

EXPERIMENTAL INVESTIGATION ON LIGHT WEIGHT PAPERCRETE BRICKS

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Received: April 25, 2025; Revised: May 29, 2026; Accepted: June 23, 2026

Abstract

Construction materials have been in demand for now days on account of rapidly increasing population and urbanisation, which causes the prices of materials to rise. Depletion of natural resources for construction materials necessitates the use of recycled products, which not only reduces waste and environmental impact but also conserves resources. In this study, the utilisation of waste paper, fly ash, quarry dust, rice husk ash, and cement for the production of light weight bricks was examined. The SEM and EDAX have been analysed to find the chemical constituents of those materials. Trial mix proportions of paper sludge, cement, fly ash, quarry dust, and rice husk ash in various proportions made lightweight bricks. In addition to these, Dr.Fixit powder has been included by weight of cement. The mix's optimisation was identified based on the compressive strength, water absorption test, and bricks' unit weight. According to the trial mix results, these bricks can achieve the highest compressive strength and the lowest water absorption during production. As a result of the study, the self weight on the structure will be decreased, allowing it to be used in the non-load-bearing walls of the building.

Keywords: Dead load reduction; Lightweight bricks; Recycled construction materials; Water absorption and compressive strength

Introduction

The construction sector uses a significant quantity of non-renewable resources (Ramakrishnan *et al.*, 2023). Lightweight bricks using waste paper are an innovative and ecofriendly solution in the field of construction (Pimraksa & Chindaprasirt, 2009). These bricks are created by utilizing waste paper as a raw material, addressing the environmental concerns associated with paper waste disposal.

The manufacturing process involves treating and processing the waste paper, mixing it with other additives to enhance its properties, and moulding and curing the mixture into brick shapes. Ghosh (2018) noted that in recent years, some countries have begun to produce building materials from recycled resources. Due to the expanding population and on-going scarcity of building materials, civil

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DOI: <https://doi.org/10.55766/sujst9573>

Suranaree J. Sci. Technol. 33(5): 010461(1-8)

engineers face issues in transforming industrial waste into viable building and construction materials. In order to meet the increasing demand for durable and eco-friendly materials in construction, lightweight bricks are being produced from waste paper. Ganesan *et al.* (2020) explored the process of creating lightweight bricks from waste paper and highlights the environmental benefits and potential applications of these bricks. Abdel-Gawwad *et al.* (2020) aimed to provide an innovative solution for reducing waste and carbon footprint in construction while maintaining adequate strength and durability. The depletion of aggregates' natural sources pushes rely on energy sources that are not renewable, and this is a more recent issue (Anusuya & Makesh, 2017). In this regard, the proposed research has to utilise industrial by products and waste paper towards sustainable development. Hayat *et al.* (2019) reported that the production of conventional clay or concrete bricks requires substantial amounts of energy and resources, contributing to environmental degradation. By utilizing waste paper as a primary raw material, lightweight bricks offer a sustainable alternative. This research paper investigates the feasibility and effectiveness of this approach. The lightweight bricks produced from waste paper exhibit favourable characteristics such as reduced weight, improved thermal insulation, and lower embodied energy.

The globe is currently dealing with a serious issue of harm to the environment caused by waste industrial products being deposited in landfills. The harmful disposal of industrial waste by products such as Fly Ash, GGBS and waste paper are alternatively used as the building materials (Cardinale *et al.*, 2021). The construction industry's growing preference for renewable, affordable, and lightweight materials has prompted efforts to conserve the environment and adhere to standards-supported material requirements (Sadek, 2012). The resulting lightweight bricks exhibit reduced weight compared to traditional bricks, making them easier to handle and transport. Moreover, these bricks possess desirable thermal insulation properties, contributing to energy efficiency in buildings. With their satisfactory mechanical strength, waste paper-based lightweight bricks offer a viable and sustainable alternative to conventional construction materials (Sangeetha *et al.*, 2020). Delcasse *et al.* (2017) explored papercrete, a composite material made from waste papers and cement, as an alternative to traditional bricks. By means of trial and error, they opted for 3 by comparing it to regular bricks. These bricks have shown promising results in terms of compressive strength, water absorption, and durability. They offer potential applications in

