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Development of Composite Materials Based on Recycled Polystyrene and Wood Residues for Building Applications

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Abstract

The building sector significantly influences the environment, notably through resource consumption and waste production. Evaluating locally available resources and adopting sustainable development practices are essential to mitigate this impact. This study proposes the fabrication of a wood-polymer composite by recycling polystyrene and wood sawdust. Polystyrene was dissolved in a solvent to obtain a polymer matrix, which was then reinforced with recycled wood sawdust. The mixture was cold-pressed to form composite panels. Physical properties such as density and absorption, as well as mechanical properties like the modulus of elasticity and flexural strength, were examined. Results show that the physical and mechanical properties of the composites vary with the particle size distribution of the wood particles. The modulus of elasticity and flexural strength increase with particle size. The maximum values obtained for the modulus of elasticity and flexural strength are 842 MPa and 3.16 MPa, respectively. These physical and mechanical characteristics indicate that the developed composite material can be used to manufacture elements such as furniture, false ceilings, and lightweight partitions, thereby contributing to more sustainable construction practices.

Keywords

Wood-Polymer Composite, Wood Sawdust, Expanded Polystyrene, Particleboard, Sustainable Construction

1. Introduction

The building sector is a major contributor to global CO_2 emissions, accounting for approximately 37% of energy-related and process-related emissions in 2021 [1]. This highlights the necessity to rethink construction methods and building management, emphasizing the use of environmentally friendly materials and the evaluation of locally available resources.

In Africa, a continent undergoing rapid transformation, the population is estimated to reach 2.5 billion by 2050 [2]. This demographic surge demands proactive anticipation of infrastructure and resource needs. The concept of sustainable building is crucial to address these challenges. It aims to minimize energy consumption and CO_2 emissions, reduce dependence on non-renewable resources, improve occupant comfort, and optimize overall costs, principles fundamental to responsible and sustainable urban development.

In the current context, where sustainable development is imperative, especially in Africa, evaluating and valorizing local resources are essential. In Benin, wood processing waste is significantly underutilized, with over 4500 tons of sawdust produced annually [3]. This wood waste can be valorized in the manufacture of particleboard.

The development of panels from wood residues is not new. Numerous studies have utilized various matrices or adhesives such as urea-formaldehyde resins [4]-[6], phenol-formaldehyde resins [7]-[9], melamine-urea-formaldehyde, and melamine-formaldehyde [10]-[12], exploring different manufacturing techniques.

However, in Benin, these technologies are less accessible, and the materials used in adhesives are excessively expensive. Additionally, conventional adhesives have significant environmental impacts due to emissions of volatile organic compounds and formaldehyde. Therefore, finding a more accessible solution for local populations is necessary. Recycling expanded polystyrene, which is also waste needing management, becomes relevant. Benin faces major challenges in managing non-biodegradable waste, with landfills receiving over 120,000 tons of various plastics annually [13], including packaging expanded polystyrene from commercial import activities.

The fabrication of wood-polystyrene composites and exploration of various formulations demonstrate a growing interest in valorizing waste into ecological solutions. Researchers have studied the potential of composite materials using recycled polystyrene and natural or synthetic fillers to reduce environmental impact and offer sustainable construction materials.

Parikh *et al.* [14] demonstrated that adding wood dust-based fillers improves the mechanical and thermal properties of a PLA-wood composite, although dimensional stability issues related to water absorption persist. Adeniyi *et al.* [15] explored wood-polystyrene composites using Isoberlinia doka dust, optimizing mechanical properties through alkaline fiber treatment but identifying limitations in filler dispersion.

Studies by Foti *et al.* [16] and Rofdi *et al.* [17] highlighted the role of particle size and polystyrene concentration on the physical and mechanical properties of composites, achieving better water resistance and homogeneous density, though increased flammability remains a challenge. Cherkashina *et al.* [18] introduced agricultural waste like hazelnut shells, improving mechanical strength through chemical surface treatments. Composites incorporating flax fibers and plasticizing additives, studied by Khedr and Elnahas [19], revealed increased tensile strength and flexibility, though reliance on organic solvents is a limitation.

