

THE EFFECTS OF FLOOR TILES MADE FROM RECYCLED PLASTICS, BOTTLES, GLASS WASTE, AND COMPOSITE MATERIALS

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Abstract

Conventional ceramic and porcelain tiles, despite their widespread use, exhibit relatively high thermal conductivity (ranging from 0.60 to 1.50 W/m-K), making them prone to absorbing and transmitting cold during winter, which can lead to indoor discomfort and increase the risk of cold-related health issues such as hypothermia, arthritis flare-ups, and respiratory infections, especially among vulnerable populations. To address these limitations, this study explores the development of sustainable composite floor tiles using recycled plastic waste, Doum palm shell, glass waste, and silica sand. Six composite samples (A-F) were produced using the compression molding method, involving mixing, heating, and pressing the materials into tile forms. The samples were evaluated for mechanical properties (tensile, flexural, impact, hardness, and compressive strength), physical properties (water absorption and density), and thermal conductivity. Among them, Sample D recorded the highest mechanical strength (tensile: 16.3 MPa; compressive: 32.8 MPa), while Sample A showed the best insulation performance with the lowest thermal conductivity (0.198 W/m-K), lowest density (1.08 g/cm³), and minimal water absorption (0.72%). Compared to conventional tiles, the developed composites are more thermally efficient, lightweight, and moisture-resistant, making them a viable, eco-friendly alternative for use in cold-prone environments and sustainable, energy-conscious construction. It is recommended that the most promising formulations be further refined for commercial applications and integrated into environmentally responsible building practices.

1. Introduction

The increasing global demand for sustainable construction materials has become a pressing issue due to the alarming rise in environmental pollution, depletion of natural resources, and the high cost of conventional building materials. A significant contributor to environmental degradation is the accumulation of non-biodegradable wastes such as plastics, glass bottles, and other solid waste materials. In many developing countries, including Nigeria, improper waste disposal has led to blocked drainage systems, flooding, land pollution, and serious health hazards (Ahmed *et al.*, 2021).

The construction industry, one of the largest consumers of natural resources, plays a critical role in environmental sustainability. Traditional floor tiles are produced from raw materials such as clay, sand, and limestone, which require extensive mining and energy-intensive processes. This not only depletes natural resources but also contributes to greenhouse gas emissions. As a result, there is an urgent need to explore alternative, eco-friendly, cost-effective, sustainable materials (Bakare *et al.*, 2020).

Recent advancements in materials engineering have shown the potential for incorporating recycled materials such as waste plastics, glass bottles, and other composite wastes into construction products. Recycling these materials into floor tiles offers a dual advantage, reducing environmental pollution and providing affordable alternatives to conventional tiles. Moreover, if properly

engineered, these waste-derived tiles can exhibit desirable properties such as high durability, water resistance, and low maintenance costs.

Despite the promising outlook, there is limited comprehensive research on the performance, effects, and long-term viability of floor tiles produced from a combination of recycled plastics, glass waste, and composite materials, particularly under varying environmental and load conditions. Understanding their mechanical properties, durability, thermal behaviour, and environmental impact is essential for widespread adoption in the construction industry (Ogunniyi *et al.*, 2021).

Floor tiles are usually thin, square, or rectangular coverings manufactured from hard-wearing ceramic, stone, metal, baked clay, plastic waste, or glass. They are generally fixed in an array to cover floors, walls, and tabletops as shown in Figure 1 and Plate I (Carneane *et al.*, 2020).

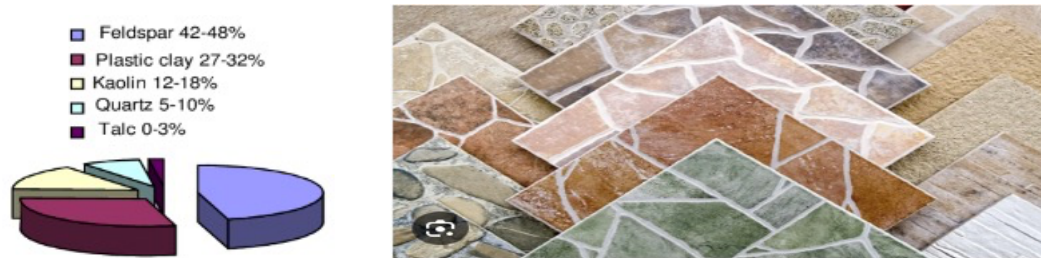


Figure 1: Composition of Floor tiles. Plate I: Floor Tile

Agricultural waste such as Doum palm (*Hyphaene thebaica*) shell is unexploited, mainly despite its abundance in northern Nigeria and sub-Saharan Africa. These palm shells are tough, fibrous, and rich in lignocellulosic materials, making them suitable for natural fillers or reinforcements in composite production (Abubakar *et al.*, 2022). Integrating Doum palm shells into floor tile production can reduce agricultural waste and add value to an otherwise discarded resource.

