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Transforming Plastic Waste into Durable Tiles: A Sustainable Recycling Approach

Om Parkash[1], Inamullah Maitlo[1], Safdar Ali[1], Sikandar Ali[2], Abdul Ghazi[1], Mahnoor Fatima[1] Ali Mehdi[1], Amjad Ali Jatoi[3*].

[1] Department of Metallurgy and Materials Engineering, Dawood University of Engineering and Technology, Karachi, Sindh, Pakistan

[2] Department of Basic Science and Humanities, Dawood University of Engineering and Technology, Karachi, Sindh, Pakistan

[3] Electrical Engineering Department, National Sun Yat-sen University, Taiwan

***Corresponding Author:** D133010003@nsysu.edu.tw

ABSTRACT

With the harmful impact of plastic waste on the environment, there is a growing need to utilize products fabricated from recycled plastic. This project aims to utilize LDPE waste to produce tiles. There are engineering and environmental benefits in utilizing plastic waste for the manufacturing of tiles. The improper treatment and disposal of non-biodegradable plastic waste is huge concern in most developing countries. LDPE plastic waste was heated at temperatures ranging from 180°C to 250°C.

Plastic waste tiles proved to be stronger, durable and cost-effective as the raw materials used is trash. The discarded plastic waste directly discharged into the environment without any proper disposal. However, their non-biodegradable state, they are a significant threat to the environment. Recycling plastic waste into other products minimizes its size and effect. The Plastic tile samples have been tested for density, Tensile Strength, Elongation, Melt flow Index, and Hardness according to ASTM Standard Testing procedures.

Key Words: Plastic waste, Durable Tiles, Sustainable Recycling Approach, Construction materials, Circular Economy.

GRAPHICAL ABSTRACT

1. INTRODUCTION

Any product that is useless and of no economic value to its owner is referred to as waste. Waste is either solid, liquid, or gas according to its state. After being used, plastic becomes a material that is harmful to the environment and the organisms in it. Wastes are categorized under four classes: radioactive, medical, toxic, and municipal wastes (Chaturvedi & Singh, 2021; Karedla, Schuster, & Shaik, 2024). It is important to note that, for the purpose of disposal, gaseous waste in a sealed vessel is considered solid waste. Polymers are long chains of organic molecules called monomers and are the monomers of synthetic and semi-synthetic plastics. Polymerization is a chemical process that results in these polymers (Hazzan, 2003). The two major types of plastics are the thermosetting polymers and the thermoplastics. Thermoplastics can be melted and reshaped over and over even when they have already solidified since they do not chemically change when heated. Thermosetting polymers, however, become permanently deformed and cannot be reshaped once heated, since they become chemically changed in an irreversible manner when heated. Since they are cheaper, light, and long-lasting compared to most other materials, they are extensively utilized. Research into alternative approaches for effectively reducing plastic waste is increasingly becoming indispensable because of the environmental impacts associated with improper plastic waste disposal (Hopewell, Dvorak, & Kosior, 2009). It is estimated, according to scientists, that it requires 300 years for the 15.342 tonnes of plastic waste produced every day to fully burn. This is a serious threat to human life and the environment. Waste incinerators that bum plastic waste at extremely high temperatures have been used for disposal for many years (Hopewell et al., 2009; Mohammad & Lina, 2007). But the gases released at this stage contaminate air and water and are very lethal to human beings (Ruj, Pandey, Jash, & Srivastava, 2015). The gases also affect a great population of people, making them vulnerable to many diseases(Pati & Dash, 2022). Based on the researchers, plastic waste will remain on our planet for more than 5000 years if not disposed of immediately without being degraded (Hopewell et al., 2009; Mohammad & Lina, 2007; Pati & Dash, 2022; Ruj et al., 2015) . Plastic is being widely explored as a filler material for various applications due to some valuable characteristics like lightweight, easy availability, low density, surface morphology, chemical inertness, thermal resistance, great workability and large surface area (Dhawan, Bisht, Kumar, Kumari, & Dhawan, 2019; Kumar, Rajadurai, & Muthuramalingam, 2018) .

