced Materials, Environmental Engineering and Sustainability, Polymer Science and Engineering
Keywords: glass waste, sawdust, hybrid composite, density, flame retardancy, ceiling boards

Introduction

The demand for advanced building materials is increasing due to rapid urbanization, population growth, and the need for resilient infrastructure. The construction industry continuously seeks materials with enhanced durability, thermal resistance, and fire-retardant properties to withstand both natural and man-made disasters [1]. Composites, which combine different materials to achieve superior mechanical and thermal properties, have gained attention for their ability to enhance strength, durability, and fire resistance [2]. In particular, utilizing agricultural and industrial waste materials in composite production has become a sustainable approach to reducing environmental impact [3].

Solid waste management remains a major challenge globally, particularly in developing nations like Nigeria, where large quantities of waste are generated but poorly managed [4]. Researchers have explored the use of waste materials such as polymers, charcoal, paper, glass, and agro-waste (e.g., sawdust) to develop eco-friendly composites for various applications [5-7]. Sawdust, a byproduct of wood processing, is a major agro-waste with limited utilization. Studies estimate that Nigeria generates approximately 1.8-5.2 million tons of sawdust annually, yet less than 5% is effectively utilized, while the rest contributes to environmental pollution through open burning [8-10]. Olaiya et al. [11] highlighted that these sawdust-based materials hold significant promise as sustainable alternatives to conventional building materials; however, limitations such as poor fire resistance, reduced durability, and limited structural applications hinder their widespread adoption [12].

Glass waste is another significant contributor to environmental pollution due to its non-biodegradability and widespread use across industries [13]. Waste glass, commonly discarded in landfills, presents disposal challenges despite its high-temperature resistance and durability [14,15]. Given that glass is naturally flame-retardant, incorporating it into composite materials could enhance their fire resistance while promoting sustainable waste management. Flame retardants are materials that delay or prevent combustion by reducing the flammability of composite materials. They can be organic (e.g., sawdust, eggshells, sugarcane residue) or inorganic (e.g., synthesized chemicals, waste glass). The inability of many

How to cite this article
Jomboh K J, Adejo A O, Garkida A D (July 22, 2025) The Impact of Glass Waste Filler on Density and Flame Retardancy in Sawdust-Reinforced Hybrid Composite Ceiling Boards . Cureus J Eng 2 : es44388-025-05687-2. DOI https://doi.org/10.7759/s44388-025-05687-2

construction materials to withstand high temperatures often limits their application in fire-prone environments [16]. Developing composites with flame-retardant properties is therefore crucial for improving safety and durability, especially in building applications such as ceiling boards.

Ceiling boards serve as protective barriers in buildings, reducing heat transfer and enhancing thermal insulation. Various materials, including wood, metal, textiles, and composites, have been used in ceiling production [17-19]. Recent studies have explored the use of recycled waste, such as rice husks, waste paper, sawdust, and corncobs among others, in fiber-reinforced composites for ceiling applications [20-22]. Recycled glass has also been used to create lightweight, fire-resistant acoustic panels, demonstrating its potential in composite material development.

This study explores the impact of glass waste filler on the density and flame retardancy of sawdust-reinforced composite ceiling boards. Since glass is nonflammable and has a density ranging from 2.2 to 8.0 g/cm^3 depending on its composition, incorporating it into sawdust composites could enhance fire resistance while optimizing material properties. By developing hybrid composite ceiling boards from recycled waste materials, this research aims to provide an environmentally sustainable, cost-effective alternative for the construction industry while addressing waste management challenges.

Materials And Methods

Materials selection and preparation

The study utilized sawdust obtained from wood processing industries and waste glass sourced from discarded containers as reinforcements. The materials were cleaned, dried, and ground into fine particles. The sawdust and glass waste were sieved to obtain uniform particle sizes for effective blending in the composite formulation. Unsaturated polyester resin was obtained and used as the matrix (see Table *1*).