This research investigates the effects of incorporating recycled plastics, glass bottles, and other composite wastes into floor tile production. The study assesses the developed tiles' mechanical, physical, and durability properties and evaluates their feasibility as sustainable construction materials. The outcome of this research can contribute significantly to waste management solutions, environmental protection, and the development of affordable, eco-friendly building materials for both urban and rural applications (Akinyemi *et al.*, 2020).

Liman *et al.* (2020) studied the use of crushed Doum palm shell (CDPS) as a partial replacement for coarse aggregate in grade 30 concrete with a water-cement ratio of 0.45. CDPS was used at 5% to 25% replacement levels. The 28-day compressive strength was 28.0 MPa at 5% and 20.2 MPa at 10%, meeting structural lightweight concrete requirements. CDPS showed higher water absorption (17.5%) and lower specific gravity (1.33) than granite, indicating lighter weight but reduced workability. Its impact value was low (1.2%), showing good shock resistance. The study recommended a maximum of 10% CDPS replacement for structural lightweight concrete, promoting the sustainable use of agricultural waste.

Murts *et al.* (2021) developed and characterised cement-based floor tiles using shredded plastic bottles, eggshells, and Portland cement. Plastic waste was collected, cleaned, and shredded into 1 mm sizes, while eggshells were cleaned, boiled, dried, crushed, and sieved to 1 mm. Ordinary Portland cement served as the binder. Ten mix ratios of cement, eggshells, and plastic were prepared with a water-cement ratio of 0.6, alongside a control sample made from cement, sand, and aggregate in a 1:2:3 ratio. Tiles were cast in 150 mm × 150 mm × 20 mm moulds, cured for 7 and 28 days, and tested for physical, mechanical, and chemical properties. The optimal mix ratio was 1:2:1 (cement: eggshell: plastic), yielding a density of 2120 kg/m³, water absorption of 0.45%, fire resistance of 12.15%, chemical resistance of 0.45%, compressive strength of 53 N/mm², and impact resistance of 1.25 m. Results showed that increasing eggshell and cement improved density, fire, and chemical resistance, while plastic reduced water absorption.

Omsibi *et al.* (2021) studied shredded polyethylene terephthalate (PET) waste as a binder to fully replace cement in floor tile production by combining it with fly ash and river sand. PET waste

collected from recycling centres was heated to 230°C, melted, and mixed with river sand at varying PET: sand ratios of 100%, 90%, 70%, 50%, and 30%. The mixture was homogenised, poured into 5 cm thick lubricated iron moulds, demoulded after one hour, cooled, and cured for 48 hours at ambient temperature. Tests were conducted on particle size distribution, silt, clay, dust content, relative density, porosity, water absorption, flexural, and compressive strength. Results showed that tiles made with 30% PET and 70% river sand achieved the highest density, flexural, and compressive strength, surpassing conventional cement concrete after 28 days of curing. This mix also exhibited low water absorption, making it suitable for waterlogged and frost-prone environments. The study concluded that PET waste can effectively serve as a binding agent for complete cement replacement in floor tiles, with an optimum limit of 30% PET content to ensure superior strength, durability, and eco-friendliness.

Ashish *et al.* (2022) developed floor tiles using waste plastics, specifically low-density polyethylene (LDPE) and high-density polyethylene terephthalate (HDPE), as matrix and binding agents, with silica sand (150 µm) as filler. Waste plastic bags and bottles were collected, cleaned, dried, shredded, and mixed with sand in three different compositions: S1 (50% LDPE + 50% sand), S2 (50% HDPE + 50% sand), and S3 (50% LDPE + 20% PET + 30% sand). The mixtures were heated to the melting point of the plastics and homogenised, then cast using static compaction under 20.7 MPa pressure. After moulding, the samples were finished to the required dimensions for testing. The silica sand used had a bulk density of 1730 kg/m³ and a specific gravity of 2.65. Test results showed that sample S2 achieved the highest mechanical properties, with compressive strength of 46.20 N/mm² and flexural strength of 6.24 N/mm², demonstrating that HDPE combined with sand offers the best strength performance among the mixes.

2. Materials and Methods

2.1. Materials and Equipment

The materials required for this research include waste plastic bottles, water, glass waste, silica sand, and Doum palm shell, which were processed to produce composite floor tiles. The equipment used comprises a two-roll mill (Allen-Bradley, Model 802T-WS1P) for compounding the composite, an electronic hydraulic press (Model No. 3851-0) for pressing the mixture into moulds, and a shredding machine for reducing plastic and glass waste into workable sizes. Testing and analysis were conducted using a Cat NV412 Charpy Impact Testing Machine for impact resistance, a Rockwell Universal Testing Machine (Type 8187.5 LKV, Model B) for evaluating compressive and flexural strength, and a standard set of sieves (150 µm) for controlling particle sizes during material preparation.

