Mix Design Optimization and Performance Evaluation of Bricks made of Waste Red Brick Aggregate and Shredded Plastic

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Abstract. With rising environmental concerns, this study addresses the high volume of construction and demolition waste from red bricks by exploring the potential of utilizing waste red bricks as a construction material. The methodology integrates recycled red brick aggregate with plastic waste to improve material properties and reduce landfill accumulation. Through trials, material properties (including a critical 24% water absorption of raw RBA) were evaluated, and shredded PET plastic was confirmed as the optimal reinforcement. The optimal mix design (PPC:RBA :: 1:3) achieved a 28 days compressive strength of 12.45 N/mm², which is higher than the 10 N/mm² requirement for a class 10 brick as per IS 1077:1992. This study provides a comprehensive overview of the technical viability of these sustainable materials, contributing to environmentally responsible construction practices in India.

Keywords: Waste Red Bricks, Sustainable Construction, Recycled Materials.

1 INTRODUCTION

1.1 Global Context: Construction Waste Management and Resource Scarcity

The global construction industry is a primary driver of economic growth but faces challenges regarding resource depletion, environmental impact, and waste management. Construction and Demolition (C&D) debris accounts for a large portion of global waste streams, placing growing pressure on the sector to adopt sustainable and eco-friendly materials. Among the most common building components, red bricks are a staple material due to their historical use, durability, and availability. However, the disposal of waste red bricks contributes significantly to C&D debris, leading to increased landfill accumulation and the depletion of natural resources. The imperative to transition towards a circular economy model necessitates innovative strategies for material reuse. This study addresses this need by exploring the potential of recycling waste red bricks and integrating them with waste products that can harm the environment if not recycled, such as plastic, to create high-performance, sustainable composites.

1.2 The Red Brick Industry in India: Environmental Impact Analysis

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India is the world's second-largest brick producer, sustaining over 100,000 brick kilns that annually produce approximately 250 billion bricks and employ about 15 million workers[7]. This massive scale of production results in significant resource degradation. It has been estimated that 300 mm depth of fertile topsoil in India will be consumed for burnt clay brick production within approximately 60 years[7]. Beyond resource depletion, the reliance on traditional firing methods utilizing coal and biomass fuels leads to extensive air pollution. Brick kilns are a major source of particulate matter (PM2.5, PM10) and gaseous pollutants like Sulfur Dioxide (SO_2), Carbon Monoxide (CO), and Hydrogen Fluoride (HF)[1]. Further, the combustion of coal contributes significantly to greenhouse gas emissions; the Indian brick industry is estimated to emit 66–84 million tonnes of CO_2 per year, accounting for 2.5% of the country's total CO_2 emissions, thereby worsening global warming. Specifically, 0.8–1.6 tonnes of CO_2 are generated for every 1000 bricks produced[1]. The recycling of red bricks offers a critical solution, enabling the production of a non-fired, kiln-free alternative brick, which promotes sustainable construction practices by simultaneously mitigating air pollution, global warming, and topsoil consumption.

1.3 Definition of Research Gap and Novelty of Research

Prior studies have focused only on pure recycled brick aggregate utilization or on using plastic waste within conventional concrete matrices. A significant research gap exists in the development of composite bricks that combine high volumes of crushed red brick waste (RBA) with shredded plastic (PET/PP) fibers. Data regarding the mechanical, chemical, and thermal properties of such hybrid composites remains limited, and there is currently no standardized mix design for blending these specific waste aggregates and fibers to achieve multi-criteria performance. The novelty of this study resides in bridging this material science gap. It focuses on developing and standardizing a viable mix proportion that successfully integrates two complex waste streams to maximize waste utilization while simultaneously achieving the structural capacity required for sustainable, non-fired masonry bricks.

1.4 Aims and Objectives

The investigation was guided by the following core objectives :

1. **Develop Composite Bricks for Enhanced Performance:** Conduct trials to determine the optimal composition of crushed red bricks, supplementary cementitious materials, and recycled fibers to achieve the best possible performance balance.
2. **Characterize Mechanical Properties:** Conduct standard tests for Water Absorption and Compressive Strength on the mix design.