non-load-bearing structures, partitions, and wall construction. Utilizing waste paper diverts it from landfills, reducing the strain on waste management systems. Additionally, the production of lightweight bricks using waste paper significantly reduces carbon emissions and energy consumption compared to traditional brick manufacturing processes. Soundara Rajan *et al.* (2017) have employed a mix ratio of (1:2:4) Cement, paper, and quarry dust are combined with 20 to 50 percent by weight of cement using GGBS to create papercrete bricks. Additionally, Dr. Fixit adding 20% by weight of cement.

As a result, GGBS only has weight equivalent to 1/3 of regular bricks. At 14 and 28 days after curing, 50% replacement of GGBS increased its compressive strength to 7.2 N/ m² and 8.7 N/ m², respectively. The brick in this paper is composed of 58% papercrete, 30% egg shell, fly ash, quarry dust, and sand. Cement makes up the remaining 12%. The compressive strength of the brick has been attained as more than 3.5 N/m² (Soundara Rajan *et al.*, 2018). Lightweight bricks made from waste paper offer a sustainable solution for the construction industry. The research demonstrates the feasibility and environmental benefits of this innovative approach. The findings encourage further exploration and development of waste paper-based construction materials to promote a greener and more sustainable future. Raut *et al.* (2013) showed that papercrete, a cement mortar containing paper sludge, can be utilized as a reinforcing material in building, according to experimental data. Its compressive and flexural strengths are acceptable compared to classical mortars, making it suitable for bed joints and external strengthening. These substitute material called Paper Crete bricks. Paper Crete, a freshly created building material produced from recycled paper fibre and Portland cement, provides an innovative replacement for conventional cement. Unlike previous papercrete studies that mainly focus on utilization of waste and strength of evaluation while the present study, the use of paper sludge proportion has fixed optimized volume to ensure consistency in material behaviour. This research investigates the feasibility of utilizing paper sludge as a low cost and lightweight construction material for sustainable brick production. The research specifically evaluates the mechanical and physical performance of papercrete bricks produced using waste paper sludge combined with cement, flyash, quarry dust, and rice husk ash. SEM paper and EDAX analysis were carried out the raw materials including flyash, quarry dust, cement and rice husk ash to evaluate their morphological and elemental composition. The incorporation of these industrial and agricultural by products enables to enhance

resource utilization, reduce environmental pollution, and develop ecofriendly alternative masonry units suitable for non-load bearing and lightweight construction applications. SEM and EDAX analysis were carried out the raw materials including flyash, quarry dust, cement and rice husk ash to evaluate their morphological and elemental composition.

Materials Study

Cement

Cement is a fine powder produced by heating a mixture of limestone, clay, and other materials to high temperatures, followed by mixing with water to form a paste that hardens over time (Abdel-Gawwad *et al.*, 2020). OPC grade 53 is confirming to IS 12269:1987 reveals in Table 1. In Figure 1 (a)

and Table 2 showed the SEM images revealed the irregular and angular shaped cement particles are clearly visible. The presence of hydrated cement products mainly: Calcium Silicate Hydrate (C-S-H gel) appearing as clustered gel like formations and Calcium Hydroxide (CH) appearing as flaky particles. The rough and dense morphology indicates active hydration behaviour while EDAX analysis identified the presence of key elements such as calcium, silicon, Aluminium and Iron in Figure 2(a) and Table 2.

Table 1. Properties of Cement

Test description	Results obtained
1. Specific gravity	3.16
2. Initial setting time	60 minutes
3. Final setting time	260 minutes
4. Fineness	411.92 m ² /kg