2.1.1. Sample collection and preparation

The plastic bottles, glass waste, and doum palm shells were sourced from Muda Lawal Market in Bauchi, while silica sand was obtained from Azare, Katagum Local Government Area of Bauchi State. The plastic bottles and glass waste were manually sorted to remove contaminants (Murts *et al.*, 2021). The doum palm fruits were cleaned by removing the edible parts and kernels, then oven-dried for 24 hours. The shells and short fibres were crushed, ground into powder, and sieved using a 150 µm mesh. These particles served as reinforcement and were mixed with crushed plastics, glass, silica sand, and water until a uniform mixture was achieved (Liman *et al.*, 2020; Murts *et al.*, 2021). Plastic and glass bottles were manually sorted based on type, colour, and quality. Contaminants such as food residues, labels, caps, and non-recyclables were removed to ensure material purity (Murts *et al.*, 2021).

The sorted materials were washed with purified water and a salt solution. The process involved an initial rinse to remove surface dirt and soaking and scrubbing in warm saltwater to eliminate stubborn residues. A final rinse with clean water was performed to ensure that all contaminants were removed, thereby improving the quality of the end product (Murts *et al.*, 2021).

2.1.2. Shredding of plastic bottles and glass waste

An industrial shredding machine reduced the shredded plastic bottles and glass waste into smaller, manageable particles. This process increased the surface area of the materials, making them

easier to incorporate into floor tiles and interlocking bricks. The machine, equipped with sharp blades and powerful motors, crushed the plastic into fine fragments for uniformity. Simultaneously, sand, white clay, and other particulate materials were sieved using a 150 μm mesh to remove large particles and impurities. This ensured that only finer particles were retained, improving the consistency and quality of the final mixture (Omsibi *et al.*, 2021).

2.1.3. Production of the mould

Due to their durability and heat resistance, the mould used for shaping the bricks and tiles was fabricated from 18-gauge mild steel (MS) sheets. The mould was manufactured by cutting and welding MS plates into a cavity size of 100 \times 100 \times 10 mm. Additionally, a hammer was produced to apply vertical pressure to compact the molten mixture. The internal surfaces of the mould were treated or polished to prevent sticking and to enable easy release of the product after cooling (Omsibi *et al.*, 2021; Ashish *et al.*, 2022).

2.1.4. Preparation of composite materials

The composite material was prepared by blending doum palm shell particles, which were sieved using a 150 μm mesh. Other composite materials including water, doum palm shell, silica sand, plastic waste, and glass waste, were measured according to the following extended mix ratios by weight: Sample A consisted of 60% plastic, 15% doum shells, 15% glass, and 10% silica sand; Sample B contained 50% plastic, 20% doum shells, 20% glass, and 10% silica sand; Sample C was made up of 45% plastic, 25% doum shells, 15% glass, and 15% silica sand; Sample D comprised 40% plastic, 30% doum shells, 15% glass, and 15% silica sand; Sample E had 35% plastic, 35% doum shells, 10% glass, and 20% silica sand; and Sample F included 30% plastic, 25% doum shells, 25% glass, and 20% silica sand. These materials were also sieved and blended with polypropylene using a two-roll mill set at 230 $^{\circ}\text{C}$ and 45 rpm. The molten polypropylene and other components were cross-mixed until a uniform mixture was achieved. The resulting composite blend was then removed from the mixer and compressed using an electrically heated hydraulic press at a mould size of 100 \times 100 \times 10 mm under a pressure of 8 MPa. The pressed samples were allowed to cool to room temperature before removal from the mould, as shown in Figure II. Finally, the composite test specimens were subjected to mechanical, physical, and thermal characterisation (Samuel *et al.*, 2019; Omsibi *et al.*, 2021).

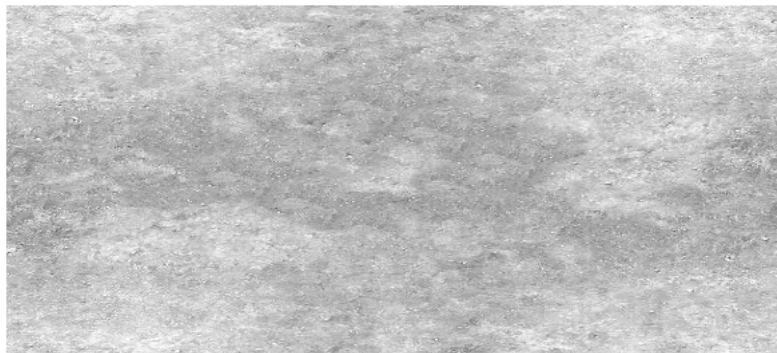


Plate II: Pressed Composite Tile Samples After Molding and Cooling

2.1.5. Mechanical properties

Mechanical properties describe how floor tile materials respond to forces like impact, hardness, flexural, compressive, and tensile strength. Key properties ensure the tiles resist cracking, breaking, and surface damage during use. These properties help guarantee the durability, strength, and suitability of floor tiles made from recycled plastics, glass waste, doum palm shells, and silica sand for construction applications.

