Development of a sustainable composite material based on rice husk and polystyrene

Abstract

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The combination of rice husk and expanded polystyrene for the fabrication of sustainable composites is a direction that is not well-explored in scientific literature. In this context, this research focuses on the feasibility and physical properties of composites developed from these materials. The methodology encompasses a mechanical grinding process of rice husks, dissolution of polystyrene in an organic solvent to form a binder, and the fabrication of composites through cold compaction. The fabricated composites were analyzed for their physical properties, particularly density, mass loss after compaction and air storage, and their swelling upon immersion. Fine-grained composites record a higher mass loss (13.17% for MF1 and 12.48% for MF2) compared to coarse-grained ones (8.43% for MG1 and 7.34% for MG2). This difference is attributed to a larger specific surface area of the fine particles, facilitating the evaporation of volatile compounds. Swelling after immersion is also influenced by granularity, with a maximum swelling of 15.53% for MG2 versus only 0.72% for MF2. These observations highlight the key role of the rice husk particle size and binder dosage in determining the properties of the composites. This work highlights the potential of these composites as both an ecological and practical solution for waste valorization while paving the way for future investigations, notably regarding their mechanical properties.

Keywords: bio-based materials; rice husk; expanded polystyrene; waste valorization; eco-material.

1. Introduction

The rapid pace of industrialization and exponential growth of the global population have led to a substantial increase in waste, including agricultural and plastic types. This phenomenon poses significant environmental challenges that call for sustainable and innovative solutions. In this scenario, waste valorization, particularly of rice husk and expanded polystyrene, presents an opportunity to mitigate these challenges.

The global rice production reached 525.5 million tons in 2021, thereby generating a considerable amount of rice husk, the disposal of which presents an environmental conundrum [1]. Similarly, polystyrene, primarily used in packaging, confronts issues related to biodegradability, further exacerbating the plastic pollution crisis.

Existing literature has predominantly focused on the use of rice husk as a mineral additive in the concrete sector, especially in Asia where this resource is abundant[2–4]. Previous studies have also explored the feasibility of rice husk as a reinforcing agent in polymer composites such as polypropylene and polyethylene[5–9]. Additional research has delved into the use of compatibilizers to enhance the composite properties[10–13]. Other matrices like different types of rubber have also been examined[14].

Various factors, such as the particle size of the rice husk, impact the mechanical properties of the composites[15]. The hydrophilic nature of rice husk can also influence water absorption in the composites, particularly at higher filler levels. Several surface modification techniques have been investigated to improve the interaction between rice husk and the polymer matrix.

However, the incorporation of expanded polystyrene in rice husk-based composites remains a scarcely explored subject in existing literature.Among the limited works available, Abdulkareem and Adeniyi[16] used melted polystyrene waste in an unspecified solvent as a binder. In their study, the rice husks were dried at 50°C and sieved to a size of 150 µm. Nak-Woon Choi et al. [17], on the other hand, employed a styrene solution in which EPS was dissolved, with the addition of Trimethylolpropanetrimethacrylate (TMPTMA) and benzoyl peroxide (BPO) as a cross-linking agent and initiator, respectively. They also included a limestone filler of size less than 2.5 µm. Their composites showed an apparent density ranging between 0.80 and 1.60 g.cm^{-3}.

In this context, the present study aims to develop composites using rice husk and expanded polystyrene as primary components. The influence of various parameters, such as the granularity of the rice husk and the dosage of the binder, on the properties of the composite will be examined. This research aspires to offer an ecological and economical alternative to traditional construction materials while contributing to waste reduction.

2. Materials and Methods

2.1. RiceHusk

The rice husk underwent a mechanical grinding process and was categorized into four distinct particle size fractions. Two granular formulations were developed from these four fractions: one fine-grained formulation and one coarse-grained formulation. The specific proportions for each formulation are detailed in Table 1, while the intrinsic physical properties of the rice husks are presented in Table2.

Table 1.Particle size distribution of rice husk formulations.