Work by Adeniyi *et al.* [20] on hybrid composites combining polystyrene with local clay and natural fibers, and by Ighal *et al.* [21] on wood-polystyrene composites reinforced with rice husks, confirm these materials' effectiveness for specific applications. Mastery of manufacturing techniques, notably optimizing filler/matrix ratios and thermal treatments, is essential to balance mechanical, thermal, and moisture absorption properties.

In Benin, where advanced composite manufacturing technologies are less accessible and conventional materials are often costly, exploring local and economical alternatives becomes relevant. Recycling expanded polystyrene offers an opportunity for valorization, especially when combined with abundant sawdust waste. Integrating principles from these studies within a framework adapted to local constraints could develop materials meeting infrastructure needs while reducing environmental impacts.

This work aims to reduce the environmental impact of wood and non-biodegradable polystyrene waste by developing particleboard using adapted technology, considering local economic and environmental constraints.

2. Materials and Methods

2.1. Wood Sawdust

The sawdust used in this study comes from the *Tectona grandis* species (**Figure 1**). It was collected from various sawmills and sieved to separate the material into several granular classes. Five compositions were considered: particles retained on the 0.630 mm, 0.315 mm, and 0.160 mm sieves, a coarse mixture, and a fine mixture (**Table 1**). The different mixtures were obtained by reconstituting the particles from the sieved fractions. Percentages of the different fractions in a mixture were chosen to achieve a fineness modulus corresponding to the desired mixture type. The proportions used for the coarse (GC4T) and fine (GC5T) mixtures are presented in **Table 2**.

Figure 1. *Tectona grandis* sawdust of various granular classes.

Table 1. Characteristics of recycled sawdust.

Code	Granular Composition	True Density (g/cm³)	Bulk Density (g/cm³)
GC0T	Retained on 1.25 mm sieve	0.258	0.119
GC1T	Retained on 0.630 mm sieve	0.270	0.126
GC2T	Retained on 0.315 mm sieve	0.278	0.161
GC3T	Retained on 0.160 mm sieve	0.294	0.171
GC4T	Coarse mixture	0.269	0.132
GC5T	Fine mixture	0.280	0.151

Table 2. Proportions of granular fractions in GC4T and GC5T mixtures.

Granular composition	**Coarse mixture (GC4T)**	**Fine mixture (GC5T)**
GC0T (1.250 mm)	40%	10%
GC1T (0.630 mm)	30%	20%
GC2T (0.315 mm)	20%	30%
GC3T (0.160 mm)	10%	40%

2.2. Expanded Polystyrene

The expanded polystyrene was recovered from packaging materials, with densities ranging between 0.015 and 0.023 g/cm^3.

2.3. Formulation of the Adhesive

The adhesive results from dissolving polystyrene in an organic solvent, specifically gasoline for this study. Preparation involves introducing polystyrene into gasoline and mixing until the adhesive is obtained, following the proportion

$$k = \frac{\text{mass of solvent}}{\text{mass of polystyrene}}.$$

The ratio k was determined after several tests. A known mass m of gasoline was weighed, and polystyrene was melted until complete evaporation of the gasoline, measuring the mass of melted polystyrene. The obtained ratio k is 1.4. Ratios less than 1.4 indicate insufficient gasoline to dissolve the polystyrene, while ratios greater than 1.4 reflect excess gasoline. The adhesive's characteristics are presented in Table 3.

Table 3. Characteristics of the adhesive.

Density (g/cm³)	Viscosity (Pa·s)
0.905	0.768

2.4. Formulation of the Composite

A dosing ratio $d = \frac{\text{mass of binder}}{\text{mass of wood sawdust}} = 2$ was selected. This choice was optimized to reduce structural defects, such as crumbling, and improve the composites homogeneity. Dosages higher than 2 lead to excess binder, forming an impermeable surface layer that prevents complete solidification of the composite's interior, weakening the material. Dosages lower than 1.5 result in a friable material.

2.5. Composite Fabrication

For the composite plates, a cold compaction process was implemented. The mixture, consisting of prepared wood sawdust and the polystyrene-based adhesive, was introduced into a metal mold designed for this experiment. Compaction was performed using a hydraulic press.