Determination of Impact Strength Property

The impact tests on the formulated composite samples were conducted using Cat. NV. 412. Standard notched samples of 80 \times 10 \times 10 mm with a 2 mm notch depth were prepared according to ASTM D2000, set at an angle of 45 $^{\circ}$. Three specimens for each composition were tested, and the average impact strength was recorded in Joules (J). The impact strength was calculated using Equation (1) (Samuel *et al.*, 2019).

$$I = \frac{E}{A} \quad (1)$$

Where I is the impact strength, E is the energy absorbed (J), and A is the area of the specimen (m²). The impact energy values of the composites developed with different lay geometries were recorded during the impact tests.

Determination of Hardness Properties

The hardness test was performed according to ASTM E18 using an Indentation Universal Hardness Testing Machine. Three readings were taken on each sample, and the average value was recorded (Samuel *et al.*, 2019).

Determination of Flexural Strength Properties

Flexural tests were conducted on rectangular specimens prepared to ASTM D790 standards, with dimensions of 125 × 12.7 × 3.2 mm. The specimens were tested using a universal testing machine with a support span length of 100 mm and a loading speed of 5 mm/min (Aboshora *et al.*, 2017; Samuel *et al.*, 2019).

Determination of Compressive Strength Property

Compressive strength tests were performed on specimens prepared according to ASTM D3410, measuring 10 × 10 × 20 mm. The tests were performed using the RT30 Electro-mechanical Alliance testing machine with capacities ranging from 20 KN to 200 KN. Axial loads were applied to determine the compressive strength in axial and radial directions (Hany *et al.*, 2017; Samuel *et al.*, 2019).

Determination of Tensile Strength Properties

According to Hany *et al.* (2017), the tensile strength test is the maximum stress a material can withstand when stretched or pulled before breaking. The tensile strength is usually found by performing a test and recording the engineering stress versus strain. According to Adamu and Baba (2021), the test specimen was prepared in the form of a dumbbell shape with dimensions (165 × 19 × 3) mm, and a gauge length of (50) mm. A 5mm/min crosshead speed was chosen and prepared according to the ASTM D 638 standard. The specimen was subjected to a tensile test using the universal testing machine. The tensile force was recorded as a function of the increase in gauge length.

Physical properties

Physical properties such as water absorption and density are critical in determining the quality and durability of floor tiles. Water absorption measures how much moisture a tile can absorb, and low water absorption is essential to prevent weakening, cracking, or moisture-related damage, especially in wet environments. Density reflects the compactness of the material, where higher density usually indicates greater strength, durability, and lower porosity, enhancing the tile's resistance to wear, cracking, and water infiltration. For floor tiles made from recycled plastics, glass waste, doum palm shells, sand, and clay, optimising both water absorption and density is essential to ensure the tiles are strong, durable, and reliable for both indoor and outdoor applications.

Determination of Water/Moisture Absorption Properties

The water absorption test followed ISO 62 and ASTM D570 standards. 20 × 20 × 5 mm samples were oven-dried at 35°C for 8 hours, cooled in a desiccator, and weighed using an electronic scale accurate to 0.001 g. The samples were then immersed in distilled water and weighed every 24 hours after drying with tissue paper. This process continued until no further change in mass was observed. The moisture content was calculated using Equation (2).

$$M_t = \frac{(w_t - w_o)}{w_o} \times 100\% \dots (2)$$

Where; M_t is the moisture content (%), w_t is the wet weight of material before drying in the sun (g), and w_o is the weight of the material after drying in the sun (g)

Determination of Density

Density was determined by measuring the mass and volume of the samples. The mass was recorded in air using an electronic balance (model MS8001S/01) and then measured while suspended in water. The volume was obtained from the displaced water based on Archimedes' principle. The density was then calculated using Equation (3). The density of both sets of the composite increases with an increase in the weight content of the doum palm shell particles.

$$\rho = \frac{m}{v} \dots (3)$$

Where ρ is the density, m is the mass of the composite sample, and v is the composite volume (Samuel *et al.*, 2019).

2.1.6. Thermal Properties

Thermal properties refer to how well the floor tiles resist or conduct heat. Thermal conductivity tests were performed to evaluate the tiles' ability to provide insulation. Lower thermal conductivity indicates better insulation, meaning the tiles can effectively reduce heat transfer, helping to maintain stable indoor temperatures. This is particularly important for tiles made from recycled plastics, glass waste, doum palm shells, sand, and clay, as sound thermal insulation improves energy efficiency and comfort in residential and commercial buildings.