Size	Coarse Mix	Fine Mix
Retained on 1.250mm sieve	40%	10%
Retained on 0.630mm sieve	30%	20%
Retained on 0.315 mm sieve	20%	30%
Retained on 0.160 mm sieve	10%	40%

Table2.Physical characteristics of rice husk

Granular Composition	BulkDensity (kg.m^{-}3)	TrueDensity (kg.m^{-}3)	Water Absorption Rate (%)
Coarse Mix	158.63±1.10	632.41±0.72	64.69±0.56
Fine Mix	203.55±0.92	751.09±0.41	82.38±0.55

2.2. ExpandedPolystyrene

The expanded polystyrene was sourced from recovered packaging materials. This material is often overlooked and discarded in the environment, thus posing a waste management challenge. Itsdensity ranges between 15 and 25 kg.m^{-3}.

2.3. Binder Preparation

The binder preparation involves dissolving the polystyrene in an organic solvent, specifically gasoline in the context of this study. The process consists of incorporating the polystyrene into the solvent and kneading the mixture until a homogeneous adhesive substance is obtained. The proportion between the solvent and the polystyrene is defined by the ratio k, formulated as follows:

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

This ratio was optimized through a series of experiments. In this approach, a predefined number of solvent was weighed and mixed with the polystyrene until the complete evaporation of the solvent, while noting the mass of dissolved polystyrene. The ideal k ratio determined from these trials is 1.4.

The viscosity of the adhesive substance varies considerably with the k ratio. A k lower than 1.4 results in an insufficient amount of solvent to completely dissolve the polystyrene, thereby yielding a pasty binder with high viscosity and undissolved polystyrene residues. Conversely, a k higher than 1.4 leads to an excess of solvent, producing a less viscous binder that proves ineffective in holding the rice husk particles in place.

2.4. Composite formulation

Two binder proportions were rigorously selected for the study, based on preliminary experimental cycles. The proportions, expressed in terms of dosaged $= \frac{\text{mass of binder}}{\text{mass of rice husk}}$, are set at 0.8 and 1. These values were optimized to minimize structural defects such as crumbling and to improve the homogeneity of the composites.

Continuing with this study, the composites will be referenced according to their dosage and the particle size of the rice husks, as stipulated in Table3.

Table3.Coding of composites based on particle size and dosage.

Particlesize	Code	Dosage
Fine	MF1	0.8
	MF2	1
Coarse	MG1	0.8
	MG2	1

2.5. Composite implementation

- RiceHuskpreparation

The rice husks are initially dried in an oven until they reach a constant mass. Different particle size classes are then weighed to constitute the fine and coarse mixes.

- Mixing

This step is crucial for ensuring a uniform distribution of the rice husks within the polymer matrix. Adequatemixingresults in a homogeneous composite.

- Specimenfabrication

For creating the composite plates, a cold compaction process is employed. The mixture, consisting of the prepared rice husks and the dissolved polystyrene-based adhesive, is introduced into a metal mold designed for this experimentation. Compaction is carried out using a hydraulic press, thus ensuring a uniform distribution of pressure across the entire volume of the mixture.

The pressure is increased progressively, without reaching a level that could cause leakage of the polymer matrix or compromise the structural integrity of the composite. This pressure threshold is maintained until a stable level is reached, indicating that the mixture has achieved a satisfactory degree of homogeneity.

After compaction, the plates are extracted from the mold and left to dry at the laboratory's controlled room temperature, maintained at 20°C ± 1°C(Fig.1). They are then weighed every 8 hours until they reach a constant mass, thereby indicating their "maturation" and the complete evaporation of any residual solvents.

The samples, machined to dimensions of 11 mm in thickness, 76 mm in width, and 314 mm in length, are subjected to a three-directional swelling test (Fig. 2). For this purpose, they are submerged in water maintained at a controlled temperature of 20°C ± 1°C for a duration of 24 hours. Following the immersion period, the samples are removed from the water and allowed to dry for 10 minutes. Their weight is subsequently measured, and their dimensions (length, width, and thickness) are recorded at specific points: width and thickness are measured at five different points, while length is measured at two different points, all uniformly spaced. These measurements enable the calculation of various parameters such as moisture content, swelling in the three dimensions, volumetric swelling, water absorption, and density[18].