Yazoghli Marzouk et al. discovered that since the volume percentage of plastic waste in concrete is less than 50%, its compressive and flexural strength is not impacted (Marzouk, Dheilly, & Queneudec, 2007). The duration to manufacture a plastic tile is shorter compared to manufacturing a cement tile. Plastic tiles have very little weight and are easy to manoeuvre. The plastic tiles are also recyclable. The size of plastic tiles also can be altered by heat it and shape it into desired form (Gardner, 2016). So, this project is to produce tiles using 100% recyclable High-Density Polyethylene (HDPE) plastic bottles. The time required for production of plastic tiles is only in a 1 hour compared to regular ceramic tiles. It is also extracted from waste product and converting them into a beneficial product. Without branching, a more densely packed structure with higher chemical resistance is created than with LDPE. HDPE is more opaque, harder, and able to withstand temperatures up to 120 °C (de Almeida Azzi et al., 2016; ENGINEERS, 2014; Kathiravan, Nasrulla, & Saravanan; Soni et al., 2023). Research indicates that the dry density of concrete is generally decreased when waste plastic is used with 10, 15, and 20% plastic aggregates instead of fine aggregates (Ismail & Al-Hashmi, 2008). Regardless of the size, shape, or kind of plastic waste utilized as aggregates, this is true. Utilizing plastic waste in concrete has the advantage of reducing the material's weight per unit, but it also lowers the material's compressive and tensile strengths (Siddique, Khatib, & Kaur, 2008; Tahir, Sbahieh, & Al-Ghamdi, 2022). Tiles and other building materials are now made using polyethylene terephthalate (PET) bottles as binders. One recycled material that has drawn a lot of interest from the construction sector is shredded plastic waste (Laryea & Leiringer, 2012). Researchers has also investigated the viability of combining wood dust and plastic waste to create environmentally friendly door panels (Huang, Lu, Ding, & Pan, 2022; Yang et al., 2012). In one study, Al-Hadithi and Hilal made roof tiles out of shredded PET waste and found that as the volume of PET increased, the sample's compressive strength decreased (Al-Hadithi & Hilal, 2016). The non-biodegradability of plastic waste makes management more difficult (Amadi, Eze, Igwe, Okunlola, & Okoye, 2012).

When compared to regular tiles, the tiles made from plastic waste are incredibly affordable and long-lasting. As recycling technologies have advanced over the past few years, the amount of plastic waste that is reused has increased (Guy, 1997; Kalali et al., 2023). Polymers have a number of key characteristics that make them extremely useful in building construction, playing an important part in contemporary building technology. Their strength and resistance to corrosion allow for a longer life of material, particularly in rough conditions, while their great insulation capability saves energy by suppressing heat, cold, and sound transmission. Polymers are also light, which decreases structural load and facilitates transportation and assembly. Polypropylene (PP) is a versatile thermoplastic known for its high melting point, lightweight nature, and resistance to chemicals (Zambrano, Tamarit, Fernandez, & Barreneche, 2024). It is used in packaging, textiles automotive parts, and more. It can be recycled and has a relatively low environmental impact. However, it can be brittle at low temperatures and is susceptible to UV degradation. High-density polyethylene (HDPE) is a type of thermoplastic polymer. It is commonly used in various application due to its strong and durable nature. HDPE is made from petroleum, and it is known for its high strength-to-density ratio, which means it is lightweight yet resilient. It has a high melting point, excellent chemical resistance, and good electrical insulation properties (Lourmpas et al., 2024; Olam, 2023). HDPE is often used in the manufacturing of pipes, container, bottles plastic that require toughness and resistance to environmental factors. They are also cost-effective because of their lower price and longer life, and their minimal maintenance needs—such as the need for less painting—provide even more added value (Ireh, Ajah, & Orie, 2025). Polymers are clean, simple to clean, and may be processed and installed with minimal labor. These benefits have contributed to extensive application of different types of plastics in construction such as Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Polyvinyl Chloride (PVC), Low-Density Polyethylene (LDPE), Polypropylene (PP), and Polystyrene (PS), each of which provides distinct properties optimized for uses.

2. MATERIAL AND METHODS:

2.1 Materials

Plastic waste bottles and caps of different colours has been used as raw material for converting into construction tiles.

2.2 Method of transforming plastic waste into Tiles:

The LDPE plastic waste such as water bottle caps were collected from various places, which are high density polyethylene (PP). The caps were washed properly using commonly available detergent to remove impurities such as dirt, dust and labels.