Thermal Conductivity

Thermal conductivity refers to the ability of a material to conduct heat. Low thermal conductivity is desirable for floor tiles as it indicates better insulation properties, reduces heat transfer through the floor, and helps maintain comfortable indoor temperatures. High thermal conductivity indicates that the material transfers heat quickly, making it a poor insulator and a good heat conductor. This leads to faster heat gain or loss for floor tiles, reducing energy efficiency and indoor comfort. Tiles made from recycled plastics, glass waste, doum palm shells, silica sand, and water are expected to exhibit lower thermal conductivity compared to conventional materials due to their composite nature. This makes them more energy-efficient, contributing to thermal comfort in buildings by minimising heat gain in hot conditions and heat loss in cooler environments. The composite floor tiles' thermal conductivity (k) can be calculated using Equation (4).

$$k = \frac{Q \times L}{A \times \Delta T \times t} \dots (4)$$

Where:

k = Thermal conductivity (W/m·K)

Q = Heat transferred (W or J/s)

L = Thickness of the sample (m)

A = Surface area of heat flow (m²)

ΔT = Temperature difference across the material (K or °C)

t = Time of heat transfer (s)

This Equation measures how effectively the composite tile conducts heat. Lower values of k indicate better thermal insulation, which is beneficial for maintaining indoor temperature and improving energy efficiency in floor tile applications.

3. Results and Discussion

3.1. Determination of Mechanical Properties (tensile, flexural, impact, Hardness, and compressive strengths)

The mechanical properties of materials are critical indicators of their performance, durability, and structural integrity in practical applications. In this study, composite floor tiles developed from

plastic waste, Doum palm shell, glass waste, and silica sand were subjected to standard mechanical tests to evaluate their strength and reliability. The properties examined include tensile strength, which measures resistance to pulling forces; flexural strength, indicating the ability to withstand bending; impact strength, reflecting resistance to sudden shocks; hardness, which determines surface resistance to indentation; and compressive strength, representing the material's ability to bear loads without crushing. The results of these tests provide essential data for understanding how the composite samples perform and help in optimising their formulation for use as alternative, sustainable construction materials, as shown in Table 1.

Table 1: Mechanical Properties of Composite Samples (A-F)

Sample	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength (kJ/m ²)	Hardness (Shore D)	Compressive Strength (MPa)
A (60% P, 15% D, 15% G, 10% S)	13.2	21.5	3.8	68	24.7
B (50% P, 20% D, 20% G, 10% S)	14.6	23.0	4.2	71	27.5
C (45% P, 25% D, 15% G, 15% S)	15.8	24.5	4.6	74	30.1
D (40% P, 30% D, 15% G, 15% S)	16.3	25.8	4.9	76	32.8
E (35% P, 35% D, 10% G, 20% S)	15.1	24.2	4.4	73	30.5
F (30% P, 25% D, 25% G, 20% S)	13.9	22.0	3.9	70	28.3

Table 1 presents the mechanical property results of composite floor tiles, including tensile, flexural, impact, hardness, and compressive strengths, for varying sample ratios from Samples A to F.

3.1.1. Tensile strength

Tensile strength indicates a material's ability to resist forces that try to pull it apart. It is a key factor in determining how well a composite can perform under tension, especially in structural or load-bearing applications. Sample D outperformed all other samples with a tensile strength of 16.3 MPa. This superior performance is largely due to its balanced combination of 40% plastic (providing flexibility and matrix cohesion) and 30% Doum Palm Shell (acting as strong fibrous reinforcement). The enhanced fibre-matrix bonding improves load transfer efficiency under stress, allowing the sample to endure higher tensile loads before failure.

3.1.2. Flexural strength

Flexural strength refers to the composite's resistance to bending or deformation under applied load, especially in tiles, panels, or slabs that must support weight without cracking. Sample D recorded the highest flexural strength at 25.8 MPa, indicating excellent structural integrity under flexural loads. The 30% Doum glass wpalm shell and 15% each of Glass Waste and silica sand contribute significantly to the increase in internal stiffness and stress distribution. This blend reinforces tension and compression zones during bending, resulting in a stronger, more resilient material.

3.1.3. Impact strength

Impact strength measures the energy a material can absorb from sudden or forceful blows without breaking. This property is critical in areas prone to physical shocks, such as industrial floors

or exterior tiles. Sample D achieved the highest impact strength of 4.9 kJ/m², suggesting superior toughness. The high fibre content (Doum Palm Shell at 30%) plays a key role by bridging cracks and dissipating energy through fiber pull-out mechanisms. Combined with a flexible plastic matrix, this allows the composite to absorb and recover from sudden loads without brittle failure.