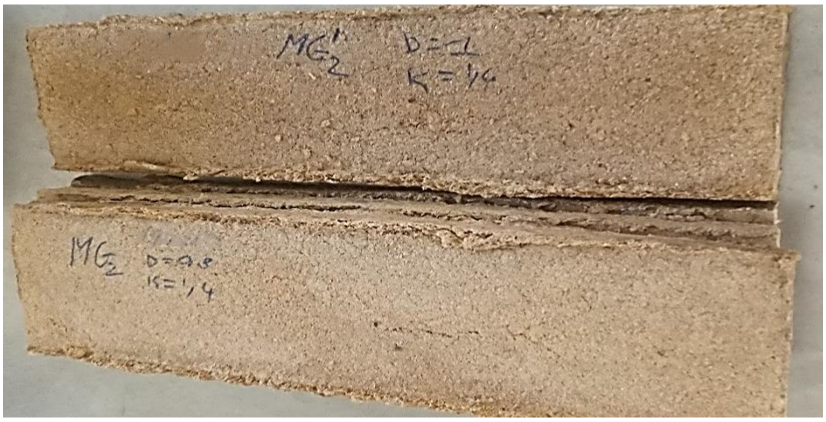

Fig.1. Plate obtained after compaction.

Fig. 2. Machined plates.

3. Results and Discussion

3.1. Mass loss of composites

The analysis of mass loss in composites after compaction and open-air storage reveals notable variations depending on composite parameters, particularly granularity and adhesive dosage.

Composites with fine rice husks (MF1 and MF2) shows a greater mass loss (13.17% for MF1 and 12.48% for MF2) compared to those with coarse granularity (MG1 and MG2), which register losses of 8.43% for MG1 and 7.34% for MG2. Several factors could contribute to this observation. On one hand, the higher proportion of fine particles in MF1 and MF2 mixtures may increase the total specific surface area exposed to air, which could facilitate the evaporation of volatile compounds and moisture. On the other hand, particle size distribution in these mixtures could favor a more porous structure, allowing for faster evaporation of volatile components. It's also possible that the chemical interactions between fine rice husks and polystyrene are more effective, leading to a faster mass loss.

As for the dynamics of mass loss, it also varies depending on the types of composites. The majority of mass loss occurs within the first 72 hours for all composites. For example, MG1 loses about 80.57% of its total lost mass within 72 hours, while MF1 loses about 79.37%. This suggests that the composites reach a certain level of "maturation" after this period, as also indicated by the fact that the mass becomes almost constant after 172 hours. It is also noteworthy that the mass loss within the first 24 hours varies considerably between composites. For example, the mass loss for MF1 is almost half of the final loss after just 24 hours, while for MG2, it's about a quarter of the final loss at the same time. This observation could indicate that the kinetics of mass loss are influenced by several factors, such as the particle size of the rice husks and the adhesive dosage.

In the context of these observations, the histogram presented in Fig.3 provides a clear and concise overview of the mass loss dynamics for different composites.

Overall, these results provide valuable insights into the behavior of the composites after the manufacturing process, which is essential for optimizing the material properties for future applications.

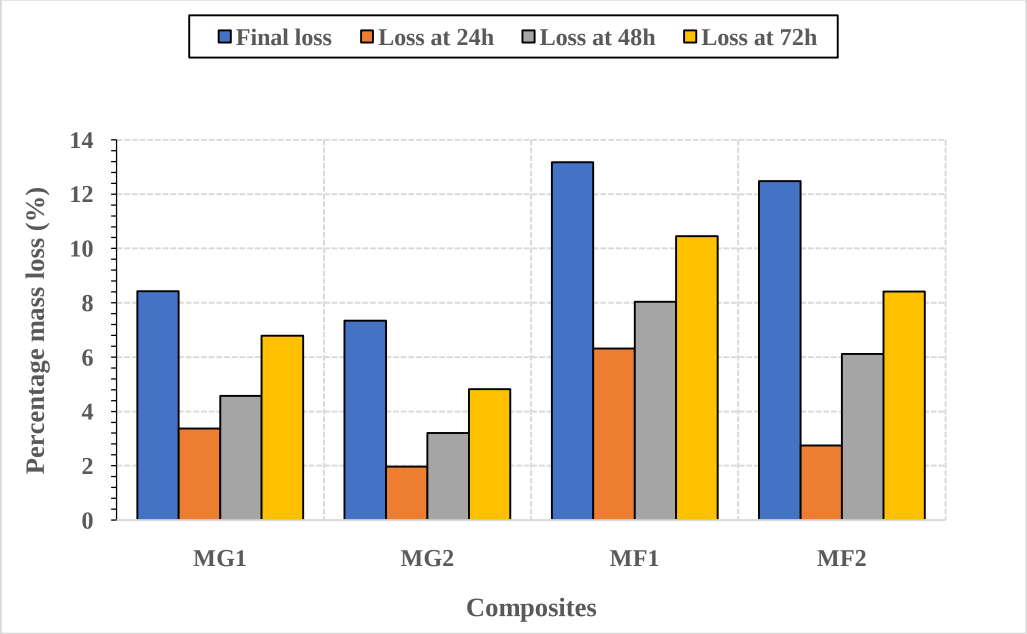

Fig.3. Percentage mass loss of rice husk-polystyrene composites over time.