The caps of the sterilized bottles were reduced to uniform sizes, about 5 mm, using an industrial plastic shredder to facilitate uniform melting. In third step, A gas stove was utilized as the heat source for the LDPE waste liquefaction and shredded material was placed in container but not directly heated to avoid irregularities during melting process. This happens because it melts the bottom portion properly and top one remains uneven, causing the formation of lumps, which leads to deterioration of material properties such as strength, durability, reduced performance, leading to defects and failure points. The equipment was mounted in a an adequately aerated atmosphere to allow for the safe release of any vapours produced during the melting process. In order to avoid such problems, steel sheet was used to transfer uniform heat and obtain homogenous material. The melting operation was monitored very closely, and the plastic was stirred constantly with the help of stainless steel.

steel rod to reach a homogeneous, liquid without overheating in certain areas. A digital infrared thermometer was employed in measuring the thermal condition of the plastic to maintain it within the best range. The molten material was then poured into the desired pentagon steel mould get the desired shape and length of the tiles. Before pouring the molten material to the mould, it was preheated to improve plastic flow, prevent thermal shock, reduce cycle time, improve surface finish, and prevent mould condensation, resulting in better quality. Once the molten material was poured into the mould, it was pressed slowly to get the shape of the mould. Applying pressure to the molten plastic when pouring it into the mould ensures complete filling, improves surface replication, reduces defects, and aids in efficient cooling. Once the mould is completely prepared the mould is cooled either by air cooling or left in open atmosphere. The process scheme of sustainable tile for construction materials is shown in Figure 1.

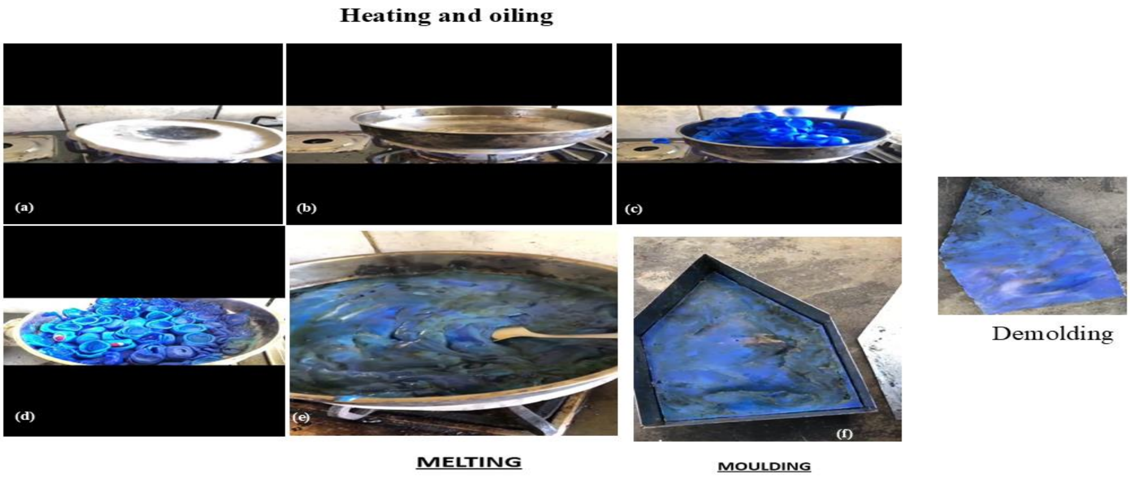

Figure 1. Process Flow diagram for Plastic waste Recycling into Sustainable Tiles.

2.3 Methods and Testing Tools:

A range of standardized testing tools and equipment, all conforming to ASTM (American Society for Testing and Materials) requirements, were utilized to determine the mechanical and physical properties of the plastic specimens. Each instrument has a specific purpose and provides data on the quality and performance of the plastic material under different conditions.

2.4 Polymer Testing Equipment for ASTM Standards:

2.4.1 Density Measurement (ASTM D792):

The density of a plastic material, as determined by ASTM D792, is calculated using the formula:

Density (ρ) = Mass (m) / Volume.

2.4.2 Tensile Testing (ASTM D638)

The Tensile testing denotes the maximums stress applied to specimen where it can resist, stretch or pull before breaking. The Ultimate tensile strength was calculated by using the following formula:

$$\text{Tensile strength} = \frac{\text{Maximum force}}{\text{Original cross} - \text{sectional area}}$$

2.4.3 Melt Flow Index (ASTM D1238):

The Melt Flow Index (MFI) for plastics is calculated using the formula:

MFI = Weight of extrudate (g) / Time (10 min).