3.1.4 Hardness strength

Hardness reflects the material's surface resistance to indentation, abrasion, or wear, directly affecting longevity in high-contact environments. Sample D showed the highest Shore D hardness value of 76, indicating a very hard and durable surface. The presence of 15% Glass Waste and 15% Silica Sand creates a dense, hard surface structure, while the reduced plastic content (40%) minimises surface softness. Sample D is well-suited for applications requiring long-term durability against scratching, pressure, and material loss.

3.1.5 Compressive strength

Compressive strength reveals how well a material can withstand crushing or compressive forces, a critical factor for bricks, floor tiles, and pavers. Sample D demonstrated the highest compressive strength at 32.8 MPa, indicating its excellent load-bearing capacity. The high proportion of Doum Palm Shell (30%) adds to the internal framework, while the glass and silica components (30% combined) enhance density and stiffness. This optimised combination ensures that Sample D can endure substantial vertical loads without cracking, making it ideal for heavy-duty construction.

Sample D (40% Plastic, 30% Doum Palm Shell, 15% Glass Waste, 15% Silica Sand) consistently outperformed the other samples across all evaluated mechanical properties. This superior performance is attributed to its optimised reinforcement-to-matrix ratio, providing sufficient plastic content to ensure proper binding while incorporating an ideal proportion of reinforcing fillers and fibres to enhance strength. The Doum Palm Shell fibres significantly improve tensile, flexural, and impact resistance by enhancing internal bonding and energy dissipation. Meanwhile, glass waste and silica sand reinforce the composite's surface and internal structure, resulting in greater hardness and compressive strength. This balanced formulation minimises brittleness and offers a robust combination of flexibility, strength, and durability, making Sample D highly suitable for structural and load-bearing applications in demanding environments.

3.2. Determination and Comparison of Mechanical Properties (Tensile, Flexural, Impact, Hardness and Compressive Strengths with Conventional Ceramic/Porcelain Tiles

The mechanical performance of composite floor tiles must be evaluated to determine their suitability as alternatives to conventional ceramic and porcelain tiles. Key mechanical properties such as tensile strength, flexural strength, impact strength, hardness, and compressive strength provide insight into the durability, load-bearing capacity, and resistance to deformation or failure under various conditions, as shown in Table 2. Comparing these properties with those of standard ceramic and porcelain tiles helps assess whether the developed composites can meet or exceed industry expectations for structural and flooring applications. This section presents the results of these tests and highlights the potential of the composite samples (A–F) as viable, cost-effective, and sustainable building materials.

Table 2: Comparison of Mechanical Properties of Composite Samples (A–F) with Conventional Ceramic/Porcelain Tiles

Property	Conventional Tile (Ceramic or Porcelain)	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F
Tensile Strength (MPa)	7 – 12	13.2	14.6	15.8	16.3	15.1	13.9
Flexural Strength (MPa)	20 – 40	21.5	23.0	24.5	25.8	24.2	22.0
Impact Strength (kJ/m ²)	< 2 (very brittle)	3.8	4.2	4.6	4.9	4.4	3.9

Property	Conventional Tile (Ceramic or Porcelain)	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F
Hardness (Shore D)	N/A (Mohs scale 6–7, no Shore rating)	68	71	74	76	73	70
Compressive Strength (MPa)	30 – 90 (high for ceramics)	24.7	27.5	30.1	32.8	30.5	28.3

Table 2 compares key mechanical properties between the developed composite samples (A–F) and conventional ceramic or porcelain tiles.

Conventional ceramic tiles generally exhibit tensile strengths between 7–12 MPa, making them relatively weak under tension. All composite samples (A–F) surpass this range, with Sample D exhibiting the highest value at 16.3 MPa. This indicates that the composite tiles offer significantly better resistance to tensile forces, suggesting enhanced performance in applications where tension and pulling stresses are a concern.

Ceramic tiles range from 20–40 MPa in flexural strength. All composite samples fall within the lower end of this range, with Sample D again performing best at 25.8 MPa. While still slightly below high-grade ceramics, the composite samples demonstrate acceptable bending resistance, with the added benefit of improved toughness.

Conventional ceramics are known to be very brittle, with impact strength typically less than 2 kJ/m². In contrast, the composite samples show a substantial improvement, with impact strengths ranging from 3.8 to 4.9 kJ/m². Sample D, at 4.9 kJ/m², has more than double the impact resistance of conventional tiles, making it far less likely to fracture under sudden shock or impact.

Ceramics are rated on the Mohs scale (6–7) and do not have a Shore D rating. However, comparing relative surface hardness, composite samples show Shore D values between 68 and 76, with Sample D being the hardest. While ceramics are more complex on the Mohs scale, the composite samples offer sufficient surface resistance while being less brittle, balancing hardness and durability.

Conventional ceramics have high compressive strength (30–90 MPa), making them ideal for bearing heavy loads. The composite samples approach this range, with Sample D achieving 32.8 MPa and Samples C and E exceeding 30 MPa. Although still on the lower end of the ceramic range, these values are impressive for plastic-based composites and sufficient for many structural and flooring applications.