3.2. Density of composites

Density measurements of the composites range between 0.693 kg.m^{-3} for MG1 and 0.720 kg.m^{-3} for MF2. These values are illustrated in Fig.4in histogram form.

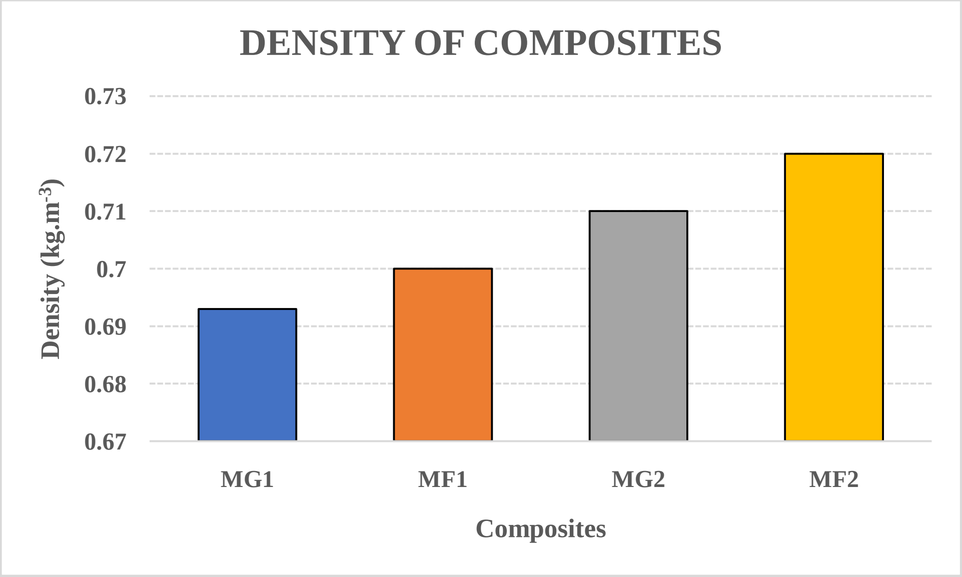

Fig.4. Distribution of density among different rice husk and polystyrene-based composites.

The density slightly increases when transitioning from a coarse mixture to a fine mixture for the same adhesive dosage. This phenomenon can be attributed to a better distribution of the polymer matrix around the finer rice husk particles, leading to a densification of the composite.

Additionally, increasing the adhesive dosage from 0.8 to 1 also seems to contribute to a slight increase in density. This could be due to the greater amount of polymer matrix present, which adds weight to the composite while improving the adherence between rice husk particles.

Compared to results by Nak-Woon Choi et al.[17], where the density of the composites ranges from 0.80 $kg.m^{-3}$ to 1.60 $kg.m^{-3}$, it is worth noting that the composites in this study have lower values. This difference could be explained by the absence of limestone fillers in the current formulation and perhaps by differences in manufacturing procedures.

3.3. Swelling of composites

Immersing the composites in water allows us to evaluate their behavior with respect to water absorption and, consequently, their durability in humid environments. The collected data show noticeable disparities among the different composites, whether in terms of swelling in thickness, length, width, or even volumetrically.

Swelling in Thickness: The MG composites, characterized by coarse granularity, display substantial swelling, with MG2 registering the most significant swelling at 15.53%. Conversely, the MF composites, with fine granularity, show more modest growth, with MF2 showing only a minimal swelling of 0.72%. This trend could stem from the intrinsically more porous structure of coarse-granularity composites, favoring increased water absorption and retention.

Swelling in Length and Width: Swelling in these dimensions is generally low for all the composites, not exceeding 3%. The orientation of rice husk particles in the composite could influence these swelling dimensions.

Volumetric Swelling: Volumetric swelling actually reflects the combination of the three dimensions. The MG2 composite shows the highest volumetric swelling, followed by MG1. The MF1 and MF2 composites, on the other hand, show significantly lower swellings.