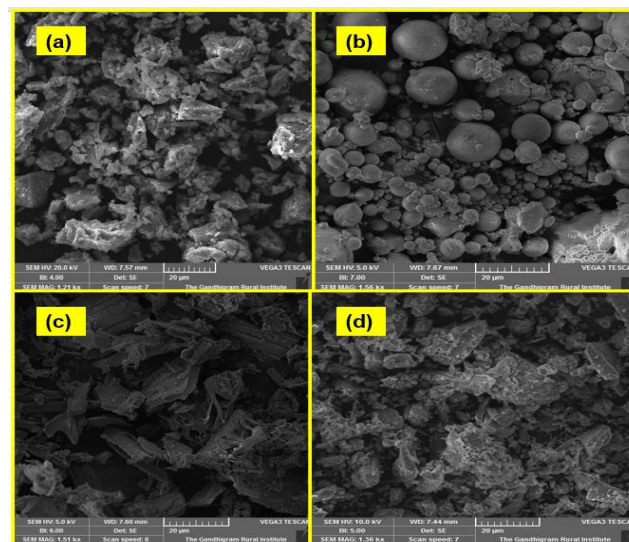


Figure 1. SEM analysis (a) OPC cement (b) Fly ash (c) Rice Husk Ash (d) Quarry dust

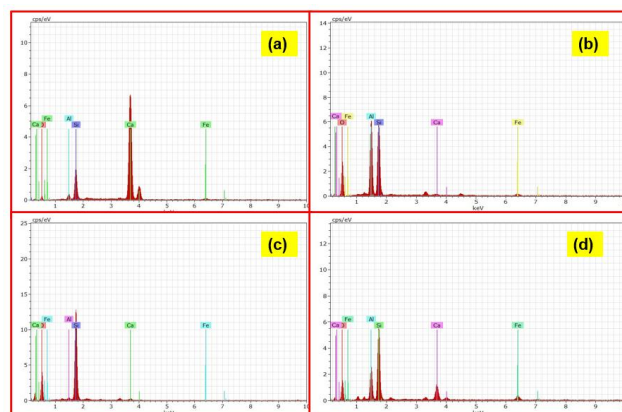


Figure 2. EDAX analysis (a) OPC cement (b) Fly ash (c) Rice Husk Ash (d) Quarry dust

Fly Ash

Fly ash is commonly used as a siliceous-aluminous material in making of concrete. It improves workability, durability, and long-term strength while reducing environmental impact by repurposing waste (Hayat *et al.*, 2019). The high concentrations of silicon, aluminium, and calcium in Figure 2(b) and Table 2 indicated that the fly ash sample contained minerals such as quartz, mullite, and calcite. SEM analysis in Figure 1(b) revealed the amorphous phase of fly ash. The presence of hollow spherical particles and fine glassy amorphous phases. These indicates the higher reactivity and potential application in cementitious application.

Rice Husk Ash

RHA is commonly utilized in the manufacturing of concrete as an additional cement like material. It enhances workability, durability, and strength while reducing the cement content. SEM analysis reveals the highly porous, fibrous and flaky structure. These porous morphology enhances water absorption and pozzolanic reactivity in Figure 2(c) and Table 2 EDAX showed that the Si and O are highly dominated in the RHA content.

Quarry Dust

In quarries, the process of crushing rock produces a by-product called quarry dust. Quarry dust serves as a substitution partially for sand in concrete and construction applications, reducing sand mining's environmental and cost impacts (Jonnala *et al.*, 2024). Figure 2(d) and Table 2 EDAX analysis revealed the presence of silica and aluminium with a high ratio of 21.33 % and 9.29%, respectively, and a small amount of iron and calcium. SEM analysis reveals the angular and rough-textured mineral particles are visible and dense crystalline structure with sharp edges in Figure 1(d).

Paper Sludge

Paper sludge is a byproduct of paper manufacturing. Depending on its composition, paper sludge can be recycled or used as an additive in construction materials (Kumari *et al.*, 2019). In Figure 3 shows that Paper sludge made from waste paper, which can be cut into tiny pieces and soaked in water in 2-4 hours until the paper degrades into paste-like consistency, after which the paper is removed from the water and mixed by hand. A water to paper ratio of 3:1 was used to achieve pulping and



Figure 3. Preparation of paper sludge

Table 2. Chemical Composition (a) OPC cement (b) Fly ash (c) Rice Husk Ash (d) Quarry dust

