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Research Article

Beyond Concrete: Resilient Pavers from Municipal Waste

Somendra Nath Roy[1]*, Arnab Hazra[2], Sayan Roy[3] and S Sarkar Roy[4]

[1]*Dept of Civil Engineering, School of Engineering & Technology, Swami Vivekananda University, India*

[2]*M/s Glass Wall Systems (India) Limited, 503-504, 5th Floor, A-Wing, Marathon Futurex, Mafatlal Mills Compound, N. M. Joshi Marg, India*

[3]*M/s Webomates Pvt. Ltd., 7/A Dakshin Para Road, Pubali Apartment, India*

[4]*Investment Associate, Energy Div., AIIB HQ, Asia Financial Centre, China*

***Corresponding author:** Somendra Nath Roy, Dept of Civil Engineering, School of Engineering & Technology, Swami Vivekananda University, India.

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Abstract

The global construction industry has a significant environmental footprint, largely due to the energy-intensive production of cement, a primary binding material in concrete. Simultaneously, in India grappling with an annual plastic waste generation of nearly 7 million tonnes, this study presents a paradigm shift for the construction industry by transforming a persistent pollutant into a valuable resource. This study investigates the feasibility of manufacturing eco-friendly paver blocks using waste plastic as a binding agent, partially or fully replacing traditional cement. By incorporating waste plastic with sand and fly ash, this research not only mitigates the long-term environmental and pollution concerns posed by plastics but also offers a sustainable, low-cost alternative to conventional paver blocks. The fabricated blocks were subjected to rigorous performance testing, with results demonstrating favourable mechanical properties and significant environmental benefits and the results were compared against existing data in the literature. This research presents a technically viable and economically attractive method for diverting plastic waste from landfills into functional, sustainable construction materials, thereby, contributing to a more circular and resource-efficient economy.

Keywords: Paver blocks, Plastic waste, Fly ash, Sustainable construction, Recycling, Waste valorization

Application of the work

Plastic pollution has become a major global concern, intensified by the absence of efficient local recycling systems. A cost-effective and simple technology has been introduced to transform mixed plastic waste into construction-grade materials. This research investigates how different proportions of plastic waste, sand, and fly ash influence the mechanical performance of the final product, comparing the results with existing literature. The method promotes community-based waste management and holds promise for generating significant environmental and economic benefits worldwide.

Introduction

Plastic waste has become a pressing global concern, closely associated with broader issues of resource depletion, energy sustainability, and environmental degradation [1,2]. Derived predominantly from non-renewable petroleum-based resources, plastics have witnessed an extraordinary surge in worldwide consumption-from approximately 5 million tonnes in the 1950s to nearly 100 million tonnes today. This rapid increase has substantially intensified the burden of municipal solid waste, with plastics now constituting approximately 3-7% of total global waste generation. In the Indian context, plastic waste represents an estimated 1-4% of municipal solid waste by weight. Although India records the world's highest recycling rate at 60%-significantly surpassing those of China (20%), Europe (20–40%), Japan (39%), South Africa (16%), the UK (17.7%), and the USA (28%)-the fraction of unrecycled plastic continues to pose serious environmental and public health challenges. Common disposal practices in India include landfilling, incineration, and open littering. Among these, open littering is particularly detrimental, as it enables plastics to bypass formal waste management systems, leading to clogged drainage networks, soil contamination, and severe impacts on terrestrial and aquatic ecosystems [3].

Despite these concerns, emerging research highlights the feasibility of incorporating plastic waste as a raw material in construction-related applications. Several studies have demonstrated the potential to repurpose waste plastics into construction components such as bricks and blocks, providing a sustainable pathway for producing low-cost and durable materials-particularly beneficial in disaster-prone or remote regions. Building upon this foundation, the present study investigates the utilization of waste plastic in the fabrication of paving tiles (also referred to as paver blocks). The primary objective is to assess the viability of substituting conventional cement-based materials with plastic waste-either partially or entirely-to develop environmentally friendly and economically feasible alternatives to traditional paving units. This work specifically examines the physical and mechanical properties of plastic-based paver blocks produced with varying proportions of sand and/or fly ash [4]. The obtained results are evaluated against conventional concrete blocks and previously published benchmarks to determine performance, durability, and sustainability. Ultimately, this study seeks to advance an innovative and scalable strategy for plastic waste management that not only mitigates environmental impacts but also supports the development of sustainable infrastructure, particularly within under-resourced communities.