Table 1. Details of Polymer Testing Equipment used in plastic waste Tiles characterization.

2.4.4 Percent (%) Elongation

The elongation % can be expressed as the stretch percentage (original length and stretched length) where the specimen stretches up to certain maximum limit before breaking point. The elongation (%) was measured by following equation:

$$\text{Elongation (\%)} = \frac{L_f - L_o}{L_o} x100$$

where, L_f represents the final length of specimen and L_o is the original length.

Equipment and Test	Model	Manufacturer	Key Specifications
Digital Density Meter	DMA 4500M	Anton Paar	0–3 g/cm³, ±0.00001 g/cm³, oscillating tube
ME204E Analytical Balance	ME204E + kit	Mettler Toledo	0.001–99.999 g/cm³, ±0.0001 g/cm³, hydrostatic
Universal Testing Machines	Instron 5566, Instron EZ 250 AMETEK		10 kN load cell, 0.001–1000 mm/min, ±0.5% acc. 250 N capacity,
Melt Flow Index Tester	MP1200	Tinius Olsen	125–400 °C, 0.325–21.6 kg load, ±2% accuracy
Digital Shore D Hardness	DD-5 Digital	Rex Gauge Co.	0–100 Shore D, ±1 unit accuracy, digital display

2.4.5 Hardness Test (ASTM D2240):

The Hardness (Rockwell) Test was performed to calculate the permanent deformation of specimen and Rockwell hardness tester was used. The Rockwell hardness (HR) was calculated by following formula:

$$\mathbf{HR= N-(d/D)}$$

where applied load denoted by N, Indentation depth denoted by d (mm), Ball diameter diamond cone width denoted by D (mm).

3. RESULT AND DISCUSSION

Tests were performed in accordance to ASTM standard: D792 for density, D638 for tensile elongation, D1238 for melt flow index, and D2240 for hardness.

3.1 Tensile strength and Elongation analysis of plastic waste LDPE tiles

The tensile strength values of the three LDPE samples showed minimal variation as shown in Figure 2, ranging between 128 MPa and 131 MPa. Sample 3 exhibited the highest tensile strength (131 MPa), followed closely by Sample 1 (130 MPa), while Sample 2 showed the lowest value (128 MPa). The variation among the samples is within a narrow range of ±1.5% from the mean tensile strength (approximately 129.67 MPa), indicating good consistency and uniformity in material properties. This suggests that the processing conditions and material formulation were well-controlled, resulting in reproducible mechanical performance. Such closely grouped tensile strength values also indicate that the LDPE samples maintain their structural integrity under tensile loads, making them suitable for applications requiring moderate strength and flexibility, such as packaging films, liners, or insulation materials.

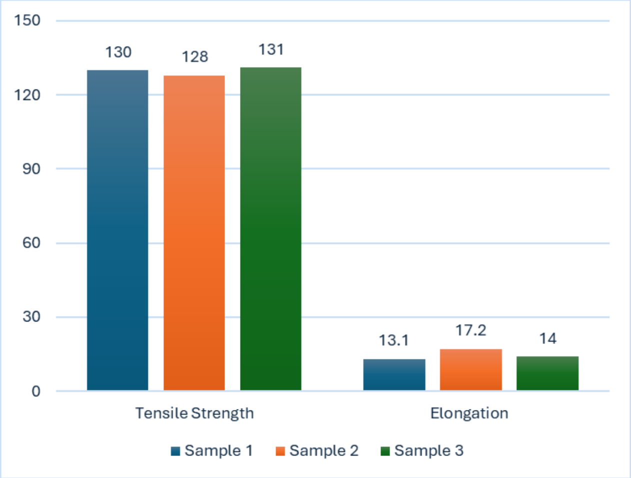

Figure 2: Tensile strength and Elongation analysis of plastic waste tiles.