Chemical constituent	OPC cement (%)	Fly ash (%)	Rice husk ash (%)	Quarry dust (%)
O	45.97	55.37	73.33	63.88
Ca	38.71	19.83	0.22	4.01
Si	12.34	12.84	25.86	21.33
Al	2.35	11.56	0.54	9.29
Fe	0.62	0.29	0.04	1.41

Table 3. Mix Design of Papercrete

Mix No	Ingredients (% weight Basis)					Water Proofing Powder Dr. Fixit 101
	Cement	Fly ash	Quarry Dust	RHA	Paper sludge	
M 1	1	2	1	1	2	20% by weight of cement
M 2	1	3	0.5	0.5	2	
M 3	1	2	1.5	0.5	2	
M 4	1	1	1.5	1.5	2	

proper fiber separation. The average fiber length was approximately 2 mm, which contributed to improved bonding with the cementitious matrix.

Water Proofing powder

Paper is the main component of the papercrete mix used in this study, and it has a high water absorption rate, so to Use of water-proofing powder reduces water absorption The ingredients that make Dr. Fixit powder water proof is waterproofing additives.

Experimental Study

In Figure 5 The workflow of this study followed a systematic sequence as material selection, preparation of mix, casting of specimen, curing and Testing. In this study, the collected waste materials were hand mixed by adjusting the ratio based on their weight showed in Table 3. Initially,

cement, flyash, quarry dust, rice husk ash and paper sludge were dry mixed thoroughly to achieve uniform distribution of all cementitious materials. Uniformity of the mix was confirmed through consistent colour and texture. Water was then added gradually while maintaining a constant water to binder ratio for all mixes to ensure consistency in the mixing process. The mixing process was continued for approximately 15 minutes to achieve better homogenization and proper dispersion of paper fibers within matrix. During mixing, moisture content was carefully regulated to obtain a semi plastic and workable consistency suitable for molding and compaction of the papercrete bricks. Papercrete bricks required being efflorescence, strength and durability. Compressive strength, Water absorption test and efflorescence Test were carried out to determine the quality of bricks in Figure 4 and Figure 5.



Figure 4. Casting and Testing of Papercrete Specimen

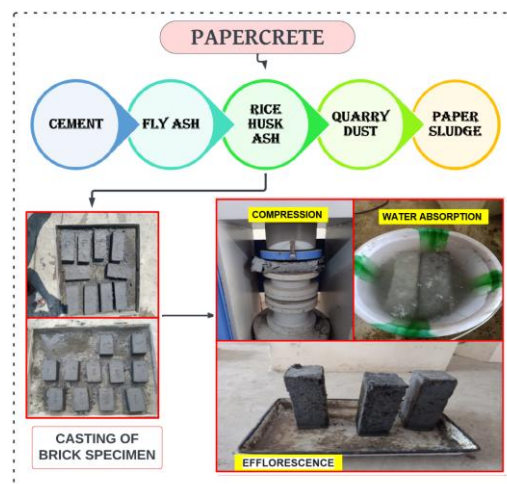


Figure 5. Overview of project

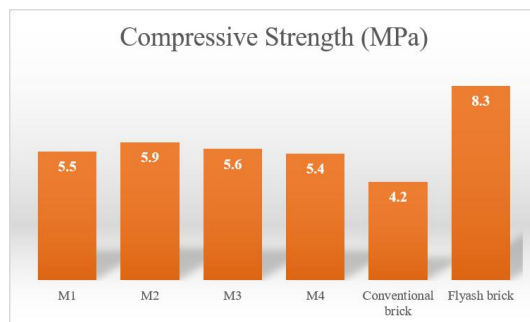
Table 4. Test results of Papercrete

S. No	Mix Name	Compressive Strength (MPa)	Water Absorption (%)	Weight of sample (kg)
1.	M1	5.5	11.9	1.08
2.	M2	5.9	10.3	1.12
3.	M3	5.6	10.8	1.05
4.	M4	5.4	11.4	1.03
5.	Conventional brick	4.2	19	3.03
6.	Flyash brick	8.3	14	2.80