Materials and Methodology

Materials

Waste Plastic:

The primary raw material used in this study is post-consumer plastic waste, sourced from local municipal collection points and nearby garbage disposal sites (Figure 1). The collected waste includes a mix of commonly discarded plastic types such as Low-Density Polyethylene (LDPE), Polypropylene (PP), Polyethylene Terephthalate (PET), and Polystyrene (PS) [5].

Figure 1: Consumer Plastic Waste.

The plastics were initially washed with water and detergent to remove contaminants like mud, grease, and other foreign materials. After drying in ambient air, the plastics were further cleaned using high-pressure water jets to ensure the removal of any residual impurities. Larger pieces were manually cut down and then processed in a plastic shredder to produce flakes ranging from 5 mm to 10 mm in size (Figure 2). These clean, dry plastic pieces formed the base material for block production.

Figure 2: Shredded Clean Waste.

River Sand:

Natural river sand was used as a filler and structural component in the plastic composite. Sand samples were randomly selected from heaps used by local construction contractors (Figure 3). The sand, golden in color, was sieved through a 600-micron mesh to ensure uniform particle size. The specific gravity of the sand was measured at 2.65 g/cm^3 according to IS: 2720 (1980) [6].

Figure 3: River Sand.

Fly Ash:

Fly ash, an industrial byproduct generated from coal combustion in thermal power plants, was incorporated as an additional binder and filler. Class-F fly ash was used in this study, procured from a local supplier (Figure 4). Its inclusion is intended to improve the thermal and mechanical properties of the paver blocks.

Figure 4: F-grade Fly Ash powder.

Preparation of Test Specimens

The test specimens were fabricated using a controlled thermal melting and manual molding procedure, as detailed below:

1. Preparation of materials: The raw materials included shredded plastic waste, river sand, and fly ash. All materials were dried and sieved to remove moisture, dust, and oversized particles prior to use.
2. Reactor setup: A narrow-neck metal reactor was cleaned thoroughly to remove any residual contaminants and preheated to a temperature of approximately 250°C using an external heating source.
3. Melting of plastic waste: One kilogram of shredded plastic was gradually fed into the preheated reactor. The plastic melted almost instantaneously, forming a uniform viscous liquid. During this stage, no emission of toxic fumes or gases was observed, confirming the safety of the thermal process.
4. Addition of filler materials: Pre-weighed quantities of river sand and/or fly ash, as specified by the target mix ratio, were added slowly into the molten plastic under continuous stirring. This gradual addition prevented clumping and ensured proper dispersion of particles within the polymer matrix.
5. Mixing process: The mixture was stirred manually and continuously for 5-7 minutes to achieve a homogeneous consistency. Care was taken to maintain the reactor temperature at around 250°C throughout this stage to avoid premature solidification.
6. Molding of specimens: The homogeneous molten mixture was immediately poured into pre-cleaned steel molds having dimensions of 70mm×70mm (Figure 5). The molds were lightly coated with oil prior to casting to facilitate easy demolding.
7. Compaction: Manual compaction was applied to the freshly cast mixture using a steel tamper to minimize internal voids and air entrapment. No hydraulic or mechanical pressing was

employed in this process.

8. Cooling and demolding: The filled molds were left to air-cool under ambient laboratory conditions for approximately 24 hours. After cooling, the specimens were demolded carefully. A dimensional shrinkage of 1-2% was observed upon solidification. The hardened samples were then stored in a dry environment until further testing.

Figure 5: Sample drying after over night.

For comparative testing, standard-size commercial fly ash bricks were cut into 70mm×70mm samples using a hacksaw, while A-grade earthen bricks (255mm×120mm×72mm) were tested in their original form as per IS standards.

Compressive Strength Testing

Figure 6: Experimental Setup for Compression test in the laboratory.

The compressive strength of the prepared plastic paver blocks (70mm×70mm), commercial fly ash blocks (70mm×70mm), and earthen bricks (255mm×120mm×72mm) was evaluated [7] using an AIM317EAN2 compression testing machine (M/s AIMIL, India) (Figure 6).