Glass-sawdust reinforced polymer hybrid composite	
Matrix	**Reinforcement**
Unsaturated polyester	Glass waste
Catalyst and accelerator	Sawdust

TABLE 1: Composition of glass-sawdust reinforced polymer hybrid composite

Experimental procedure

Composite Fabrication

The composite samples were prepared by mixing varying proportions of sawdust and pulverized glass waste with unsaturated polyester resin (UPR) as the binder. The proportions of sawdust and glass waste in the composite samples were varied based on preliminary wettability studies, which were conducted to determine the maximum filler loading each reinforcement could effectively absorb without compromising resin bonding. These tests revealed that sawdust, as a natural fiber, had a saturation point at 20% loading with 80% UPR, while pulverized post-consumer glass waste reached its saturation at 40% loading with 60% UPR. These saturation points informed the upper limits of the experimental design, with filler contents varied between 0 and 20% for sawdust and 0-40% for glass, while UPR ranged from 60 to 100%, ensuring a total mixture composition of 100%. The lower limit (0%) allowed for comparison against a control sample (100% resin) to assess the influence of each filler. Mixture combinations within these ranges were generated using Design Expert software, which applied statistical mixture design methods to systematically explore the effects of different compositions. The resulting mixtures were thoroughly mixed, poured into glass molds and subjected to compression molding under controlled temperature and pressure, after which the samples were cured and prepared for subsequent testing.

Density measurement

Density was determined by direct measurement of mass and volume in accordance with ASTM D792 [23]. Each sample's mass was measured using a digital weighing balance. The width, height, and length of the samples were then recorded using a caliper, and the volume was calculated based on these dimensions. Density was then obtained using the formula:

$$p = m/V$$

Where: ρ = volumetric density, g/ cm^3; m = the mass of the test sample, g and V = the volume of the sample, cm^3

Flame retardancy test

Flame resistance test was carried out using the horizontal burning method in accordance with ASTM D635 [24] with specimen sizes of 125 mm long × 13 mm wide × 5 mm thickness to be rated (Figure 1). These test measured the ability of the material to withstand fire and the rate at which it burns under controlled conditions. A Bunsen burner was used to apply flame to the samples in a horizontal setup. After ignition of flame, it was timed until the flame extinguished itself. The time and distance that the flame propagates was measured and recorded. Linear burning rate in mm per minute was measured (Figures 2-6). Attention was also given if the flame burns through the test samples or drops from the test sample to ignite the cotton below. The test observes the flame spread along a sample in order to determine the relative burning behavior of the material as well as time of ignition.

