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Development of Filler-Reinforced Sustainable Polymeric Composites for the Implementation of Green Technology in Building Construction †

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Abstract: This study investigates the fabrication of sustainable polymer-based floor tiles utilizing recycled high-density polyethylene, low-density polyethylene, polypropylene, and polyethylene terephthalate. The process incorporates rice husk ash and natural sand to create eco-friendly construction materials. The materials underwent assessment for density, water absorption, flexural strength, compressive strength, and abrasive wear. The results reveal a density range from 1.07051 to 1.6151 g/cm^3, and water absorption ranging between 0.1996% and 0.68434%. Optimal flexural and compressive strengths were observed for HD70R15S1 and PET70R15S15, reaching 5.96 and 24.7933 MPa, respectively. Three-body abrasive wear testing indicates a minimum of 0.03095 cm^3 for PET70R15S15 and a maximum of 0.17896 cm^3 for HD70R15S15 composites.

Keywords: sustainability; recycling; polymeric composites; characterizations; circular economy

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1. Introduction

The exponential increase in the human population has been complemented by fast industrialization and urbanization, which has produced enormous amounts of waste. In 2012, a World Bank report stated that by 2025, the quantity of municipal solid waste (MSW) produced annually in metropolitan areas should have doubled to 1.3 million tons. The majority of MSW is made up of paper, plastic, and food/organic waste. Particularly in the context of impoverished and emerging countries, the issue is equally concerning in rural areas where there is a lack of scientific waste management solutions. Since plastic waste is produced in large quantities and is categorized as a solid waste, it poses a major threat to the world. The ecosystem, economy, and aesthetics are all harmed when plastic waste ends up in the oceans [1]. It is anticipated that 300 million metric tons of plastic garbage will be generated annually [2]. Plastic is widely used in many industries, such as the automotive, manufacturing, packaging, and healthcare sectors, which results in a large global waste production of plastic waste. According to Environmental Protection

Agency (EPA) research, just 7% of the millions of tons of plastic waste created each year is recycled; the remaining is disposed of in landfills. Due to the significant expense and energy associated with landfilling, this waste has been dumped in aquatic bodies. Furthermore, plastic is carelessly discarded into the environment due to its low biodegradability, which significantly limits its potential for recycling. A sustainable method of handling plastic waste will be made possible by recycling it.

Moreover, it has been discovered that recycling and reusing plastic waste is more efficient than burning and disposing of it in a landfill [3]. Husk is created as a byproduct of the milling process. When paddy is processed, about 78% of its weight is converted into rice. The remaining 22% of the weight of the paddy is composed of husk. Rice husk is burned to create steam during the parboiling process. The volatile and organic portion of rice husk makes up around 75% of its composition, with the remaining 25% being transformed into rice husk ash (RHA). Mostly, RHA is composed of 85% to 90% of amorphous silica. For every 1000 kg of milled paddy, about 220 kg (22%) of husk is produced. Additionally, roughly 55 kg or 25% of RHA is created during the boilers' burning of rice husk. Rice husk has been viewed as a highly promising agricultural waste because of its accessibility and capacity to burn into a substantial volume of ash. Ash contains around 90% silica. It is estimated that 5 tons of rice paddy yields approximately 1 ton of husk, and it has been calculated that globally, there may be 120 million tons of husk accessible each year for the manufacturing of pozzolana [4]. There is about 24 million tons of RHA available as pozzolana because the ash percentage by weight is just about 20%. A substantial portion of rice is grown in several nations worldwide. Historically, rice husk has been burned or dumped, even though it has been utilized as low-grade fuel. It is considered waste. Nowadays, composite materials that are embedded in a matrix are known as reinforcement arrangements (also known as fillers) and are widely used [5,6]. In addition to increasing the likelihood of load transfer, the matrix provides good binding. Consequently, the materials that are produced are often anisotropic and very heterogeneous [7]. Factors like the kind of matrix and charge, the form and number of charges, the interface quality, and the manufacturing process can all have an impact on the properties of the composite material [8]. There are numerous conceivable combinations because the reinforcement and matrix can be made of metal, plastic, or ceramic materials [9]. Most of the time, there are not many discontinuous phases in a continuous phase of composite material. Fillers and matrices are the principal basic materials used in the creation of composites. In the case where the composite comprises multiple discontinuous phases of different kinds, it is called a hybrid [10]. The discontinuous phase is known as the reinforcing material or reinforcement, and the continuous phase is referred to as the matrix. The matrix's roles include holding the fillers in place, distributing the constraints, providing chemical resistance for the structure, and giving the finished product the right shape [11]. The filler is added to the base polymer, which enables appreciable modification of the properties, and improvement of the surface properties. Composite materials are made of a mixture of components with similar mechanical and physical qualities [12]. Reinforcements with higher tensile strength and high modularity can be added to a polymer matrix to improve its mechanical and thermal properties [13]. The research literature has shown that polymeric composites offer some advantages over metallic composites [14]. According to the kind of matrix they employ, composite materials are divided into three categories: metallic, mineral, and biological [15]. Among the various types of organic composites are cardboard, laminated tires, and reinforced plastics [16]. Metallic composites represent a recent advancement in composite materials, as demonstrated by numerous studies [17,18]. The aforementioned discussion makes it evident that substantial work has been performed in the fields of composite materials and polymeric composites, but there has not been much documented in any of the literature regarding the use of waste plastics as matrices or agro-waste as filler. The objective of the research was to develop sustainable polymeric composites for building construction applications, such as floor tiles, pavements, etc., for non-traffic areas of public places. The research developed polymer-based composites by