Overall, the composite samples, especially Sample D, demonstrate mechanical properties that equal or surpass conventional ceramic tiles' tensile and impact strength, approach ceramic performance in flexural and compressive strength, and offer a durable surface hardness. Additionally, the composite tiles are likely less brittle, lighter, more impact-resistant, and potentially more sustainable due to recycled materials such as plastic waste, Doum Palm Shell, and glass waste. These advantages make them highly promising as alternative, low-cost, and durable construction materials.

3.3 Determination and Comparison of Physical Properties (Water Absorption and Density of Composite Floor Tile Samples (A–F))

The physical properties of construction materials, particularly water absorption and density, play a crucial role in determining their durability, structural suitability, and long-term performance in service conditions. Water absorption affects the tile's ability to resist moisture ingress, leading to swelling, degradation, or microbial growth, especially in humid or wet environments. Conversely, density influences the material's weight, strength, and handling ease during installation. This section evaluates the water absorption and density of composite tile samples (A–F) produced from plastic waste, Doum palm shell, glass waste, and silica sand. The results are then compared with those of conventional ceramic, as shown in Table 3, and porcelain tiles to assess whether the developed composites offer competitive or improved physical performance for practical building applications.

Table 3: Comparison of Water Absorption and Density of Composite Floor Tile Samples (A-F) with Conventional Ceramic and Porcelain Tiles

Sample	Plastic Waste (%)	Doum Shell (%)	Glass Waste (%)	Silica Sand (%)	Water Absorption (%)	Density (g/cm ³)
A	60	15	15	10	0.72	1.08
B	50	20	20	10	0.88	1.15
C	45	25	15	15	1.03	1.22
D	40	30	15	15	1.18	1.29
E	35	35	10	20	1.25	1.33
F	30	25	25	20	1.10	1.31
Conventional Tile (Ceramic/Porcelain)	-	-	-	-	0.1 - 0.5 (Porcelain) 5 - 10 (Ceramic)	1.80 - 2.40

Table 3 compares the water absorption (%) and density (g/cm³) of composite floor tile samples made from varying proportions of plastic waste, Doum palm shell, glass waste, and silica sand, alongside standard values for conventional tiles such as ceramic and porcelain.

3.2.1. Water absorption of composite tiles

Water absorption is a critical measure of a tile’s durability in humid or wet environments, and while porcelain tiles are highly water-resistant (0.1–0.5%) and ceramic tiles are more porous (5–10%), our composite samples A–F exhibit intermediate values ranging from 0.72% to 1.25%. These figures fall well below typical ceramic but above porcelain levels, reflecting improved moisture resistance due to the hydrophobic nature of plastic (highest in Sample A at 60%, yielding 0.72%), and greater porosity from higher Doum palm shell content (highest in Sample E, producing 1.25%) This indicates that higher plastic content improves water resistance, making these composites suitable for moderately wet environments. This trend mirrors findings in recent studies, where increased natural fiber content in polymer composites leads to higher water uptake due to the fibers' hydrophilicity (Chang *et al.*, 2021; Priyadarshana *et al.*, 2024). These studies also show that water absorption onset saturates around 10 days of immersion and that moisture movement is primarily driven by Fickian diffusion (Chang *et al.*, 2021). Therefore, our results demonstrate that balancing hydrophobic and hydrophilic components can yield composites with moderate water resistance suitable for indoor applications, aligning with current literature on bio-based composite panels (Li *et al.*, 202).

3.2.2. Density of composite tiles

Density reflects how compact and heavy a material is, influencing its structural strength, handling ease, and suitability for various construction applications. Conventional ceramic and porcelain tiles typically have high densities ranging from 1.80 to 2.40 g/cm³, contributing to their mechanical strength and making them heavy, increasing transportation and installation challenges. In contrast, the composite tile samples developed in this study exhibit significantly lower densities, ranging from 1.08 g/cm³ (Sample A) to 1.33 g/cm³ (Sample E). Sample A, with the highest plastic content (60%), is the lightest due to the low density of plastic, while Sample E, with higher amounts of inorganic fillers like silica sand and glass waste, is the densest among the composites. These results align with recent reviews by Singh and Patel (2024), who reported that natural-fibre-reinforced polymer composites generally fall within a density range of 1.3 to 1.5 g/cm³ due to the lightweight nature of bio-fillers such as sisal and wool. Similarly, Imon (2023) confirmed that polymer-matrix composites with low-density reinforcements reduce overall weight without significantly compromising mechanical performance. This trend reinforces the understanding that increasing filler content raises density, while increasing polymer content lowers it. Ultimately, the reduced density of the developed composites offers a practical advantage in creating lightweight, easier-to-install flooring materials that maintain adequate structural integrity, supporting their use in sustainable and cost-effective construction.