2 LITERATURE REVIEW

Table 1. Summary of Literature Review

Sr. No.	Title	Author/Journal	Year	Summary
1.	Development and performance evaluation of recycled brick waste-based geopolymer brick	Mohammed Rihan Maaze, Sandeep Shrivastava	2024	Geopolymer bricks made from recycled red brick waste showed 6–6.9 N/mm^2 strength, qualifying as first-class bricks, and offered cost reduction.
2.	Composite Bricks using Waste Materials	C. Kesava Raja et al.	2020	Composite bricks using crusher sand, PPC, sawdust, hydrotons, and coco peat achieved 7.0–7.4 N/mm^2 strength, meeting first-class standards at a lower cost.
3.	Insulation Properties of Bricks Made with Cotton and Textile Ash Wastes	Remzi Gemci, Orhan Aksogan, Hasan Kaplan	2010	Bricks incorporating cotton and textile ash waste achieved compressive strength of 8.95–13.4 MPa but exhibited high water absorption (35–42%).
4.	Case Studies in Construction Material	Frank Ikechukwu Aneke, Celumusa Shabangu	2021	Bricks using scrap PET plastic waste and foundry sand showed high compressive strength (38.14 MPa), low water absorption, and were 25 times cheaper than traditional clay bricks.
5.	Potential Use of Brick Waste as Alternate Concrete-Making Material	Chee Lum Wong et al.	2018	Brick dust was successfully used to replace cement (up to 20%) and aggregates (around 10%), though resulting in higher water absorption due to increased porosity.
6.	Insulation	Asena	2021	A review of bricks

	Properties of Bricks with Waste Rubber and Plastic: A Review	Karslıoğlu Kaya, Eren Balaban		incorporating waste rubber and plastics indicated acceptable strength with up to 20% waste content, but increased water absorption.

As seen in table 1, so far, the studies have focused on either utilizing recycled brick waste in conventional mixes or on incorporating plastic waste with other materials like sand or conventional aggregates. Existing studies involving recycled bricks and plastic have investigated only up to 20% waste content or reported a high water absorption (35-42%). This study is unique in its approach as it focuses on systematically optimizing a mix design to integrate a high volume of both RBA and shredded PET plastic, aiming to achieve a superior compressive strength and a low water absorption simultaneously, which is a critical gap not fully addressed in previous waste utilization studies.

3 MATERIALS AND METHODS

3.1 Methodology

The experimental phase of this study was systematically designed to transition from material characterization to the optimization and performance testing of the final composite brick. The determination of the appropriate proportion and quality of crushed red brick material for construction use was done by conducting a series of planned tests.

3.2 Test 1 - Sieve Analysis

Broken unused red bricks were used for this study. All brick fragments were visually inspected to ensure that they were free from major contaminants (plaster, mortar).The plastic waste was sourced from local waste collection centers. The PET bottles were washed, air-dried and shredded into fibers (manually) approximately 3-4 cm in length. Portland Pozzolana Cement (PPC) was used as the binder, complying with IS 1489 (Part 1):1991.The objective of this test was to determine the grain size distribution of the crushed red brick material, which is essential for evaluating its suitability as fine aggregate in concrete or mortar. Waste or used red bricks were crushed manually using basic tools such as rammers and steel rods to simulate field conditions and reduce the bricks to smaller fragments. The crushed material was then passed through a 4.75 mm sieve (shown in Fig 1). Particles that passed through the 4.75 mm sieve were collected in the pan below the sieve. The manual crushing process was effective in producing red brick particles of a size appropriate for use as fine aggregate. Only particles smaller than 4.75 mm were considered acceptable for mix design and used in further material testing, ensuring uniformity and adherence to fine aggregate standards.

Fig 1. Crushing of waste bricks into a fine powder

3.3 Test 2 - Water Absorption

The objective was to determine the water absorption capacity of crushed red brick material. This test was conducted in accordance with IS 3495 (Part 2):1992.

The test was conducted on crushed brick particles that were retained on a 4.75 mm sieve, meaning finer (powdered) material was excluded as it wasn't suitable for this test. The sample was thoroughly dried before the test to remove any existing moisture. The dried sample was submerged in water for 24 hours to allow for full absorption. After 24 hours, the sample was removed and weighed again. The increase in weight was used to calculate the percentage of water absorbed.