FIGURE 1: Test specimens for flame analysis

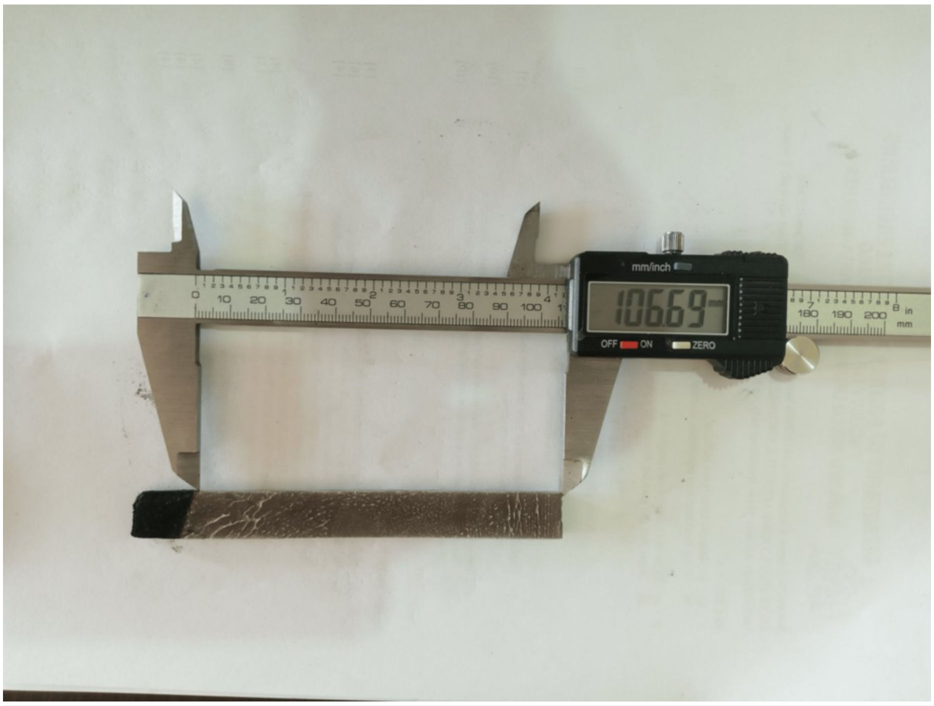

FIGURE 2: Measurement of extent of burning

FIGURE 3: Flame propagation for hybrid sample 13/27/60 wt.%

FIGURE 4: Flame propagation for hybrid sample 20/20/60 wt.%

FIGURE 5: Flame propagation for control sample 0/0/100 wt.%

FIGURE 6: Flame propagation for glass reinforced sample 0/40/60 wt.%

Results

Density of composite boards

The density of the composite ceiling boards as presented in Table 2 ranged from 1.11 g/cm³ to 1.91 g/cm³. The highest density values were observed in samples with 0/40/60 wt.% glass/UPR composition (1.90-1.91 g/cm³), whereas the lowest density of 1.11 g/cm³ was recorded in pure UPR control sample 0/0/100 wt.%. As shown in Figure 7, a general upward trend in density was observed with increasing glass content. This pattern suggests that glass waste filler contributes significantly to material compactness, likely due to its higher inherent density compared to sawdust and polyester resin.

S/N	Samples (%)	Length (cm)	Width (cm)	Thickness (cm)	Volume (cm^3)	Mass (g)	Density (g/cm^3)
1	7/33/60	3.10	2.80	0.35	3.04	4.88	1.61
2	20/0/80	2.80	2.70	0.40	3.02	4.43	1.47
3	10/0/90	3.05	2.80	0.45	3.84	5.07	1.32
4	10/7.5/82.5	3.00	2.70	0.45	3.65	4.71	1.29
5	15/12.2/72.5	2.90	2.75	0.45	3.59	4.98	1.39
6	0/40/60	2.40	2.65	0.30	1.91	3.64	1.91
7	0/40/60	2.60	2.20	0.35	2.00	3.79	1.90
8	5/27.5/67.5	3.15	2.70	0.35	2.98	4.45	1.49
9	20/0/80	2.70	2.60	0.50	3.78	4.60	1.22
10	20/20/60	3.05	3.00	0.40	3.66	4.88	1.33
11	13/27/60	2.90	2.80	0.40	3.25	4.58	1.41
12	0/0/100	2.80	2.70	0.40	3.02	4.12	1.36
13	0/20/80	2.85	2.60	0.40	2.96	4.22	1.43
14	0/0/100	2.80	2.10	0.50	2.94	3.25	1.11
15	20/20/60	3.10	3.05	0.40	3.78	4.34	1.15
16	0/20/80	2.75	2.40	0.40	2.64	4.09	1.55

TABLE 2: Density for composite ceiling board

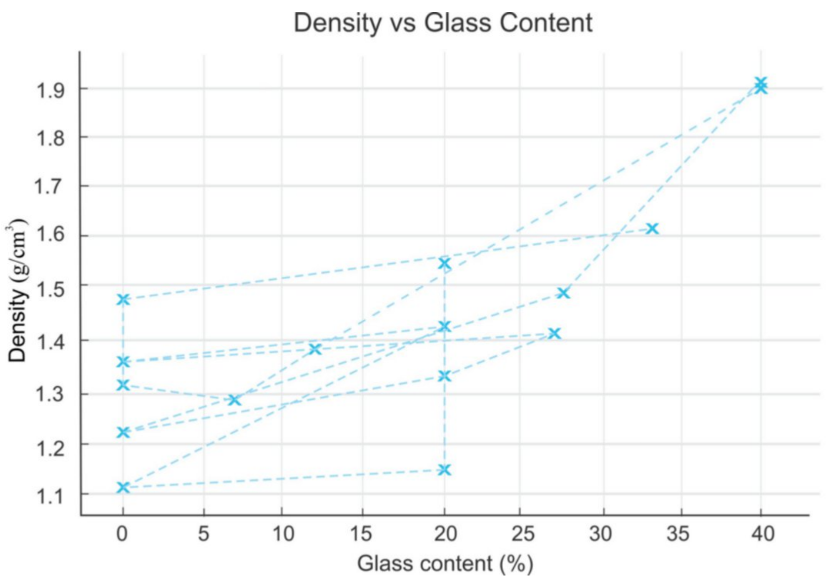

FIGURE 7: Impact of glass waste content on density of sawdust-reinforced composite boards

Flame retardancy of composite boards

Figure 8 presents results for flame resistivity across the composite samples. The flame resistivity values ranged from 3.34 mm to 16.15 mm, with lower values indicating better flame resistance. Samples with hybrid compositions 13/27/60, 20/20/60, and 7/33/60 wt.% demonstrated the best flame resistance (3.34 mm to 4.46 mm). These compositions achieved an excellent balance between density and fire resistance, as shown in Table 3. Moderate flame resistivity was observed in sawdust/UPR composites (20/0/80 wt.%

and 10/0/90 wt.%) with values ranging from 7.48 mm to 10.82 mm. Meanwhile, the pure UPR samples (0/0/100 wt.%) displayed the poorest flame resistivity (15.53-16.15 mm), indicating inferior flame retardancy. Glass-only reinforced samples (0/40/60 wt.%) also performed poorly with values between 11.65 mm and 11.72 mm, likely due to inadequate filler-matrix interphase bonding and uneven particle dispersion. Ignition times were also assessed and ranged from 1 to 3 seconds, with most hybrid samples igniting within 1 second. Higher ignition times were observed in samples with higher resin content, such as the control.