3.3. Determination and Comparison of Thermal Properties (Thermal Conductivity of Composite Floor Tile Samples (A-F))

This section evaluates the thermal conductivity of composite floor tile samples (A–F) to assess their insulation performance compared to conventional ceramic and porcelain tiles. Since high thermal conductivity in traditional tiles can lead to discomfort during cold seasons, the aim is to determine if the composites, made from plastic waste, Doum palm shell, glass, and silica sand, offer better thermal insulation, enhancing indoor comfort and energy efficiency.

Table 4: Thermal Conductivity of Composite Floor Tile Samples (A–F) Compared with Conventional Ceramic/Porcelain Tiles

Sample	Plastic Waste (%)	Doum Shell (%)	Glass Waste (%)	Silica Sand (%)	Thermal Conductivity (W/m·K)
A	60	15	15	10	0.198
B	50	20	20	10	0.226
C	45	25	15	15	0.244
D	40	30	15	15	0.261
E	35	35	10	20	0.254
F	30	25	25	20	0.269
Conventional Tile (Ceramic/Porcelain)	–	–	–	–	0.60 – 1.50

Table 4 presents the thermal conductivity of composite floor tile samples (A–F) material, indicating its ability to transfer heat, and lower values are desirable for improving insulation and indoor thermal comfort. Conventional ceramic and porcelain tiles, with thermal conductivity values ranging from 0.60 to 1.50 W/m·K, tend to conduct heat efficiently, making them feel cold during winter and increasing energy use for heating. In contrast, the composite tile samples (A–F) developed in this study exhibit significantly lower thermal conductivity values, ranging from 0.198 W/m·K (Sample A) to 0.269 W/m·K (Sample F), indicating superior insulating properties. Sample A, with the highest plastic content, showed the lowest thermal conductivity due to the plastic’s naturally low heat transfer rate. At the same time, the gradual increase in fillers such as glass waste and silica sand contributed to slightly higher but still lower-than-ceramic values in other samples. This trend aligns with Ben Helal et al. (2023) findings, who observed that polymeric foams and plastic-based composites can achieve low thermal conductivity due to their amorphous structure and poor heat conduction pathways. Similarly, Alazzawi et al. (2023) highlighted the effectiveness of natural fibre-reinforced composites for building insulation, reporting values as low as 0.05–0.10 W/m·K when using high bio-fibre content. These insights support the thermal performance of the composite tiles developed in this work. This research aims to create sustainable and low-cost alternatives to conventional tiles and reduce cold-floor effects during winter, thereby enhancing thermal comfort in living spaces and contributing to lower heating costs in energy-conscious buildings.

4. Conclusion

The composite floor tile samples (A–F), formulated from plastic waste, Doum palm shell, glass waste, and silica sand, showed excellent mechanical, physical, and thermal performance. Sample D emerged as the best overall, exhibiting superior mechanical properties with a tensile strength of 16.3 MPa, flexural strength of 25.8 MPa, impact strength of 4.9 kJ/m², hardness of 76 Shore D, and compressive strength of 32.8 MPa. In terms of physical properties, Sample A, which contains the highest plastic content (60%), showed the lowest water absorption (0.72%) and lowest density (1.08 g/cm³), making it lightweight and highly moisture resistant. For thermal performance, Sample A also recorded the lowest thermal conductivity (0.198 W/m·K), indicating excellent insulation capability compared to conventional ceramic/porcelain tiles (0.60–1.50 W/m·K). These results confirm that the composites offer a durable, water-resistant, lightweight, and thermally efficient alternative to traditional tiles, making them ideal for sustainable and energy-conscious construction.

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Recommendations

i. Based on the superior mechanical, physical, and thermal performance, the composite tiles, particularly Sample D for strength and Sample A for insulation, are recommended for indoor flooring, especially in residential and institutional buildings where lightweight, durable, and thermally comfortable materials are preferred.

ii. Given their low thermal conductivity, especially in Sample A ($0.198 \text{ W/m}\cdot\text{K}$), these composites are highly recommended for deployment in cold or temperate regions, where maintaining indoor warmth and reducing heating energy costs is essential.

iii. While the composites performed well under controlled conditions, long-term durability testing in outdoor environments (exposure to UV, rainfall, and freeze-thaw cycles) is recommended to evaluate their suitability for external applications such as walkways or patios.

iv. Further optimisation by fine-tuning the ratio of plastic, Doum shell, and fillers is recommended to tailor specific properties, such as improving mechanical strength and thermal insulation in a single formulation.

v. It is recommended that the most promising formulations (especially Samples D and A) be produced at pilot scale for real-world testing and cost analysis to assess their commercial viability and scalability in the construction industry.

vi. Policymakers and builders should consider integrating these eco-friendly tiles into green building standards and affordable housing programs, due to their use of recycled materials and potential to reduce environmental impact.

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