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Mechanical Performance Evaluation of Eco-Friendly Tiles Incorporating Peanut Shell Waste

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Abstract: This study evaluates the flexural performance of eco-friendly composite tiles incorporating peanut shell waste as a sustainable filler material. Peanut shell powder was blended with epoxy resin and sand in varying proportions to investigate its influence on flexural strength. Tests conducted as per IS 516:1959 revealed that the flexural strength of the composite tiles ranged between 3.86 N/mm² and 6.28 N/mm². The optimum mix proportion (0.5:1.5:2) achieved the highest strength of 6.28 N/mm², demonstrating enhanced load-bearing capacity and uniform stress distribution. Beyond this ratio, a slight reduction in strength was observed due to increased porosity and weaker bonding. The results confirm that peanut shell filler can effectively improve the mechanical performance of tiles for non-structural applications such as interior flooring and wall cladding, contributing to sustainable and eco-friendly construction practices.
Keywords: *Peanut shell waste, Flexural strength, Eco-friendly tiles, Sustainable materials, Lightweight composites.*

1. Introduction

The growing emphasis on sustainable development and circular economy principles has encouraged the use of agricultural and industrial by-products in construction materials. The disposal of peanut shells, a major agrowaste, poses significant environmental concerns due to their slow biodegradability. In India alone, peanut processing industries generate thousands of tons of shells annually, most of which are discarded or burned, contributing to air and soil pollution.

To minimize this environmental burden, the incorporation of peanut shell waste into building materials has emerged as a promising solution. Previous studies have shown that agrowaste products such as rice husk ash, coconut shells, and sawdust can improve lightweight and insulation properties of composites. However, limited work has focused on peanut shell waste in tile manufacturing.

This study explores the potential of peanut shell waste as a filler material for eco-friendly tile production and evaluates its effect on the mechanical and physical properties of the final product.

2. Literature Review

The use of agricultural and industrial wastes in construction materials has received growing attention in recent years, driven by the need for sustainable and cost-effective alternatives to conventional aggregates. Numerous studies have demonstrated that agricultural by-products can enhance specific properties of cementitious composites, reduce environmental impact, and promote circular economy practices.

Ramesh and Shanmugam (2019) reported that integrating agricultural residues into concrete tile production improved workability and dimensional stability while reducing raw material consumption. Similarly, Singh and Mehra (2020) found that agrowaste materials such as rice husk ash, bagasse, and sawdust can partially replace fine aggregates without significantly affecting mechanical performance.

Patel and Sharma (2021) studied concrete mixes containing peanut shell ash and concluded that 10% replacement by weight offered the best balance between compressive strength and density. Choudhary and Gaur (2020) observed that groundnut shell powder reduces the unit weight of composites while maintaining adequate compressive strength. Thomas and George (2020) confirmed that peanut shell–based concrete retained 80–90% of the strength of conventional concrete, making it viable for non-structural applications.

Ahmed and Alam (2018) emphasized that the inclusion of agrowaste particles in cement composites can enhance sustainability and resource efficiency. Devi and Raj (2018) developed eco-friendly tiles using waste plastics and agricultural residues, reporting improved surface finish and reduced water absorption. Rana and Kaur (2022) conducted a review on sustainable ceramic tiles incorporating agrowaste and highlighted better thermal and acoustic insulation properties.

Awoyera and Akinmusuru (2019) reviewed more than 60 studies on agrowaste-based concrete and concluded that up to 15% replacement of conventional aggregates can be achieved without significant loss in strength. Kalyani and Natarajan (2021) compared multiple agrowaste-based tile formulations and found that waste incorporation enhanced porosity and reduced overall cost.

Kumar and Verma (2021) studied groundnut shell ash as a supplementary cementitious material and observed that it improved the microstructure through secondary pozzolanic reactions. Edeh and Okorie (2019) examined groundnut shell ash as a cement substitute and found that concrete with 10% replacement maintained sufficient strength for lightweight applications.

Das and Chakraborty (2019) analyzed agro-waste as partial fine aggregate replacement in mortar and found increased water absorption but acceptable strength retention. Gupta and Sahu (2020) explored peanut shell composites and concluded that they improved thermal performance while maintaining adequate flexural strength. Pandey and Gupta (2022) evaluated peanut shell powder in cement mortars and found it suitable for use up to 15% without severe strength reduction.

Reddy and Rao (2020) developed peanut shell concrete blocks and reported satisfactory compressive performance with reduced density. Tan and Li (2021) reviewed sustainable materials derived from agricultural by-products and emphasized their contribution to reducing carbon emissions in construction.