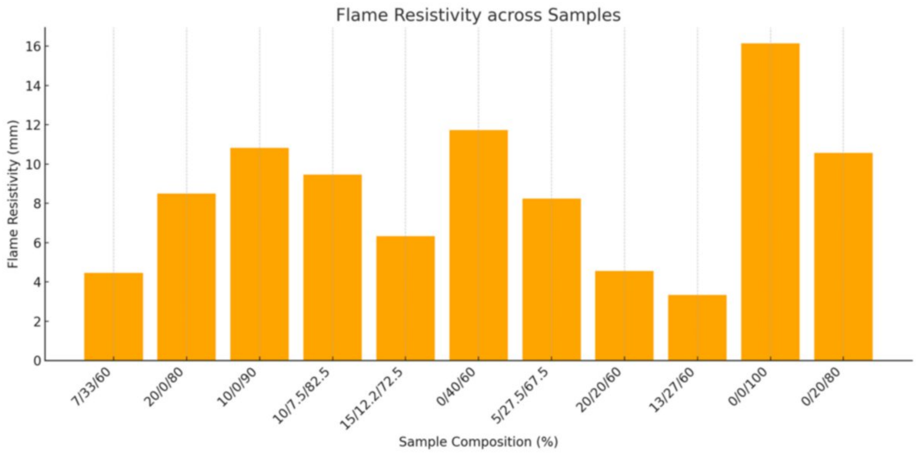

FIGURE 8: Effect of flame resistance on sample compositions

Rank	Sample (%)	Density (g/cm³)	Flame Resistivity (mm)	Ignition Time (s)
1.	13/27/60	1.41	3.34 (Best)	1
2.	20/20/60	1.33	3.72	1
3.	7/33/60	1.61	4.46	1

TABLE 3: Flame resistivity rankings indicating three best compositions

Statistical summary of key parameters

To validate these results, statistical analysis was conducted. Table *4* summarizes the range, mean, standard deviation (SD), and correlation coefficients with respect to glass content. Density showed a significant positive correlation with glass content ($r = +0.68$, $p < 0.01$), confirming that glass addition increases composite density. While flame resistivity showed a significant negative correlation ($r = -0.72$, $p < 0.01$), indicating that moderate glass content improves flame resistance, excessive glass content without sawdust compromises flame performance. Ignition time exhibited no significant correlation with glass content, implying that ignition behavior is influenced more by resin composition than by filler variation. Ignition time (s) varied between 1 and 3, with a mean of 1.31 seconds and an SD of 0.67. However, no significant correlation was observed between ignition time and glass content, indicating that variations in the glass filler proportions had a minimal impact on ignition behavior.

Parameter	Range	Mean ± SD	Correlation with glass content
Density (g/cm³)	1.11–1.91	1.42 ± 0.21	*r* = +0.68 (*p* < 0.01)
Flame resistivity (mm)	3.34–16.15	8.23 ± 4.12	*r* = -0.72 (*p* < 0.01)
Ignition time (s)	1–3	1.31 ± 0.67	Not significant

TABLE 4: Statistical summary of key parameters in sawdust-reinforced composite ceiling boards

Discussion

Impact of glass waste on composite density

The results demonstrate a clear increase in composite density with rising glass waste content, ranging from 1.11 g/cm³ in the control sample (0/0/100 wt.%) to a maximum of 1.91 g/cm³ in the 0/40/60 wt.% formulation. This trend is statistically supported by a strong positive correlation between density and glass content ($r = +0.68$, $p < 0.01$), as shown in Table *4* and illustrated in Figure *7*. These findings are consistent with known material properties, where polyester resin typically exhibits a density of 1.1-1.15 g/cm³ and natural fiber composites range from 0.8 to 1.6 g/cm³ [25].