For each block type, five specimens were tested, and the maximum load at failure was recorded. The average compressive strength was calculated using the formula:

Compressive strength (N/mm^2) = [Ultimate load in N/Area of cross section (mm^2)].

Similarly tensile strength has been measured using the formulae $f_{ct}=0.7\sqrt{f_{ck}}$ N/mm^2

Fire Resistance Test

Given that plastic is inherently flammable, evaluating the thermal stability of the paver blocks is essential. The specimens were subjected to incremental heating in an oven, starting from 50°C up to 200°C, with each temperature held for 2 hours [8].

It was observed that composite plastic-sand paver blocks remained structurally intact up to 180°C due to the insulating effect of the sand. Beyond this threshold, minor surface cracking appeared, and further heating led to gradual deterioration.

Water Absorption Test

To evaluate the porosity and durability of the prepared specimens, water absorption tests were conducted following a standard immersion method [6]. The procedure adopted is described below:

1. Specimen preparation: All specimens were visually inspected for surface defects such as cracks or voids before testing. Only intact samples were selected for the water absorption study to ensure accuracy and consistency of results.
2. Initial drying: Each specimen was oven-dried at a temperature of approximately 105±5°C for a period of 24 hours to remove any residual moisture.
3. Recording of dry weight: After drying, specimens were allowed to cool to room temperature in a desiccator to prevent moisture uptake from the atmosphere. The dry weight (W_1) of each specimen was then accurately recorded using a digital weighing balance with a precision of 0.01g.
4. Immersion in water: The dried specimens were completely submerged in clean, potable water maintained at room temperature. The immersion period was maintained for 24 hours to allow adequate water penetration into surface pores and voids.
5. Post-immersion handling: After the immersion period, the specimens were removed from the water and their surfaces were gently wiped with a damp cloth to remove excess surface water without extracting water from the pores.
6. Recording of wet weight: The saturated weight (W_2) of each specimen was immediately recorded using the same balance to minimize evaporation losses.
7. Calculation of water absorption: The percentage water absorption (WA %) was calculated as per IS: 2386 (Part 3)-1963 [6].

Hardness Test

Surface hardness was evaluated using the Mohs scale [9]. A scratch test was conducted by attempting to mark the surface with:

a) A sharp steel tool (Mohs hardness=5)

b) A sharp glass plate (Mohs hardness≥6)

No visible scratches were observed in either case, indicating a high surface hardness of the plastic paver blocks and confirming their structural robustness (Figure 7).

Figure 7: No scratches have been observed on the surface of the samples after hardness test.

Results and Discussion

A series of experimental batches were prepared using various combinations of shredded plastic waste, river sand, and fly ash. The mechanical and physical properties of the resulting paver blocks-including compressive strength, tensile strength, water absorption, and fire resistance-were assessed and compared with commercial alternatives and existing literature [10,11].

Table 1 presents a summary of the measured values for different block types, alongside reported reference data where available.

Compressive and Tensile Strength Analysis

The compressive strength of plastic-sand-fly ash composite blocks showed considerable enhancement over conventional fly ash and earthen blocks. Mix B2 (Plastic: Sand: Fly Ash=1:2:2) recorded a strength of 12.68N/mm^2, which is more than double that of commercial fly ash and concrete blocks. The best performing batch was B4, with a high compressive strength of 16.91N/mm^2, though still lower than a reported value of 25N/mm^2 for similar composites [11]. It is worth noting that B4 used a significantly lower sand content (1:0.4), suggesting that reduced filler material results in higher plastic density and strength. Tensile strength, derived from compressive values, followed a similar trend. B4 again topped with 2.87N/mm^2, indicating better resistance to cracking and improved flexibility compared to inorganic brick types.

Table 1: Comparative Properties of Plastic-Based and Commercial Blocks.