Experimental Results

Compressive Strength

The compressive strength was determined using a 200-ton capacity compression testing machine (Ghosh, 2018); the results are presented in Figure 6. The specimen is subjected to a constant load until it can no longer support itself and eventually collapses (Yugasini *et al.*, 2020). The pressure that was applied had been monitored continuously. The maximum load applied to the specimens was recorded. The specimen in Table 4 undergoes a 28-day compressive strength test. In 28 days, M2 is stronger in compression than M1 and M3 by having a compressive strength of 5.9 N/mm² and which are greater than the other mix in Figure 6. Following the papercrete bricks higher than conventional brick but lower than flyash brick. The incorporation of paper sludge attributes to the overall porosity and lightweight nature of the material. Hence the paper sludge content was fixed at 2% for all mixes to maintain consistency throughout the experimental program. Therefore, the observed variation in compressive strength is primarily attributed to the interaction of the binder materials rather than the influence of paper sludge.

**Figure 6. Result on compressive strength**

Water Absorption

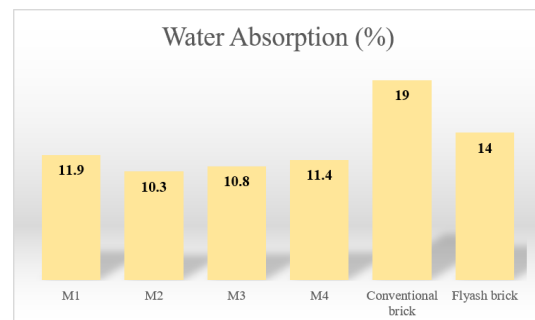
A water absorption test was performed in accordance with ASTM C67/C67M-23 (ASTM International, 2023). For 24 to 28 hours, the test specimens were immersed in

water so that their upper surfaces were at least 6 inches below the water's surface. Each specimen must be separated by at least 18 inches (Shermale & Varma, 2015). The immersed weight (W_i) of the samples is recorded when they are suspended from a metal wire and fully submerged in water. A 3/8-inch (9.5-mm) wire mesh was inserted, any visible surface water was wiped away with a moist cloth, and the mesh was allowed to drain for 60 ± 5 seconds before being weighed and recorded as W_s (saturated weight). After being dried for at least 24 hours at 212 to 239°F (100 to 115°C) in a vented oven, the weight of the desiccated specimens was measured and recorded as W_d (oven-dry weight). Papercrete's Absorption of Water is shown in Figure 7 and Table 4. Table 3 shows that the water absorption of M1 brick was moderately more than that of M2, however it remained within the 10% allowed range. Figure 7 M2 has the least water absorption when compared to M1, M3 and M4 Which is significantly lower than conventional bricks (19%) and also lower than flyash bricks (14%). The residue weight of the mixture was M1 (1.38kg), M2 (1.32kg), M3 (1.37kg) and M4 (1.27kg).

$$\text{Proportion of water absorbed} = \frac{w_s - w_d}{w_d} \times 100\%$$

Where, W_d - Weight of specimen after oven-drying (kg)

W_s - Sample's saturated weight (kg)

**Figure 7. Result on water absorption**

Efflorescence

Efflorescence is the occurrence of a white powdery substance on the surface of bricks. This phenomenon is attributed to the absorption of moisture from the air by alkaline salts present in the bricks. As the absorbed moisture evaporates, it leaves behind a deposit of powdery material. Additionally, efflorescence may be induced by the presence of pyrite in the clay used for brick production or if the water employed in the clay mixing process contains gypsum. To assess and address efflorescence, follow the steps outlined below using a set of five randomly selected bricks. This procedure helps in assessing the susceptibility of bricks to efflorescence under controlled conditions. It is crucial to ensure that the immersion depth is consistent and that the environmental conditions are maintained within the specified temperature range. By repeating the water application and drying process, any efflorescence that may occur can be observed and documented (Atlawu *et al.*, 2022). This methodology aids in understanding the efflorescence potential of bricks and is essential for quality control in brick manufacturing as per IS 3495 (Part 3):1992 (Yugasini *et al.*, 2019). The efflorescence test results indicated that the developed papercrete bricks exhibited no visible signs of efflorescence. None of the tested specimens showed the presence of white salt deposits after the testing period, confirming the absence of harmful salts within the brick matrix. This behaviour suggests that the incorporation of paper sludge did not adversely affect the durability characteristics of the bricks in terms of crystallization and surface deterioration.