The increased density is due to the inherently higher mass of glass particles compared to sawdust and resin, confirming that glass is a high-density filler. Composites with 40% glass consistently recorded the highest densities, which supports findings from previous research by Gupta et al. [26], Ahmad et al. [27], and Ramesh et al. [28]. All of these studies observed that inorganic fillers significantly enhance the bulk density of polymer matrices. A similar trend was also reported by Amena and Hossain [29] in recycled polyethylene terephthalate-sawdust composites. While higher density is often linked to improved mechanical strength, it can present challenges in applications where weight is a concern, particularly in ceiling installations, where increased mass may complicate handling, mounting, or structural safety.

Although past research has shown that alternative fillers such as hollow glass microspheres (HGMs) can reduce composite weight without compromising performance [30], other studies note that particle size, geometry, and interfacial bonding with the resin matrix are also critical to optimizing density and mechanical performance [31,32]. Therefore, the positive density-glass relationship found in this study supports glass waste as effective structural filler but highlights the need for careful selection and processing of filler types, especially in weight-sensitive applications like ceiling boards.

Additionally, past research has shown that alternative fillers such as HGMs can reduce composite density while maintaining performance [30]. Other studies also emphasize that filler particle size, geometry, and interfacial bonding with the resin matrix is critical to achieving optimal density and load-bearing capacity [31,32]. This highlights that although the positive correlation observed in this study supports glass waste as effective structural filler, careful selection and surface treatment of filler materials remain essential in weight-sensitive designs.

The findings suggest that moderate glass filler content strikes an ideal balance between increased density and manageable weight. This makes it suitable for ceiling boards that require both rigidity and lightness. However, excessively high glass content, while beneficial for structural mass, may limit practical use due to challenges in handling and installation. Future research should explore the effects of varying glass particle sizes, aspect ratios, and surface treatments on both density and mechanical properties. Additionally, life-cycle assessments and simulations of installation performance could provide valuable insights to optimize design for building material applications.

Impact of glass waste on flame retardancy

Flame resistivity analysis revealed that hybrid compositions with moderate glass content specifically 13/27/60, 20/20/60, and 7/33/60 wt.% exhibited superior flame resistance, with flame spread values ranging from 3.34 to 4.46 mm (Figure *8*; Table *3*). These results were supported by a statistically significant negative correlation between glass content and flame resistivity ($r = -0.72$, $p < 0.01$), indicating that moderate levels of glass filler enhance flame retardancy. The optimal range of 20-33 wt.% glass appears to provide sufficient inorganic content for fire resistance while maintaining good dispersion and matrix bonding.

In contrast, samples containing high glass content without sawdust reinforcement, such as 0/40/60 wt.%, demonstrated poor flame resistance. Despite glass being non-combustible, its flame-retardant effect was limited when used in isolation. This is likely due to inadequate bonding with the resin and uneven filler dispersion, which can facilitate heat conduction and flame propagation. Similarly, the pure resin control

(0/0/100 wt.%) also underperformed in fire resistance tests, further emphasizing the critical role of hybridization. The inclusion of sawdust likely contributed to improved fire performance by promoting char formation during combustion, which can serve as a thermal barrier and slow flame spread.

Ignition time results showed no significant correlation with glass content, suggesting that ignition behavior is more influenced by the matrix composition, particularly the polyester resin, which decomposes thermally at a slower rate than natural fibers. This indicates that while glass content plays a key role in flame resistivity, it does not significantly affect ignition delay in the tested formulations.

Notably, samples without any glass filler also performed poorly in flame tests despite having moderate densities, highlighting that flame resistance is not governed by density alone but rather by the composition and interaction of filler materials. These results align with findings from Ferreira et al. [33], who reported that poorly bonded or overly concentrated glass fillers can impair flame resistance by increasing thermal conductivity. Lee et al. [34] also found that single inorganic fillers often fail to provide adequate fire protection, advocating for hybrid filler systems to create denser, more cohesive char layers. Likewise, Sabee et al. [35], Korobeinichev et al. [36], and Murad et al. [37] emphasized that glass fillers alone are insufficient and often require flame-retardant additives to enhance performance.

The strength of this study lies in its identification of specific hybrid compositions that achieve an effective balance between density and fire resistance. It highlights that moderate glass content is not only advantageous but essential for optimizing fire safety in composite ceiling boards. These findings align with those of Rakhman et al. [38], Zhang et al. [39], and Diharjo et al. [40], all of whom similarly demonstrated that well-integrated glass fibers can enhance both fire resistance and mechanical strength in polymer composites. However, the absence of additional flame-retardant additives, which could further improve the flame performance of glass-reinforced systems, represents a limitation. Additionally, the study's focus on static flame exposure, rather than dynamic fire conditions, typical of real-world scenarios, presents another constraint.