The crushed bricks absorbed 24% of water by weight.

3.4 Test 3 - Trial Design

The objective of Test 3 was to identify the most suitable ratio of Portland Pozzolana Cement (PPC) to Red Brick Aggregate (RBA).

Table 2. Material Proportions for Trial Mix Design

Sample	Cement (PPC)	Red Brick	Water
Sample 1	1	3.00	1.13
Sample 2	1	1.00	0.50
Sample 3	1	1.86	0.75

Table 2 shows the trial mix designs taken into consideration for this test. Water content was taken as 30% by weight of cement and 24% by weight of crushed red brick to fulfill the water absorption. Further water was added as per the desired workability. Above proportions are represented as ratios with respect to cement weight.

Proportioning Rationale: The initial trial ratios (1:3, 1:1, 1:86) were selected to represent a wide range of PPC: RBA ratios to determine the optimal mix proportion that balances strength and waste utilization.

Three different mixes were created by carefully measuring and mixing specific quantities of PPC, red brick, and water. All samples were prepared using 70mm x 70mm x 70mm moulds and cured by submerging in water. After preparing and curing the samples, their mechanical properties were measured, including compressive strength, weight, and density. Compressive strength was measured using a compression testing machine in accordance with IS 3495 (Part 1):1992 for common burnt clay bricks, applied to the non-fired composite bricks.

Table 3. Trial Mix Design

Sr. No.	Proportions (gms)	Compressive Strength (N/mm^2)	Weight (kg)	Density (kN/m^3)
Sample 1	PPC - 750 (25%) Red Brick - 2250 Water - 847	3.31	0.686	19.62
Sample 2	PPC - 1000 (50%) Red Brick - 1000 Water - 500	12.80	0.715	20.43
Sample 3	PPC - 700 (35%) Red Brick - 1300 Water - 522	7.09	0.716	20.47

Table 3 contains details regarding the compressive strength, weight and density of the trial mix designs. The Portland Pozzolana Cement (PPC) used in the study contains - Cement and Fly Ash (35%).The trial design demonstrated that PPC content is the dominant factor in achieving compressive strength: Sample 2 (highest PPC) yielded the highest strength (12.80 N/mm^2), while Sample 1 (lowest PPC) yielded the lowest (3.31 N/mm^2). This correlation highlights the crucial role of a low water-cement ratio and balanced RBA content for optimal strength, as seen in Sample 2 (lowest RBA, lowest water). Density showed less variation, Samples 2 (20.43 kN/m^3) and 3 (20.47 kN/m^3) were nearly identical, suggesting that the influence of PPC on density is less significant than on strength. The strength increase observed is due to the binding capability of PPC i.e. as the PPC content increases, the extent of binding also increases, thereby increasing the compressive strength.

For further analysis, Samples **1** and **3** were selected for the 28 days compressive strength testing, as the compressive strength of sample 2 came out to be 12.80 N/mm^2 which is higher than 10 N/mm^2 (Characteristic 28 days compressive strength of Class 10 bricks). This decision was taken as sample 2 would reach a compressive strength significantly higher than 10 N/mm^2 after 28 days even without the addition of the PET plastic shreds

(their addition would also increase the strength), which was not necessary as the main aim of the research is the development of composite bricks having a compressive strength of around 10 N/mm² (Class 10 grade).
Five cubes ((70 x 70) mm) were cast for each trial batch (Samples 1 and 3). Fig 2 shows the samples prepared for the 28 days compressive strength test and Fig 3 shows the testing of the samples.