recycling waste plastics and rice husk ash. This work shows how waste plastics, such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), and polyethylene terephthalate (PET), can be used as matrices to create sustainable polymeric composites. As fillers, natural sand and rice husk ash (RHA) are utilized. The composites are found in applications such as floor tiles, which can successfully replace conventional floor tiles. The aim of the research was to develop and investigate the workability of the developed polymer-based composite. However, the objective was to provide alternative and novel sustainable building materials with little cost and mitigate the problem associated with the disposal of solid waste. The research is imperative from several points of view. The research is presented in sections: materials and methods; later, results and discussions are provided; and finally conclusions are derived.

2. Materials and Methods

Discussions of the materials and techniques for the fabrication of the composites and characterization techniques are provided in this section.

2.1. Materials

The waste plastics LDPE, HDPE, PP, and PET have been used as matrices. Table 1 lists the characteristics of the waste plastics used. A granularity size of 600 µm in natural silica sand has a bulk density of 2.65 g/cm^3 and a mohs hardness of seven, while RHA is utilized as filler; its chemical composition and physical attributes are listed in Table 2. Figure 1 shows pictures of the raw ingredients.

Table 1. Properties of plastics.

Type of Plastics	Property				
	Tensile Strength	**Specific Gravity**	**Hardness in DUROMETER**	**Min. Heat Deflection Temperature**	**Flexural Modulus of Elasticity**
HDPE	5000 MPa	0.98	D 69	181 °C	200,000 MPa
LDPE	1500 MPa	0.96	D 55	131 °C	3000 MPa
PET	12,400 MPa	1.49	D 87	249 °C	40,000 MPa
PP	6300 MPa	0.93	D 75	209 °C	225,000 MPa



Figure 1. Images of raw materials (**a**) HDPE, (**b**) LDPE, (**c**) PP, (**d**) PET, (**e**) RHA, and (**f**) sand.

Table 2. Characteristics of RHA.

Chemical Composition								Physical Property		
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	LoI	Mean Particle Size	Specific Gravity	Surface Area
87.30%	0.84%	0.73%	1.40%	0.57%	1.12%	3.68%	8.55%	6.27 µm	2.08 g/cm^3	36.47 m^2/g

2.2. Methods

In Figure 2, a process flow chart illustrates the method used to create the composites used in the study. Waste plastic was gathered from several waste collection locations, cut to open, and then completely cleaned in water to remove any contaminants. In order to guarantee that all moisture was eliminated, the plastics were thereafter fully dried in an outside environment. The polymers were then combined according to the compositions listed in Table 3 after being shred into smaller pieces. To achieve a uniform blend of mixes, the mixtures were heated to the polymers' melting point and blended. After that, the composites were cast with a 20 MPa load using the hydrostatic compaction technique. Afterward, the samples were removed to eliminate burr and particles after being allowed to cool. The specimens were set up to undergo several composite characterization procedures. Images of the developed samples are shown in Figure 3.

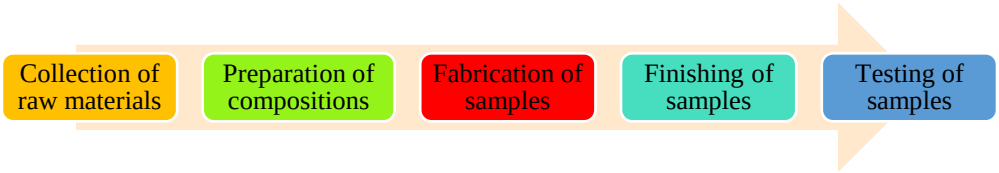

Figure 2. Process flow chart.

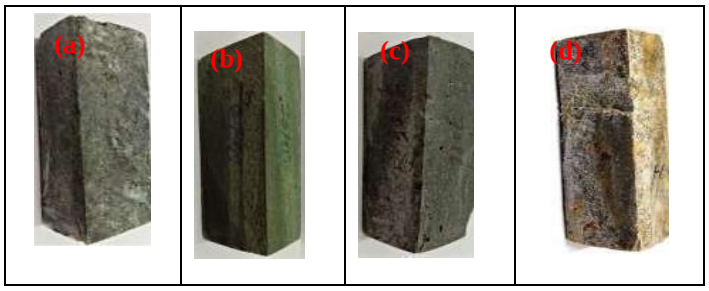

Figure 3. Images of the composites (**a**) LD70R15S15, (**b**) HD70R15S15, (**c**) PP70R15S15, and (**d**) PET70R15S15.