From an application perspective, these findings indicate that hybrid composites with well-balanced filler ratios could serve as safer alternatives to traditional ceiling board materials, especially in buildings where fire resistance is a paramount concern. For successful industry adoption, it will be important to optimize filler dispersion and interfacial bonding to enhance flame retardant performance while maintaining mechanical integrity. Future research should assess composites' mechanical and thermal properties. Additionally, exploring the incorporation of flame-retardant additives or surface treatments, as well as investigating bio-based resins and other industrial waste fillers, could further improve the environmental and commercial viability of these materials.

Recommendations

The findings of this study underscore the importance of optimizing filler composition to achieve a balance between structural performance and fire safety in composite ceiling boards. Hybrid formulations containing 20-33% glass waste particularly the 13/27/60, 20/20/60, and 7/33/60 wt.% compositions demonstrated the most effective combination of high density and superior flame resistance, recommending them for practical building applications. In contrast, extreme formulations such as pure resin (0/0/100 wt.%) or glass-only (0/40/60 wt.%) composites exhibited inferior fire performance and should be avoided. Achieving uniform filler dispersion and improving matrix-filler interaction are crucial for enhancing both density and flame retardancy. Moving forward, additional research should focus on evaluating the composites' mechanical, thermal, and acoustic properties, as well as their durability under environmental conditions such as moisture and temperature fluctuations. Furthermore, exploring the use of bio-based resins and other agro-industrial waste fillers could improve the sustainability profile of the composites. Life cycle assessments and economic analyses are also needed to determine their viability for mass production. Finally, direct comparisons with conventional ceiling materials would help position these composites within the broader construction material market, highlighting their advantages and identifying areas for improvement.

Conclusions

This study examined the impact of glass waste filler on the density and flame retardancy of sawdust-reinforced polyester composite ceiling boards. The results indicated that increasing the glass waste content generally led to a higher composite density, due to the inherently greater density of glass compared to sawdust and resin. A strong positive correlation ($r = 0.68$, $p < 0.01$) confirmed this relationship. However, while moderate glass contents (20-33 wt.%) in hybrid compositions significantly improved flame resistance by reducing flame spread, excessive glass content (40 wt.%) without sawdust reinforcement resulted in poorer fire performance. This decline in performance is likely due to weak bonding at the filler-matrix interface. Statistical analysis revealed a significant negative correlation ($r = -0.72$, $p < 0.01$) between glass content and flame resistivity, indicating that properly incorporated glass filler enhances flame retardancy. The optimal composition of 13/27/60 wt% exhibited exceptional flame resistance, with a burning extent of just 3.34 mm, while achieving a density of 1.41 g/cm^3, outperforming all other compositions tested. These findings underscore the importance of a balanced mixture of sawdust, glass, and resin in optimizing both mechanical strength and fire safety. A glass waste content of approximately 20%-33% is recommended for high-performance composite ceiling boards, while formulations with no glass or excessively high glass content should be avoided in safety-critical applications. Future research should explore additional properties of these hybrid composites and their performance in standard building material fire rating tests to support their commercial adoption.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Kator J. Jomboh

Acquisition, analysis, or interpretation of data: Kator J. Jomboh, Andrew O. Adejo, Adele D. Garkida

Drafting of the manuscript: Kator J. Jomboh

Critical review of the manuscript for important intellectual content: Andrew O. Adejo, Adele D. Garkida