After compaction, the plates were removed from the mold and left to dry at room temperature. They were weighed every 8 hours until reaching a constant mass, indicating "maturation" and complete evaporation of residual solvents. Finally, the plates were machined (**Figure 2**) to dimensions of 11 mm thickness, 76 mm width, and 314 mm length [22].
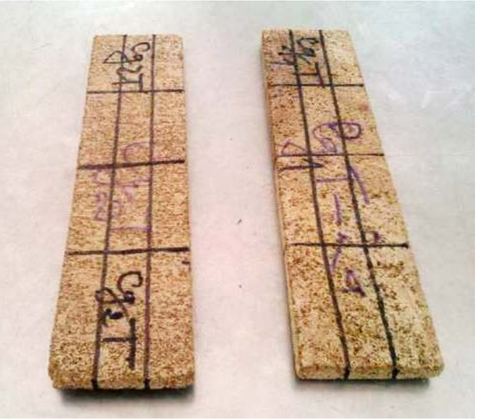
Figure 2. Machined plates.

3. Results and Discussion

3.1. Compaction Rate

The compaction rate varies with the granular composition. **Figure 3** illustrates the influence of granulometry on this rate. Larger particles exhibit higher compaction rates than finer particles. The compaction rates of mixtures GC1T (0.630 mm), GC2T (0.315 mm), and GC3T (0.160 mm) are 46.67%, 43.33%, and 33.33%, respectively. This is due to a higher proportion of voids in mixtures with large particles, with compaction aiming to reduce these voids.

The GC4T (coarse) mixture, although mainly composed of large particles, shows a lower compaction rate due to the presence of fine particles filling the voids, reducing compaction capacity. Conversely, the GC5T (fine) mixture presents a higher compaction rate than GC3T, mainly due to the presence of large particles promoting better granule adjustment.

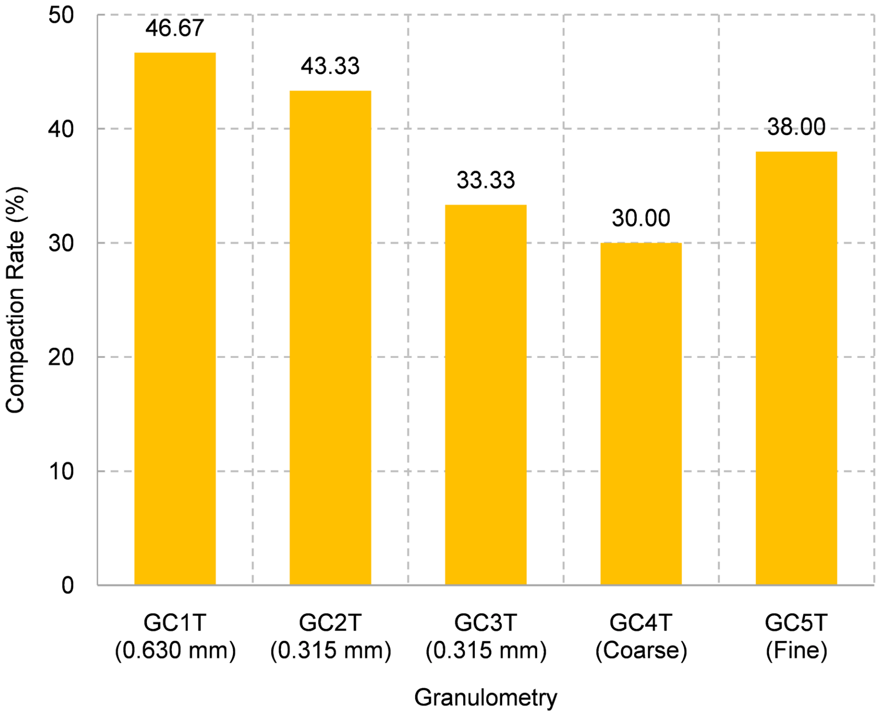

Figure 3. Influence of granulometry on compaction rate.

3.2. Mass Loss

All mixtures stabilized after 48 hours. Mass losses for mixtures GC1T, GC2T, GC3T, GC4T, and GC5T are 25.31%, 25.61%, 25.88%, 25.78%, and 25.55%, respectively. Minor variations indicate that granulometry does not significantly affect the composites' mass stabilization, which lose about 26% of their weight during the process.