Table 3. Compositions of the composites.

S. No.	Sample Designation	LDPE	HDPE	PP	PET	RHA	Sand
1	LD70R15S15	70	-	-	-	15	15
2	HD70R15S15	-	70	-	-	15	15
3	PP70R15S15	-	-	70	-	15	15
4	PET70R15S15	-	-	-	70	15	15

2.3. Characterization Techniques

The developed composites are characterized for different properties. The density of the composites was evaluated as per ASTM D3171 test procedures for density [19]. The density establishes the composition percentage and the amount of empty space in the composite. The ASTM C373 standard test for water absorption was followed when conducting the water absorption (Wa) test. By measuring the porosity and moisture content, the test could

establish whether the composite materials were suitable to be used as floor tiles. The mechanical characterizations compressive (Cs) and flexural strength (Fs) were performed according to ASTM C648 and ASTM C1505 breaking strength of ceramic tile. Compressive strength, which was determined using a 500KN hydraulic compression testing machine (CTM), is a measure of the strength of floor tiles under compressive force. The strength of the floor tiles as a result of the bending force was determined by flexural strength using a hydraulic universal testing machine (model HL59020, 600KN capacity). Three-body abrasive wear was measured with a dry abrasion tester (TR-50). The G65 standard test for dry abrasion was used, with 68 N of force and 0.8980 m/s of sliding speed.

3. Results and Discussions

The evaluated values for physical, mechanical, and tribological properties are summarized in Table 4. Density increases with the density of the matrix as seen by the density of the composite PET70R15S15, which reaches its maximum density of 1.6151 g/cm^3. In contrast, 1.070 g/cm^3 is the minimum density achieved by the composite LD70R15S15. Therefore, the density of the composites is found to be satisfactory for applications in pavements and floor tiles. Water absorption for the composites is found in the range of 0.199 to 0.684% and denotes an inverse relationship with the density of the composites. Moreover, the density of the created composite samples for pavements is less than 5%, meaning that the composites can be employed as floor tiles in ambient environments. The PP70R15S15 composite material achieves optimal values in terms of compressive and flexural strength, measuring 24.79 and 5.96 MPa, respectively. Whereas, the composite LD70R15S15 shows a minimum compressive and flexural strength of 7.5015 and 1.07269 MPa, respectively. Sufficient binding between the matrix and filler in the composition is answerable for providing good strength to the composite [19]. Mechanical strength data indicate a linear relationship between the composites' density and mechanical strength. Furthermore, there is a strong correlation seen between the flexural and compressive strengths. It is noticed that for the generated samples, the compressive strength is greater than 3.5 MPa hence, the composites can be employed as floor tiles and pavements. The abrasive wear response of the composites reveals that the maximum abrasive wear was found to be 0.17896 cm^3 for LD70R15S15, whereas the composite PET70R15S15 attains a minimum abrasive wear of 0.03095 cm^3. While HD70R15S15 experiences maximal wear due to low strength and poor elasticity, minimal wear is caused by the PET matrix's appropriate strength and the filler's total encapsulation by the matrix.

Table 4. Resulting properties of the composite.

S. No.	Sample	Density (g/m^3)	Wa (%)	Cs (MPa)	Fs (MPa)	Abrasive Wear (cm^3)
1	LD70R15S15	1.07051	0.684	7.5015	1.072	0.04670
2	HD70R15S15	1.67632	0.397	8.5327	1.684	0.17896
3	PP70R15S15	1.33893	0.523	24.7933	5.96	0.07468
4	PET70R15S15	1.6151	0.199	20.81	4.895	0.03095

4. Conclusions and Future Scope

The recycling of waste plastics and the development of value-added products using rice husk ash were identified as viable solutions for addressing challenges associated with solid waste generation. Issues arising from the mismanagement of plastic waste and the demand for shelter due to the increasing global population present significant hurdles. Consequently, this research successfully developed composites for floor tiles and pavements, exploring the recycling potential of solid waste. The combination of rice husk ash (RHA) and sand as fillers in plastics effectively addressed traditional drawbacks and limitations. This study emphasizes waste recycling, a crucial element of sustainability, urging communities to transform waste materials into sustainable products. Experts involved in cleaner

product production can benefit from the research outcomes, particularly in promoting sustainability within infrastructure development. The research supports the recycling of waste plastics and agricultural residues, effectively tackling issues related to the low biodegradability of plastic waste. By offering the community alternative and sustainable building materials, the research provides a successful replacement for conventional floor tiles. The developed product has minimal or no environmental impact, reducing construction costs and mitigating the harmful effects of waste products. The developed composites exhibit the required workability for implementation as floor tiles and pavements. However, it should be noted that the research demonstrated limited compositions for composite fabrication. There are ample opportunities to convert other types of plastics and agro-industrial wastes into sustainable products. Evaluating other properties through more suitable compositions can enhance the applicability and conventional production of sustainable flooring tiles.

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