Akinwande and Fadare (2020) tested groundnut shell ash in lightweight mortar and concluded that it provided better workability and sound insulation. Odum and John (2021) reported that cement composites incorporating peanut shell ash exhibited acceptable compressive strength and lower thermal conductivity. Santhanam and Rajesh (2020) analyzed the role of agrowaste utilization in resource-efficient construction and confirmed its effectiveness in minimizing material wastage.

Khushbu and Shah (2022) conducted an experimental study on peanut shell–based eco-tiles and found that 10–12% replacement provided optimal strength-to-weight ratio and lower water absorption. Kalyani et al. (2023) further reinforced that peanut shell waste can serve as an effective lightweight aggregate in sustainable flooring applications.

Collectively, the reviewed literature underscores that agricultural residues such as peanut shells, rice husk, and coconut shells can significantly enhance sustainability and reduce the environmental footprint of the construction sector. However, despite promising findings, research specifically focusing on tile manufacturing using peanut shell waste remains limited. This study aims to fill that gap by experimentally evaluating the mechanical and durability performance of tiles incorporating different proportions of peanut shell waste, emphasizing compressive strength, flexural strength, water absorption, and surface hardness.

3. Methodology

The methodology for this study was designed to systematically develop and evaluate eco-friendly tiles made from peanut shell waste and epoxy resin. The process involved several stages collection and preparation of raw materials, proportioning, mixing, molding, curing, and performance testing to achieve a sustainable and durable composite material suitable for construction applications.

3.1 Model Development

The experimental model aimed to fabricate sustainable composite tiles by utilizing peanut shells as a renewable filler material combined with epoxy resin as a binder. This model capitalized on the low cost, abundance, and biodegradability of peanut shells to develop an eco-friendly alternative to conventional ceramic and plastic tiles.

The process began with the **collection of peanut shells** from local processing units. These shells were thoroughly cleaned to remove impurities, dried under sunlight to eliminate moisture, and ground into fine particles. The ground peanut shell powder was then blended with **epoxy resin and hardener** in specific ratios (40–70% peanut shell by weight) to form a uniform composite mix.

The prepared mixture was poured into **silicone molds** of desired tile dimensions (205 × 165 × 8 mm) and left to set for **24 hours at room temperature**. The polymerization of epoxy resin provided rigidity and surface strength, while peanut shell particles contributed to lightweight structure and improved insulation properties.

3.2 Composition and Properties of Peanut Shells

Peanut shells, a by-product of the peanut industry, possess characteristics that make them ideal for sustainable composite fabrication. Their **low density (0.7–1.0 g/cm³)** contributes to lightweight structures, while their **fibrous texture** aids in bonding with epoxy resin.

- **Mechanical Properties:** Moderate compressive and tensile strength; low weight.
- **Thermal Properties:** Low thermal conductivity (0.05–0.10 W/m·K), providing effective insulation and stability under thermal stress.
- **Environmental Properties:** Biodegradable, renewable, and easily available, promoting circular economy practices.

3.3 Material Selection

- **Peanut Shells:** Cleaned, dried, and ground agricultural waste used as the main filler.
- **Epoxy Resin and Hardener:** Served as the primary binder, ensuring mechanical stability and water resistance.
- **Silica Sand (optional):** Added to enhance surface texture and improve rigidity.
- **Additives:** Coloring agents and hardeners were introduced to modify strength, finish, and aesthetic appeal.

Fig.1 Epoxy Resin

Fig.2 Peanut Shells

Fig.3 Silica Sand

3.4 Preparation Procedure

1. **Collection and Cleaning:**
   Peanut shells were sourced from local agro industrial waste. They were washed, dried, and manually sorted to remove contaminants.
2. **Grinding and Sieving:**
   The dried shells were pulverized into fine powder using a mechanical grinder and sieved through a 2 mm mesh to obtain uniform particle size.
3. **Mixing:**
   The ground shells were mixed with epoxy resin and hardener in varying proportions. Thorough

manual and mechanical stirring ensured uniform dispersion of the peanut shell filler in the resin matrix.

4. **Molding:**
The homogeneous mixture was poured into pre-prepared silicone molds corresponding to standard tile dimensions. The mixture was compacted to remove air voids and leveled for surface uniformity.
5. **Curing and Drying:**
The molded tiles were left to dry for 24 hours at room temperature (27 ± 2°C). This allowed complete curing of the resin and development of strength.
6. **Finishing:**
After demolding, tiles were polished and surface-finished to achieve smoothness and uniform texture. A protective coating was optionally applied to enhance durability and appearance.