This mass loss is mainly due to the evaporation of residual solvents in the polymer matrix. During fabrication, polystyrene dissolved in gasoline acts as a binder, but gasoline, being a volatile organic solvent, gradually evaporates, significantly reducing the composite's total mass. This phenomenon is uniform across different granular compositions, as the solvent's volatile properties are not influenced by particle size.

3.3. Density

The densities of plates GC1T, GC2T, and GC3T are 0.600 g/cm^3, 0.693 g/cm^3, and 0.727 g/cm^3, respectively. With slight variations in moisture content, it appears that finer granulometry leads to higher composite density. Thus, density decreases with increasing particle size. This trend is also confirmed for mixtures GC4T (0.705 g/cm^3) and GC5T (0.778 g/cm^3), as shown in **Figure 4**.

This is because mixtures with fine granulometry allow denser particle stacking, reducing voids and increasing overall composite density. In contrast, mixtures with large particles have more voids, decreasing density.

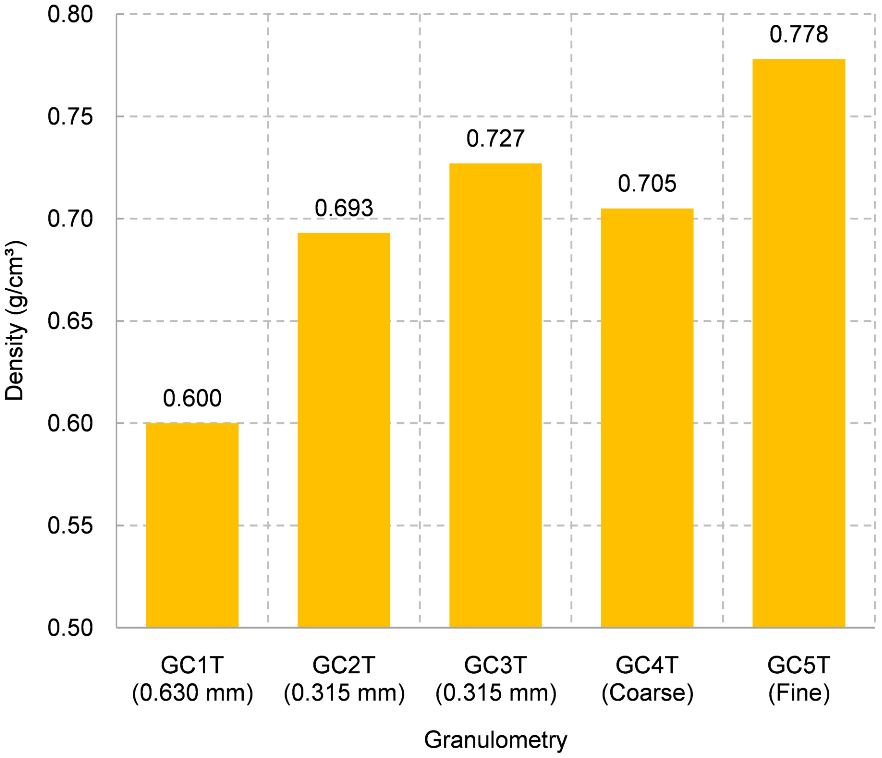

Figure 4. Density variation by granulometry.

3.4. Mechanical Properties of the Panels

The mechanical properties of the composite panels show a significant influence of sawdust granulometry on the modulus of elasticity in bending (MOE) and flexural strength (MOR) (**Figure 5**). Panels containing coarse sawdust (GC1T and GC4T) exhibit higher MOE and MOR values, with 842 MPa and 3.16 MPa respectively for GC1T, reflecting better structural rigidity and increased capacity to withstand mechanical loads. Conversely, panels with fine granulometry (GC3T and GC5T) show decreased mechanical properties, with MOE and MOR of 748 MPa and 2.25 MPa for GC3T, possibly due to a more compact but fragile structure limiting homogeneous stress dissipation. A balanced combination of fine and coarse particles in GC4T provides an interesting compromise with intermediate performance.

The results align with performance ranges generally observed in similar composites. For instance, Foti *et al.* [16] reported MOR values of 2.37 MPa for wood and recycled polystyrene composite panels, while Rofdi *et al.* [17] noted higher performance. Optimized density and control of hot pressing parameters improved mechanical properties in these studies. However, the composites developed here rely on a cold compaction process, adapted to local constraints and less sophisticated, justifying slightly lower mechanical results.