Weight of the Papercrete Brick

Conventional bricks range in weight from 3 to 3.5 kg, while papercrete bricks weigh between 1 and 2 kg (Mishra, 2014). Figure 8 displays the papercrete bricks can only weigh a maximum of less than 2 kg, they are lightweight and will lower the overall cost of building because low dead load which is lower than flyash brick.

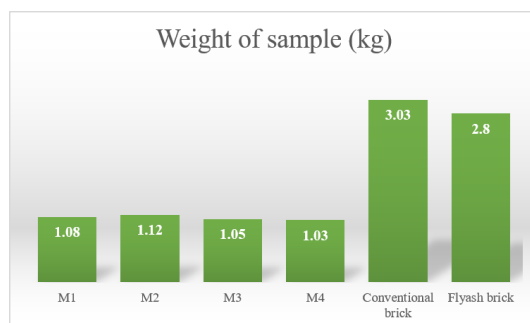


Figure 8. Weight of Specimen

Cost Benefit Analysis

The cost of papercrete bricks is between Rs.5 and Rs.6 per brick based on the current cost of materials and fact that each brick weighs roughly 1.07 kg. This is somewhat less expensive than flyash bricks which costs Rs.5 and Rs.7 each and standard burnt clay bricks which costs Rs.6 and Rs.9 per piece. Utilization of inexpensive and waste materials like paper sludge, flyash and rice husk ash is primarily responsible for the lower cost. Papercrete bricks are even more economical because of reduction in unit weight, which not only reduces material costs but also handling and transportation expenses.

Conclusion

The importance of sustainable practices in the brick manufacturing industry to mitigate the negative effects on the environment. In this research and development effects focussed on creating eco-friendly papercrete bricks that are made from Fly ash, Cement, Rice husk ash, Quarry dust and Paper sludge. To examine the quality of bricks using the following tests: compressive strength, water absorption and Efflorescence test. In M2 mix as more volume of flyash other than quarry dust and RHA which its achieved the comparatively higher compressive strength of 5.9 MPa than M3 and M4. Moreover, M2 has least water absorption values within acceptable range which is substantially lower than conventional bricks and higher than flyash bricks. The effect of paper sludge exhibited the less density and enhanced the internal bonding of the structure reduced the migration of moisture and salts to the surface. Therefore, no visible salt was observed on the specimen surfaces. Moreover, the reduction of dead load of the structure which leads to low cost construction. In addition to find the chemical composition and micro pores through SEM and EDAX Analysis for all those materials of production of bricks. In the context of promoting resource efficiency and waste management, the utilization of waste paper, fly ash, quarry dust, and rice husk also helps to create a circular economy and cost efficiency.

Funding

The author received financial support from the Tamil Nadu State Council for Science and Technology (TNSCST) under the Student Project Scheme (Grant Amount: ₹7,500) for carrying out this research.

Author Contribution

Kalaimani Ramakrishnan - Writing-Original Draft

Vigneshkumar Chellappa - Review & Editing

Karthikeyan Ganesan - Review & Editing

Dharmar sakkarai - Review & Editing

Ethic Approval and Consent to Participate

This study did not involve human participants, animals, or biological samples. Therefore, ethical approval and informed consent were not required. The experimental work was conducted in accordance with the relevant institutional laboratory safety procedures and research standards.

Declaration of Generative AI Use

The authors declare that no Generative AI tools were used in the preparation of this manuscript.

Acknowledgment

The authors are grateful to the Management and Principal of Ramco Institute of Technology, Rajapalayam, Tamil Nadu, India for providing the necessary facilities for carrying out the research work. Also, the authors are grateful for the funding agency Tamil Nadu State Council for Science and Technology (TNSCST) and thank S. Muthu Sanjay, Final year B.E. Civil Engineering, Ramco Institute of Technology, Rajapalayam, for their valuable support throughout the research work.

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