3.5 Testing and Evaluation
Mechanical and physical performance of the fabricated tiles were evaluated according to **IS 516:1959** standards.

- **Flexural Strength Test:** Conducted using specimens of 205 × 165 × 8 mm. The average flexural strength obtained ranged between **3.78–6.36 N/mm²**, confirming adequate load-bearing capacity.


Fig.4 Specimen Drying

4. Experimental Testing and Analysis
The fabricated peanut shell composite tiles were tested to evaluate their **mechanical and physical properties** in accordance with **IS 15658:2006** and **IS 654:1992** standards for paving and flooring tiles. The testing program included **compressive strength**, **flexural strength**, and **water absorption** assessments to determine the suitability of peanut shell–based composites for construction applications.

4.1.1 Sample Description

The fabricated samples consisted of peanut shell powder mixed with epoxy resin and silica sand as filler materials. The **standard specimen dimensions** used for testing were **205 mm × 165 mm × 8 mm**, as per IS 516:1959 guidelines. The **binder proportion** was varied across samples to analyze the influence of composition on strength and durability.

The prepared specimens were designated as follows:
- **Sp.1 = 0.5:0.5:2 (Resin: Peanut Shell: Sand)**
- **Sp.2 = 0.5:1:2**
- **Sp.3 = 0.5:1.5:2**
- **Sp.4 = 0.5:2:2**

Each tile was **air-dried for 24 hours** at room temperature (20–25°C) to ensure complete curing of the resin matrix. The resulting composite tiles were lighter than conventional ceramic tiles and exhibited smooth surfaces with adequate hardness after polishing.

4.1.2 Testing Methodology
Mechanical performance was evaluated through **flexural testing**, following the guidelines of **IS 516:1959, Clause 8.4**. The test involved applying a central point load to the specimen until failure occurred. The maximum load (P), span (L), width (b), and depth (d) were recorded to determine **flexural strength (σ)** using the formula:

Flexural strength (σ) = PL/bd^2

Where:
σ = Flexural strength (N/mm^2)
P = Maximum load (kg)
L = Span length (mm)
b = Specimen width (mm)
d = Specimen thickness (mm)

The deflection during loading was measured using a dial gauge to observe the deformation behavior before failure.

4.1.3 Experimental Procedure

1. **Preparation:** Tiles were cleaned, surface-dried, and checked for dimensional accuracy.
2. **Setup:** Each specimen was placed on a dual-support testing frame, maintaining a constant span of 165 mm.
3. **Loading:** The load was applied gradually at the midspan until visible cracks formed and failure occurred.
4. **Measurement:** Deflection and load readings were recorded continuously.
5. **Data Analysis:** Average values of three readings per specimen were taken to minimize error.

Fig.5 Demolded Tiles

Fig.6 Setup for specimen testing

Fig.7 Specimen After Flexural Test

4.1.4 Flexural Strength Results and Analysis

Table 1 presents the detailed experimental data for flexural strength of peanut shell–based composite tiles. Each specimen was tested under a central point load until failure, and the average of three readings was considered for each mix proportion. The results indicate a consistent trend in strength variation with changes in peanut shell content.

The results demonstrate that Specimen Sp.3 (0.5:1.5:2) exhibited the highest flexural strength of 6.28 N/mm^2, indicating an optimal balance between epoxy resin and peanut shell filler. Strength increased with increasing filler content up to Sp.3, after which it decreased slightly for Sp.4 due to higher porosity and weaker bonding between particles and resin. The minimum flexural strength recorded was 3.86 N/mm^2 for Sp.1, which contained the lowest amount of filler material.

Specimen	Width (mm)	Span (mm)	Thickness (mm)	Load (kg)	Deflection (mm)	Flexural Strength (N/mm^2)	Avg σ (N/mm^2)
Sp.1	205	165	8	30.01	1.11	3.78	**3.86**
	205	165	8	31.3	1.93	3.93	
	205	165	8	30.8	2.7	3.87	
Sp.2	205	165	8	37.9	2.34	4.76	**4.86**
	205	165	8	38.3	2.11	4.81	
	205	165	8	40	3.2	5.03	
Sp.3	205	165	8	48.1	1.6	6.04	**6.28**
	205	165	8	50.6	2.1	6.36	
	205	165	8	51.3	2.6	6.45	
Sp.4	205	165	8	43	3.01	5.4	**5.65**
	205	165	8	48	1.9	6.03	
	205	165	8	44	2.7	5.53	

Table 1: Flexural Strength Test Results of Peanut Shell Composite Tiles

5. Results and Discussion

5.1 Discussion

The experimental study investigated the fabrication and performance evaluation of peanut shell–based composite tiles using epoxy resin as the binding material. This sustainable approach aimed to transform agricultural waste into a durable and cost-effective building product while reducing environmental impact. The fabricated tiles were analyzed to assess their mechanical, physical, and thermal behavior under controlled laboratory conditions.