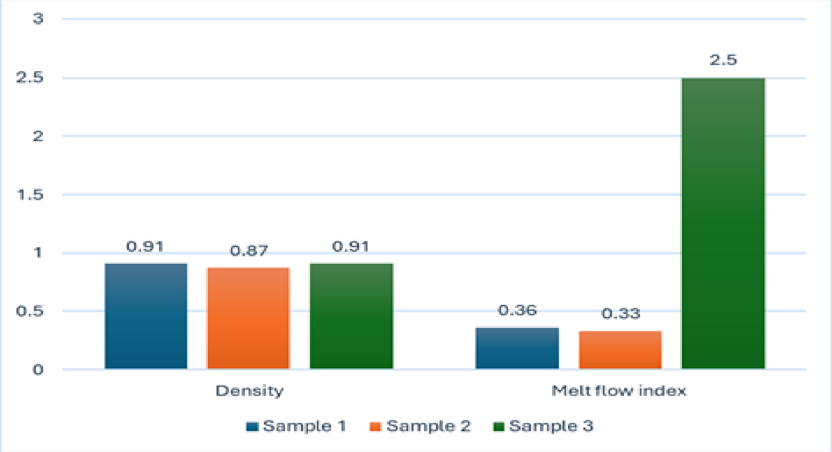

Figure 3: Density and Melt flow Index analysis of plastic waste tiles.

3.2 Density and Melt flow Index analysis of plastic waste LDPE tiles

The analysis of the given density and melt flow index (MFI) results for LDPE (Low-Density Polyethylene) samples were shown in figure 3. The typical density range of LDPE is 0.910–0.940 g/cm³, which reflects its highly branched molecular structure and low crystallinity. The Samples 1 and 3, with densities of 0.91 g/cm³, fall within the expected range and indicate a standard LDPE structure with moderate chain branching and crystallinity, whereas, Sample 2, with a density of 0.87 g/cm³, is notably lower than the typical LDPE range. This reduced density suggests a higher degree of molecular branching, leading to decreased crystalline regions and increased amorphous content with possible inclusion of lighter additives, impurities, or processing differences that disrupted polymer packing.

3.3 Hardness comparison of plastic waste LDPE Tiles:

ASTM D2240 is the standard test method for rubber property-durometer hardness, and it is widely applied to polymers, elastomers, and plastics. In this case, the Shore D scale is used, which is appropriate for harder plastics including rigid thermoplastics like LDPE when modified or compounded. The test results of 70–72 Shore D for the plastic waste LDPE tiles indicate a significantly higher surface hardness compared to virgin LDPE, suggesting structural modification due to: Reprocessing effects, such as crosslinking or oxidative stiffening during recycling, Blending with stiffer polymers or fillers (e.g., HDPE, calcium carbonate, or other inorganic materials) and Compaction and pressure molding, which can enhance densification and reduce surface elasticity.

4.4 Comparative Evaluation Sample Failure

Figure 5 and table 2 shows comparative analysis of tiles sample under tensile strength expressed in kg/cm² and the failure load is calculated on a 1 cm² cross section area.

The tensile test the results showed 130 kg/cm², 128 kg/cm² and 131 kg/cm² of sample 1, sample 2 and sample 3 accordingly wich indicate that all three samples have similar strength indicating excellent mechanical resistance to tensile failure.

Moreover, according to the results, sample 3 have highest tensile strength, of 131 kg/cm² while sample 2 have lower tensile strength of 128 kg/cm² but have highest elongation 17.2% indicating excellent ductility and flexibility suitable for application where deformation and strength involve. However, Sample 1 shows high tensile strength between sample 2 and 3 which is 130 kg/cm² and show the highest hardness (72 shore D) as shown in previous table. This suggests better rigidity and surface resistance

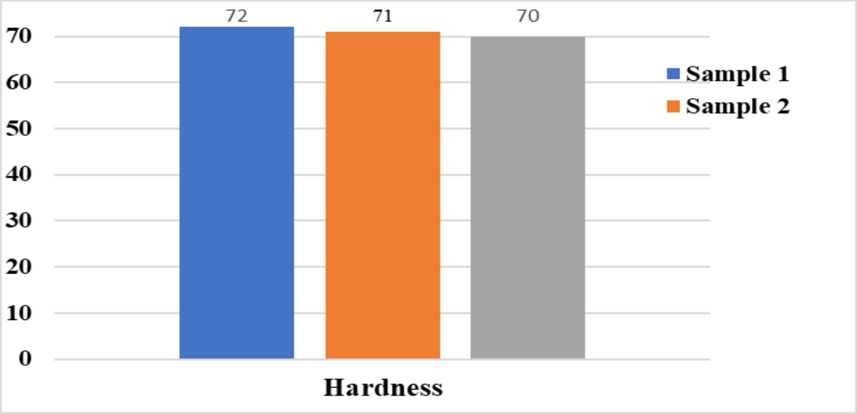

Figure 4 Hardness comparison of plastic waste tiles.