Sl. No.	Type Of Block / Mix Ratio	Compressive Strength (N/Mm^2)	Tensile Strength (N/Mm^2)	Compressive Strength (N/Mm^2)	Water Absorption (%)	Water Absorption (%)
		(This Study)	(This Study)	(Reported)	(This Study)	(Reported)
B1	Plastic : Sand = 1 : 4	6.6	1.8	5.12 [10]	0.92	1.08 [10]
B2	Plastic : Sand : Fly Ash = 1 : 2 : 2	12.68	2.21	–	0.89	–
B3	Plastic : Sand : Fly Ash = 1 : 2 : 0.5	10.96	2.09	–	0.97	1.28 [Reported]
B4	Plastic : Sand = 1 : 0.4	16.91	2.87	25.00 [11]	–	–
B5	Plastic : Fly Ash = 1 : 0.4	13.68	2.74	–	–	–
B6	Plastic : Sand = 1 : 2	10.38	2.25	–	–	–
C1	Commercial Fly Ash Block	6.05	–	4.19 [10]	8.92	8.01 [10]
C2	Commercial Earthen Block	6.52	–	3.15 [10]	8.94	9.08 [10]
C3	Cement : Sand = 1 : 4 Concrete Block (28 days)	5.45	–	7.17 [10]	–	3.71 [10]

Water Absorption Characteristics

The water absorption of plastic-based paver blocks was found to be significantly lower compared to conventional masonry materials. All plastic-based formulations exhibited absorption values of less than 1%, with mix B2 showing the minimum value of 0.89%, indicating excellent resistance to moisture ingress.

In contrast, fly ash and earthen bricks demonstrated considerably higher water absorption rates, reaching up to 8.94%, which adversely affects their durability, particularly in humid or high-rainfall environments. The markedly low water absorption observed in plastic-based paver blocks underscores their superior suitability for outdoor and moisture-prone applications.

Fire Resistance and Durability

Fire resistance testing revealed that the plastic composite blocks maintained structural integrity up to a temperature of approximately 180°C. Beyond this threshold, the onset of micro-cracking and minor structural degradation was observed. Nevertheless, this level of thermal stability is considered sufficient for most civil engineering applications, particularly those involving non-load-bearing, pedestrian, and landscaping structures. The inclusion of sand as a filler material was found to enhance the fire resistance of the composite by functioning as an effective thermal barrier, thereby delaying heat transmission through the matrix.

Surface Hardness and Finish

Scratch tests using steel and glass tools (Mohs hardness=5-6) confirmed that the plastic composite surfaces were highly resistant to surface deformation, suggesting excellent wear resistance. This quality makes them suitable for use in areas with moderate foot traffic.

Conclusion

The experimental investigation conclusively demonstrates that waste plastic can be effectively repurposed for the production of durable, cost-efficient, and sustainable paver blocks. The findings confirm that incorporating plastic with sand and fly ash in optimized proportions produces composite blocks exhibiting enhanced compressive and tensile strength, very low water absorption, and good thermal stability when compared with conventional masonry materials. Beyond their engineering performance, these plastic-based blocks offer a practical and eco-sustainable solution for managing plastic waste, particularly in regions experiencing resource scarcity. Owing to their favorable physical and thermal properties, they are well-suited for various non-structural and light-duty construction applications.

Based on the results of this study, the following conclusions can be drawn:

1) Sustainable Waste Utilization:

The proposed process provides a feasible and environmentally responsible approach to reusing municipal plastic waste. It aligns with the principles of the circular economy, significantly reducing the volume of plastic directed to landfills and promoting value-added recycling.

2) Superior Mechanical Properties:

The developed plastic paver blocks exhibited higher compressive and tensile strengths compared to commercial fly ash and earthen blocks. Mix proportions such as 1:2:2 (Plastic: Sand: Fly Ash) and 1:0.4 (Plastic: Sand) demonstrated particularly strong mechanical integrity and cohesion.

3) Minimal Water Absorption:

With absorption rates consistently below 1%, the plastic-based blocks displayed excellent resistance to moisture ingress, ensuring long-term durability in humid or variable climatic conditions.

4) Thermal and Surface Performance:

The blocks retained structural stability up to 180°C and exhibited high scratch and abrasion resistance, underscoring their suitability for pedestrian pathways and other light structural applications.

5) Cost-Effective and Scalable Production:

As the manufacturing process does not require cement, hydraulic pressing, or water curing, it offers a low-cost and energy-efficient alternative that can be easily implemented in both rural and urban contexts.

6) Recommended Applications:

Based on the material performance, plastic paver blocks are best suited for non-traffic and light-traffic areas, including building premises, garden pathways, monuments, embankments, pedestrian corridors, residential lanes, service roads, and tourist walkways.

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Conflict of Interest

None.

Data Availability Statement

All data used in this study appeared in the article.

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