Fig 2. Sample preparation for 28 days test

Fig 3. Compressive strength testing at 28 days

Table 4. Results of 28 days Compressive Strength Test (For Trial Mix Design)

Trial No.	**Sample No.**	**Weight (kg)**	**Load (kN)**	**Compressive Strength (N/mm²)**
Trial 1	T1 - 1	0.677	58	11.84
	T1 - 2	0.685	58.3	11.90
	T1 - 3	0.688	65.2	13.31
	T1 - 4	0.694	62.4	12.73
Average				**12.45**
Trial 3	T3 - 1	0.702	127.5	26.02
	T3 - 2	0.691	135.2	27.60
	T3 - 3	0.701	123	25.10

	T3 - 4	0.671	106.3	21.69
Average				**25.10**

Table 4 shows the results of the 28 days compressive strength test. Trial 1 was selected due to its acceptable strength (approximately 12 N/mm²), with further plastic inclusion expected to increase the compressive strength. According to the Indian Standard IS 1077:1992, the values obtained allow the composite bricks to be classified. Trial 1 meets the minimum requirement for a class 10 brick, while trial 3 significantly exceeds this requirement, indicating its potential for high performance applications.

3.5 Test 4 - Composite Material Finalization

The objective of this test was to identify the optimal type of plastic waste for inclusion by evaluating the early-age (3 days) compressive strength of different composite mixes, thereby ensuring maximum reinforcement and performance enhancement for the final product. The established Base Mix (Trial 1) proportion (Cement : Red Brick : Water :: 1:3.00:1.13) was used for all samples in this phase.Three distinct composite mixes were prepared, each incorporating a different form of shredded plastic waste at a constant initial percentage to ensure a fair comparison of their binding properties. The plastic materials tested were: Mix A (Shredded Polyethylene Terephthalate (PET) plastic), Mix B (Shredded Polypropylene (PP) plastic), and Mix C (Composite Blend of both PET and PP plastics). Samples were cast and subjected to a 3-Day Compressive Strength Test. Fig 4 shows the casted samples and Fig 5 shows the mixing process required for casting the samples.

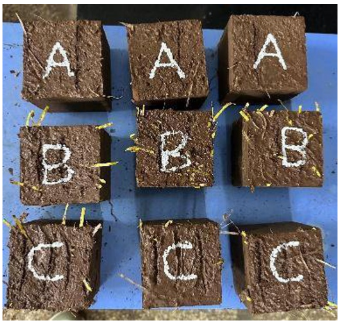

Fig 4. Cubes for composite material finalization

Fig 5. Raw mix with Polypropylene fibers

Table 5. Results for 3 days Compressive Strength Test (For Composite Material Finalization)

Mix	Plastic Type	Sample Weight (kg)	Force (kN)	Average Compressive Strength (N/mm²)
Mix A	Shredded PET Plastic (Water Bottle)	0.695	24.8	5.1
		0.698	25.9	
		0.677	24.3	
Mix B	Shredded Gunny Bag Plastic (PP)	0.668	22.6	4.48
		0.667	20.2	
		0.669	23.3	
Mix C	Composite (PET + PP)	0.663	21.9	4.69
		0.685	23.3	
		0.680	23.6	

Table 5 shows the results of the 3 days compressive strength test conducted on the samples. Shredded PET Plastic (Mix A) was finalized as it appeared to be the best material for reinforcement. The superior performance of shredded PET over Polypropylene (PP) is attributed to the morphology of the PET shreds, which behave more like reinforcing fibers. These high aspect ratio fibers effectively restrict crack propagation, significantly improving the material's early age compressive strength through enhanced bonding within the Cement-RBA mix.

4 CONCLUSION

This study proved the technical feasibility of developing a sustainable composite brick using high volumes of recycled Red Brick Aggregate and shredded PET plastic waste. The mix optimization trials successfully identified the ratio (PPC:RBA :: 1:3) that maximized waste incorporation while maintaining structural integrity. Quantitatively, the optimal mix achieved a 28 days compressive strength of 12.45 N/mm², classifying it as a high performance masonry unit, exceeding the 10 N/mm² requirement for a first class brick as per IS 1077:1992. The incorporation of shredded PET plastic was proven to be the most effective reinforcement as it contributed to the material's structural performance. The findings strongly imply that this composite material is suitable for non load bearing walls and potentially for load bearing structures depending on local building codes and factors of safety. This simultaneously addresses the resource depletion from traditional brick production and the environmental challenge of plastic waste management.

Limitation and Future scope. While mechanical properties were successfully evaluated, a current limitation is the long term durability data (e.g. water resistance and freeze-thaw cycles) and a full life cycle assessment. Future research should focus on microstructural studies, scaling up the production process and evaluating the cost effectiveness against conventional methods.

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