Overall interpretation: The MG composites seem to absorb more water, which could be due to a more porous structure, allowing water to penetrate more easily and cause more significant swelling. The MF composites, on the other hand, seem to be less affected by water immersion, suggesting a denser polymer matrix or better adherence around the fine particles, thus limiting absorption.

However, a contradiction arises when observing that MF composites, despite their fine granularity, record a greater mass loss in open air. This trend could be explained by a larger specific surface area of fine particles, facilitating the evaporation of volatile compounds and moisture. It's essential to note that mass loss and swelling are two distinct phenomena, although influenced by the composite structure. Mass loss is mainly due to the evaporation of volatile compounds and moisture, while swelling is influenced by the composites' ability to absorb and retain water within their structure. Chemical interactions between the rice husks and the binder could also play a role in these observations. For instance, better adherence between the rice husks and the polymer matrix in MF composites would reduce their water absorption capacity, which could explain their lesser swelling despite increased mass loss.

In summary, although all composites show some level of post-immersion swelling, the observed variations indicate that the granularity of the rice husk plays a key role in determining the composites' water resistance. These results provide valuable information for future optimization of the composites based on the specific applications envisioned. A more in-depth study of the composites' microstructure could offer deeper insights into the influence of granularity on porosity and, by extension, on swelling.

The histogram in Fig.5 provides a clear and concise visual representation of these results, greatly facilitating their understanding.

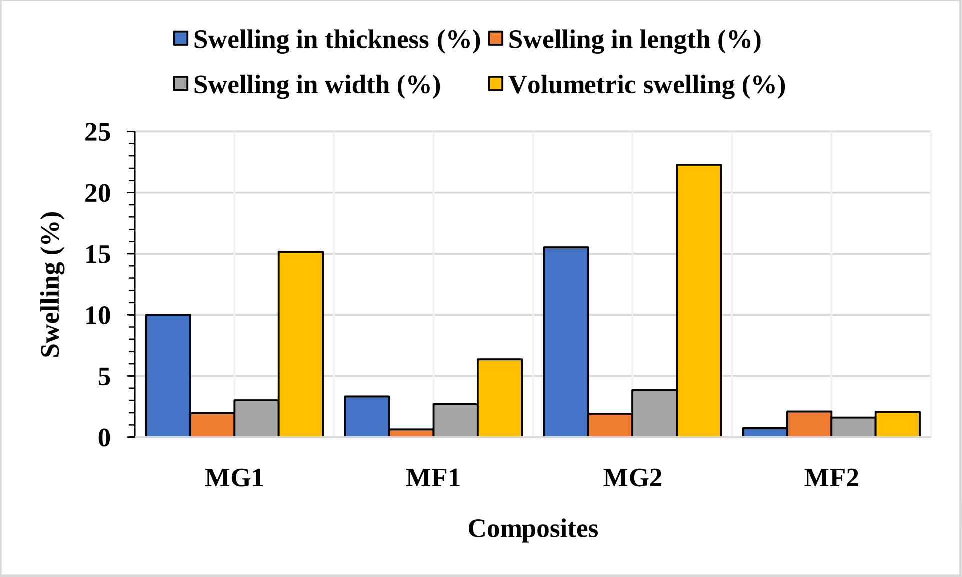

Fig.5. Swelling behavior of Rice Husk-Polystyrene Composites after 24-hour water immersion.

4. Conclusion

This study explored the development of composites based on rice husk and expanded polystyrene, a field still minimally covered in scientific literature. The primary objective was to propose a viable solution for the valorization of these common yet problematic wastes. Different granulates of rice husks and binder dosages were examined, and their effects on the physical properties of the composites, consisting of mass loss, density, and swelling upon immersion, were studied.

Fine-granularity composites recorded higher mass loss when exposed to air but showed better resistance to water absorption upon immersion, suggesting stronger adhesion between the rice husks and the polymer matrix. Coarse-granularity composites, on the other hand, exhibited more significant swelling upon immersion, indicating a more porous structure.

These initial observations pave the way for more in-depth studies to optimize these composites for applications in civil engineering. Future research could notably address aspects of durability, mechanical strength, fire resistance, and environmental assessment, including biodegradability and recyclability.

In summary, this study contributes to the expansion of knowledge in the field of bio-based composites and offers a new perspective for the sustainable management of agricultural and plastic wastes.

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