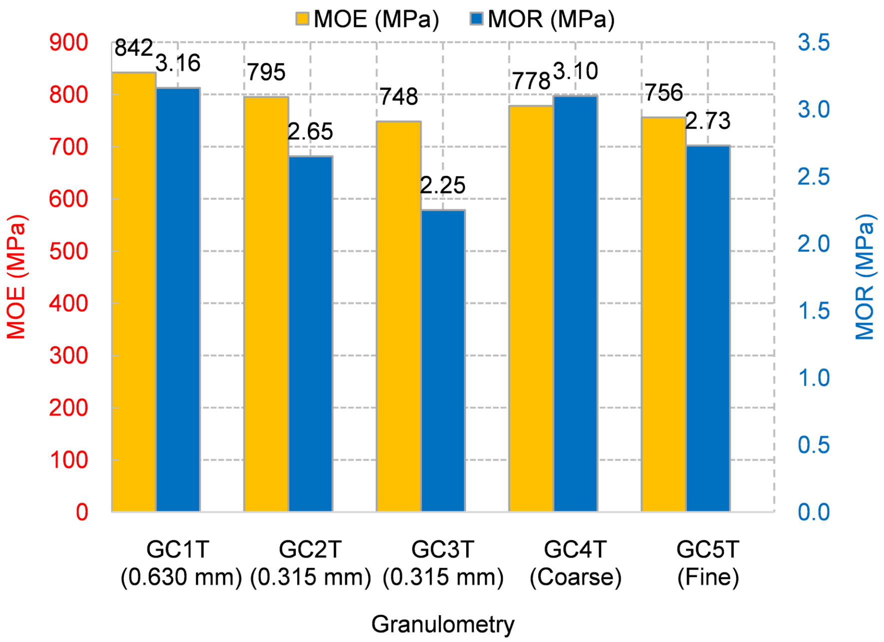

Figure 5. Influence of granulometry on mechanical properties.

Studies like Cherkashina *et al.* [18] showed significantly higher MOR, reaching 20 MPa, by incorporating reinforcing fillers like modified hazelnut shells. These improvements result from advanced chemical treatments and better matrix-particle compatibility. Khedr *et al.* [19] also confirmed that adding plasticizers or coupling agents, such as titanium dioxide, can significantly increase mechanical strength and flexibility. These processes, though effective, require resources and technologies not always aligning with local economic and environmental constraints.

The properties obtained remain competitive and relevant for specific applications. The panels could be used in lightweight partitions, furniture panels, or non-load-bearing elements in construction. Akinterinwa *et al.* [23], exploring composites based on rice husk and recycled polystyrene, suggested similar applications for materials with comparable mechanical and physical properties.

4. Conclusions

Developing composite panels from recycled wood sawdust and dissolved polystyrene is an approach that valorizes local waste while offering alternatives to conventional materials. In developing countries, where access to advanced technologies and costly materials is limited, this approach provides an adapted response to growing needs for ecological and economical construction materials.

The results demonstrate that the panels' mechanical properties, notably a modulus of elasticity in bending (MOE) up to 842 MPa and flexural strength (MOR) reaching 3.16 MPa, reflect the influences of granulometry, adhesive proportions, and the cold compaction process employed. Granular formulations containing coarse particles exhibit superior mechanical performance due to better stress distribution within the material.

Comparisons with previous studies reveal that, although our results show lower properties than those achieved using sophisticated processes like hot pressing or chemical reinforcements, they remain consistent within a simplified manufacturing framework. Higher performance in some studies is due to the use of plasticizers, advanced chemical treatments, or special fillers, incompatible with an approach centered on local resource valorization and accessible processes. These differences justify the performance gaps while underscoring this approach's relevance for local applications.

The panels developed are suitable for use in lightweight partitions, furniture panels, or non-load-bearing decorative elements. These applications align with local needs for low-cost materials with reduced environmental impact. Despite the absence of advanced technologies, the obtained performance confirms the feasibility of local production of ecological composite panels. This approach addresses waste valorization challenges and the growing demand for environmentally friendly materials, particularly in developing regions.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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