Supervision: Adele D. Garkida

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

References

1. Pastuszak PD, Muc A: Application of composite materials in modern constructions. Key Engineering Materials. 2013, 542:119-29. 10.4028/www.scientific.net/kem.542.119
2. Anjum N, Iqbal RM, Zhang X, et al.: Effect of bio-fillers on the mechanical, thermal, and fire properties of gypsum composites. Construction and Building Materials. 2025, 466:140274. 10.1016/j.conbuildmat.2025.140274
3. Yi XS: An introduction to composite materials. Composite Materials Engineering. Institute of Aerospace Materials, Beijing; 2018. 1:1-61. 10.1007/978-981-10-5696-3_1
4. Abd'razack NTA, Yusuf AE, Utange JZ: An appraisal of solid waste generation and management in Jalingo City, Nigeria. Journal of Environment and Earth Science. 2013, 3:1-8.
5. Dębska B, Lichołai L, Godek P: Polymer composites modified by waste materials containing wood fibers. Journal of Ecological Engineering. 2016, 17:72-78. 10.12911/22998993/65448
6. Jomboh KJ, Yakubu MK, Eze WU, Garkida AD, Alemaka EM: Weathering resistance of post-consumer glass and sawdust reinforced polyester composites. Advances in Powder and Ceramic Materials Science 2023. TMS 2023. The Minerals, Metals & Materials Series. Springer, Cham; 2023:99-107. 10.1007/978-3-031-22622-9_10
7. Adejo AO, Jomboh KJ: Effect of drying on textured coat synthesized from waste glass for building application. TMS 2023 152nd Annual Meeting & Exhibition Supplemental Proceedings. The Minerals, Metals & Materials Series. Springer, Cham; 2023. 337-43. 10.1007/978-3-031-22524-6_31
8. Ogunwusi AA : Wood waste generation in the forest industry in Nigeria and prospects for its industrial utilization. Civil and Environmental Research. 2014, 6:2224-5790.
9. Oluoti K, Megwai G, Pettersson A, Richards T: Nigerian wood waste: a dependable and renewable fuel option for power production. World Journal of Engineering and Technology. 2014, 2:234-48. 10.4236/wjet.2014.23025
10. Akhator P, Obanor A, Ugege A: Nigerian wood waste: a potential resource for economic development. Journal of Applied Sciences and Environmental Management. 2017, 21:246-51. 10.4314/jasem.v21i2.4
11. Olaiya BC, Lawan MM, Olonade KA: Utilization of sawdust composites in construction—a review. SN Applied Sciences. 2023, 5:1-25. 10.1007/s42452-023-05361-4
12. Suoware TO, Umeh SI, Edelugo SO: Development and prediction of flame retarded particleboard fire behaviour in real scale. Nigerian Journal of Technology. 2021, 40:558-63. 10.4314/njt.v40i4.10
13. Ting GHA, Tay YWD, Qian Y, Tan MJ: Utilization of recycled glass for 3D concrete printing: rheological and mechanical properties. Journal of Material Cycles and Waste Management. 2019, 21:994-1003. 10.1007/s10163-019-00857-x
14. Mandal AK, Ghosh S, Haldar B, Nag S, Mandal S: Waste incorporation in glass: a potential alternative and safe utilization. Advanced Materials from Recycled Waste. 2023, 133-54.
15. Saifullah M, Hasan M, Debnath T, Rob MA, Tusar AH, Rabbani ML: Investigation of the use of waste glass and waste paper as an alternative construction binding material: an approach towards sustainable environment.