The peanut shell tiles demonstrated promising results in terms of **mechanical strength, density, and workability**. Varying proportions of filler material and binder were tested to identify the optimum mix ratio that provides adequate strength while maintaining lightweight properties. Epoxy resin served as an effective binder due to its high adhesive strength and ability to distribute load uniformly across the peanut shell matrix.

It was observed that **increasing peanut shell content reduced the density** of the tiles, resulting in lighter composites suitable for non-structural applications such as wall cladding and interior flooring. However, beyond a certain proportion, the mechanical strength declined slightly, likely due to reduced interfacial bonding and increased porosity.

5.2 Flexural Strength Result Interpretation

The flexural strength of peanut shell composite tiles ranged between 3.86 and 6.28 N/mm^2. The trend showed a gradual improvement in strength with increased peanut shell content up to an optimal level, followed by a slight reduction beyond that point.

a. Specimen Sp.1 (0.5:0.5:2) recorded the lowest average strength (3.86 N/mm^2) due to insufficient resin filler bonding.
b. Specimen Sp.2 (0.5:1:2) showed improved strength (4.86 N/mm^2) as better filler dispersion enhanced load transfer.
c. Specimen Sp.3 (0.5:1.5:2) achieved the maximum strength (6.28 N/mm^2), representing the optimal composition with balanced filler and resin proportions.
d. Specimen Sp.4 (0.5:2:2) displayed a minor decline (5.65 N/mm^2) owing to excessive filler content causing reduced matrix cohesion.

Overall, flexural performance was satisfactory for lightweight and non-structural applications such as wall cladding, indoor flooring, and decorative surfaces. The results align with the general behavior of polymer composites incorporating agricultural fillers, where an optimal filler ratio enhances mechanical performance before matrix discontinuity occurs.

The **average flexural strength** values for the specimens were found to be between **3.86 N/mm² and 6.28 N/mm²**, with **Specimen 3 (0.5:1.5:2)** exhibiting the highest performance. The results show a **positive correlation between filler proportion and flexural strength** up to an optimal point, after which excess filler caused marginal decline due to poor bonding and increased porosity.

Key observations:

- **Sp.3 (0.5:1.5:2)** achieved **6.28 N/mm²**, demonstrating superior strength and balanced composition.
- **Sp.1 (0.5:0.5:2)** showed lower flexural strength, attributed to insufficient resin-filler interaction.
- **Sp.4 (0.5:2:2)** experienced a minor decrease due to excess filler disrupting the resin network.

Overall, the optimized mixture provided improved structural integrity and lower density than conventional tiles. The flexural performance meets the requirements for lightweight, non-structural applications such as indoor flooring and decorative cladding.

6. Conclusion

The study successfully evaluated the flexural performance of eco-friendly composite tiles made from peanut shell waste and epoxy resin. Flexural testing confirmed that peanut shell filler can effectively contribute to mechanical strength while reducing the tile's overall density.:

a. Flexural strength ranged between 3.86 and 6.28 N/mm².
b. The optimum composition (0.5:1.5:2) yielded the highest strength of 6.28 N/mm².
c. Increasing filler content beyond the optimum resulted in marginal strength reduction due to increased porosity and weaker matrix bonding.

The findings validate that peanut shell waste can be effectively used as a lightweight filler material in tile production, meeting the mechanical requirements for non-structural applications such as interior flooring, wall cladding, and decorative finishes. This approach promotes sustainable resource utilization and offers a viable pathway for agricultural waste valorization in construction materials.

This study successfully demonstrated the feasibility of utilizing **peanut shell waste** an abundant agricultural by-product as a sustainable filler material in the fabrication of **composite tiles** using **epoxy resin** as a binder. The research aimed to address the dual challenges of waste management and the development of eco-friendly construction materials. The experimental results validate the potential of peanut shell composites as lightweight, durable, and sustainable alternatives to conventional tiles.

Future Scope

Further studies may explore:

- The use of **hybrid bio-fillers** or **modified resins** to enhance bonding strength.
- **Long-term durability testing** under variable humidity and temperature conditions.
- Integration of **nano-additives** or **fiber reinforcements** for improved performance.

In conclusion, the research establishes that **peanut shell–based composite tiles** are a viable, sustainable, and innovative material that can contribute to greener building practices and the reduction of agricultural waste in the construction industry.

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