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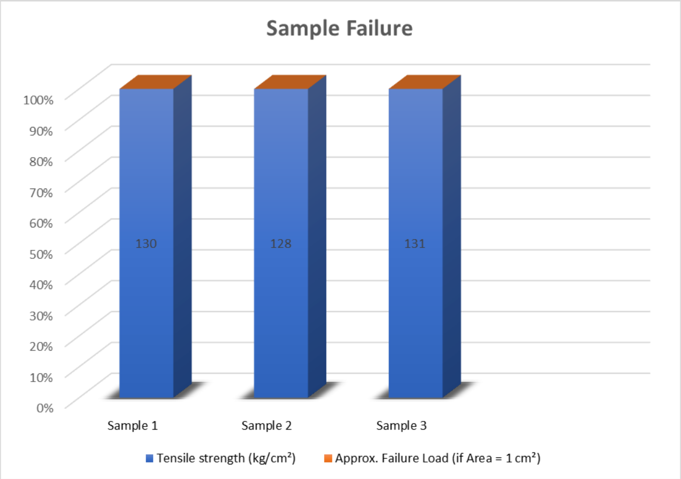

Figure 5 Comparative evaluation of sample failure

Table 2 Combined results of mechanical properties.

S. No.	Test	Unit	Result	ASTM Standard
Sample 1				
	Density	g/cm³	0.91	D792
	Tensile Strength	kg/cm²	130.0	D638
	Elongation	%	13.1	D638
	Melt Flow Index @ 190°C & 2.16kg	g/10 min	0.36	D1238
	Hardness	Shore D	72.0	D2240
Sample 2				
	Density	g/cm³	0.87	D792
	Tensile Strength	kg/cm²	128.0	D638
	Elongation	%	17.2	D638
	Melt Flow Index @ 190°C & 2.16kg	g/10 min	0.33	D1238
	Hardness	Shore D	71.0	D2240
Sample 3				
	Density	g/cm³	0.91	D792
	Tensile Strength	kg/cm²	131.0	D638
	Elongation	%	14.0	D638
	Melt Flow Index @ 190°C & 2.16kg	g/10 min	2.50	D1238
	Hardness	Shore D	70.0	D2240

4. CONCLUSION

The research explores the utilization of LDPE (Low-Density Polyethylene) plastic waste for manufacturing tiles and bricks, presenting an innovative approach to address the environmental challenges posed by plastic waste accumulation. The study emphasizes the need for sustainable alternatives to traditional construction materials and highlights the engineering and environmental implications of incorporating plastic waste in tile production for recycling and reducing environmental impact of pollution.

The data reflects variability in polymer structure and processing behaviour among the LDPE samples. Sample 3 is more processable but likely weaker mechanically, while Sample 2 shows an anomalous combination of low density and low MFI, warranting further investigation. Such variations can critically influence the suitability of each sample for specific industrial applications such as packaging, moulding, or film manufacturing.

The hardness results of the plastic waste LDPE tiles (72, 71, and 70 Shore D) indicate significantly enhanced surface rigidity compared to conventional LDPE. The close values across all three samples confirm process reliability and material consistency. The increased hardness likely results from material modification during recycling, making these tiles potentially suitable for durable, load-bearing, or high-traffic applications.

Based on ASTM D2240 testing, the Shore D hardness values of 70–72 for the plastic waste LDPE tiles reflect a significant increase in rigidity compared to standard LDPE. The results suggest that material modifications during recycling, such as filler incorporation or thermal reprocessing, have enhanced surface hardness. The low variability between samples confirms process uniformity, making the recycled LDPE tiles potentially suitable for structural, construction, or high-wear applications. The study asserts that plastic waste, when used as a binding groundmass in tile production instead of cement, offers a viable solution to the environmental problems associated with non-biodegradable plastic waste.

Comparing the cost and properties of plastic waste tiles with concrete tiles, the research suggests that plastic tiles are stronger, tougher, more economical, and resistant to heat and corrosion. The findings indicate that these plastic tiles could serve as a better alternative to traditional cement tiles, contributing to environmental sustainability and reduced plastic waste in landfills.

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