American Journal of Environmental Economics. 2024, 3:116-29. 10.54536/ajee.v3i1.3266
16. Masuelli MA: Introduction of fiber-reinforced polymers-polymers and composites: concepts, properties and processes. Fiber Reinforced Polymers - The Technology Applied for Concrete Repair. IntechOpen, 2013. 10.5772/54629
17. Menon M: False ceiling materials: the different types and where to use what . (2018). Accessed: August 27, 2018: https://www.urbancompany.com/blog/false-ceiling-materials-the-different-types-and-where-to-use-what.
18. Egbeyale GB, Adewole A, Akintayo RA, Oladimeji SA, Aladejana K: Thermal properties of some selected materials used as ceilings in building. Proceedings of the Nigerian Society of Physical Sciences. 2024, 1:109. 10.61298/pnspsc.2024.1.109
19. Oyebanjo OO, Oyebanjo OA, Ogunlana YO: Comparison of the thermal properties of some selected ceiling materials for cost effectiveness in Nigeria. Journal of Science and Information Technology. 2022, 17:27-35.
20. Diao H: Carbon Fibre Reinforced Polymer Composites with Enhanced Ductility [dissertation]. Imperial College London, London; 2014.
21. Acoustical Surfaces. Recycled glass ceiling & wall tiles | acoustic ceiling panels. (2021). Accessed: May 4, 2025 : https://www.acousticalsurfaces.com/acoustical-panels/.
22. Madu OG, Nwankwojike BN, Ani OI: Optimal design for rice husk-saw dust reinforced polyester ceiling board. American Journal of Engineering Research. 2018, 7:11-6.
23. ASTM International: Standard Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement. ASTM. ASTM International, West Conshohocken, PA; 2020. 792-20.
24. ASTM International: Standard Test Method for Rate of Burning and/or Extent and Time of Burning of Plastics in a Horizontal Position. ASTM. ASTM International, West Conshohocken, PA; 2022. 635-22.
25. Sahu P, Gupta MK: A review on the properties of natural fibres and its bio-composites: Effect of alkali treatment. Proceedings of the Institution of Mechanical Engineers Part L Journal of Materials Design and Applications. 2019, 234:198-217. 10.1177/1464420719875163
26. Gupta N, Zeltmann SE, Shunmugasamy VC, Pinisetty D: Applications of polymer matrix composites. Lightweight Ballistic Composites: Military and Law-Enforcement Applications. Wiley, 2012. 53-80. 10.1002/9781118312197.ch3
27. Ahmad F, Choi HS, Park MK: A review: Natural fiber composites selection in view of mechanical, light weight, and economic properties. Macromolecular Materials and Engineering. 2015, 300:10-24.
28. Ramesh M, Palanikumar K, Reddy KH: Mechanical property evaluation of sisal-jute-glass fiber reinforced polyester composites. Composites Part B: Engineering. 2013, 48:1-9.
29. Amena BT, Hossain N: Influence of physical-mechanical strength and water absorption capacity on sawdust-waste paper-recycled plastic hybrid composite for ceiling tile application. Journal of Composites Science. 2024, 8:176. 10.3390/jcs8050176
30. Yalcin B, Amos SE: Hollow glass microspheres in thermoplastics. Hollow Glass Microspheres for Plastics, Elastomers, and Adhesives Compounds. 2015, 35-105. 10.1016/B978-1-4557-7443-2.00003-7
31. Kobykhno I, Kiryanov A, Klinkov V, et al.: Effect of glass filler geometry on the mechanical and optical properties of highly transparent polymer composite. Polymers. 2022, 14:5179. 10.3390/polym14235179
32. Jomboh KJ, Garkida AD, Alkali VC: The effect of particle size on the morphology of polyester and epoxy-based auto-hybrid composites. TMS 2022 151st Annual Meeting & Exhibition Supplemental Proceedings. The Minerals, Metals & Materials Series. Springer, Cham; 2022. 1:599-608. 10.1007/978-3-030-92381-5_57
33. Ferreira TRM, Lechtman MA, Dias FL, Silva AB: Effect of hollow glass microspheres addition on density reduction and mechanical properties of PA6/glass fibers composites. Polímeros. 2022, 32:10.1590/0104-1428.210060
34. Lee SH, Lee SG, Lee JS, Ma BC: Understanding the flame retardant mechanism of intumescent flame retardant on improving the fire safety of rigid polyurethane foam. Polymers. 2022, 14:4904. 10.3390/polym14224904
35. Sabee MMSM, Itam Z, Beddu S, et al.: Flame retardant coatings: additives, binders, and fillers. Polymers. 2022, 14:2911. 10.3390/polym14142911
36. Korobeinichev O, Shaklein A, Trubachev S, et al.: The influence of flame retardants on combustion of glass fiber-reinforced epoxy resin. Polymers. 2022, 14:3379. 10.3390/polym14163379
37. Murad MS, Hamzat AK, Asmatulu E, Asmatulu R: Flame-retardant fiber composites: synergistic effects of additives on mechanical, thermal, chemical, and structural properties. Advanced Composites and Hybrid Materials. 2025, 8:31. 10.1007/s42114-024-01111-1
38. Rakhman A, Diharjo K, Raharjo WW, Suryanti V, Kaleg S: Improvement of fire resistance and mechanical properties of glass fiber reinforced plastic (GFRP) composite prepared from combination of active nano filler of modified pumice and commercial active fillers. Polymers. 2023, 15:51. 10.3390/polym15010051
39. Zhang W, Zhang X, Qin Z, Wu Y, Zhang W, Yang R: High-transparency polysilsesquioxane/glycidyl-azide-polymer resin and its fiberglass-reinforced composites with excellent fire resistance, mechanical properties, and water resistance. Composites Part B Engineering. 2021, 219:108913. 10.1016/j.compositesb.2021.108913
40. Diharjo K, Sutrisno T, Afandi R, Himawanto DA: Enhancing of fire resistance on CFRP using Sokka-clay particle for lightweight car body panel. 2014 International Conference on Electrical Engineering and Computer Science (ICEECS), Kuta, Bali, Indonesia. 2014, 188-92. 10.1109/ICEECS.2014.7045243