Sustainable Papercrete Bricks by Utilizing Recycled Construction Waste

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Abstract. Papercrete is an innovative and eco-friendly building material that incorporates recycled paper and reduces the reliance on cement. Its composition offers a promising solution to meet the rising demand for sustainable concrete while minimizing environmental impacts. By utilizing high volumes of paper waste, papercrete helps address the depletion of natural aggregate resources and mitigates the environmental challenges posed by abandoned paper waste globally. This research explores the potential of paper waste as a key ingredient in producing lightweight, cost-effective concrete for construction. Through a series of experiments, the study aims to optimize the papercrete mix by analyzing its compressive strength. The strength varies from 4.22 to 2.21 MPa shows the reduction with increase in pulp content. The water absorption is from 11 to 18% with increase in pulp content still in permissible limits. The focus is on reusing waste materials, such as discarded paper and debris from construction sites, to develop an affordable alternative to traditional bricks, thereby contributing to more sustainable construction practices.

1 Introduction

The global demand for paper is substantial, with approximately 450 million tons produced annually. This high production rate contributes significantly to deforestation, as 42% of global wood harvests are dedicated to paper production. The environmental consequences are severe, including deforestation, the release of chlorine-based bleaches during manufacturing, and methane emissions from decomposing paper. Additionally, the pulp and paper industry ranks as the third-largest industrial polluter globally.

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The challenge of finding adequate landfill sites further exacerbates the issue, especially in rapidly growing economies, where municipal solid waste management is a pressing concern. For instance, India generated about 62 million tons of municipal solid waste in 2015, with only 12% properly processed. The remaining 88% was dumped in unsanitary landfills or open areas, contributing to environmental hazards. Organic waste, chemical waste and many inert materials like stone dust were generated and utilization of these materials in construction field to improve properties of natural materials like soil and sub soil is practicing in recent days to safeguard the natural materials [1-2].

Building materials face increasing demand due to rapid urbanization and housing needs, leading to shortages of raw materials. This crisis has necessitated the search for alternatives, turning industrial waste into viable building materials. Repurposing waste not only mitigates environmental pollution but also supports cost-effective building designs. Among these alternatives, wastepaper offers dual benefits: addressing the need for affordable housing and aligning with the growing emphasis on sustainable construction practices.

This study focuses on developing innovative alternatives to conventional building bricks by utilizing paper waste. With the rising demand for construction materials, papercrete emerges as a promising solution. By converting wastepaper into papercrete, natural resources can be conserved while effectively managing industrial waste. Papercrete, composed of fly ash, wastepaper, quarry dust, and cement, can be moulded and dried to create lightweight and durable building materials. Low carbon footprint, low embodied energy, high strength to weight ratio, excellent thermal insulation, high sound absorption, cost-effectiveness, and aesthetics are just a few of its many benefits in the construction sector [3].

Papercrete also boasts several functional benefits. It enhances sound absorption, resists fire, fungi, and pests, and can be waterproofed using solutions like boric acid and borax. Its lightweight nature makes it ideal for interior walls in high-rise buildings, particularly in seismic zones. Using papercrete reduces the structural load, thereby lowering the steel reinforcement and foundation depth requirements [4]. Incorporating wastepaper into construction materials presents an economically viable and environmentally responsible alternative to traditional disposal methods such as landfills or incineration.

This research aims to evaluate the papercrete properties such as workability, durability and strength, to establish its feasibility as a cost-effective and sustainable building material. Studies have shown that adding 5% to 10% paper pulp to concrete enhances its compressive strength [5]. With its numerous advantages, papercrete holds immense potential to revolutionize the construction industry while addressing environmental challenges.

2 Review of Literature

Papercrete derives its name from its primary components: a blend of water, cement, and cellulose fibres sourced from recycled materials such as newspapers, lottery tickets, records, and phone books. The resulting mixture resembles oatmeal in texture and is typically poured into moulds and sun-dried to form construction blocks or panels. This innovative construction material is composed of re-pulped paper fibres combined with Portland cement, or soil. While papercrete has demonstrated sufficient strength in small-

scale structures, its long-term durability remains under study. Currently, it is predominantly used as an in-fill material for non-load-bearing walls.

However, an essential property of papercrete is its stiffness, which determines how much it compresses under load. While significantly less stiff than traditional concrete, its stiffness is adequate for supporting roof loads in low-rise buildings. This characteristic makes papercrete a viable material for specific applications, particularly in small structures prioritizing lightweight, eco-friendly construction solutions. Various waste materials like paper, plastic, stone dust, slag, organic wastes and waste ashes were used practically to improve properties of weak soil and also used as a replacement to cement. Researchers showed the improvement in soil swell and strength properties using organic waste ash admixtures. Admixtures like lime; stone dust was used to improve soil properties.

The effects of substituting Portland cement with paper pulp in M20 & M30 mixtures were investigated [6]. Replacement levels ranged from 0% to 20%, with compressive strength tests conducted at 14 and 28 days. The results revealed that higher paper pulp content led to a reduction in compressive strength. Optimal strength was observed at 5% and 10% replacement levels, beyond which the strength decreased. This indicates that a moderate inclusion of paper pulp can enhance the early strength of concrete mixtures, but excessive amounts compromise mechanical performance.

Researchers have evaluated seven papercrete mixes, replacing OPC with wastepaper pulp at varying levels from 5% to 35% [7]. A mix ratio of cement, sand, and coarse aggregate (1:1.5:2) with a water-cement ratio of 0.4 was used. Beam specimens were tested for flexural strength after 28 days of curing. Results showed increased water demand with higher paper content due to the absorptive nature of cellulose fibers. While flexural strength declined at replacement levels beyond 10%, mixes with 5% and 10% replacements demonstrated adequate bending stress, making them suitable for lightweight components such as boards, partitions, and roofing sheets.

The fine aggregate replacement with paper pulp at levels of 5%, 10%, and 15% in M30 concrete has been explored [8]. Flexural strength increased with 15% paper pulp content at 7 days. However, 28 days strength declined across all replacement levels. These findings suggest that while paper pulp can enhance short-term flexural strength, it may not sustain long-term performance. The replacement of Cement with papercrete in M25 Concrete with 10-50% has been explored [9]. The properties of papercrete vary depending on the proportions of cement and sand was emphasized. Mix with higher cement and sand content exhibit greater density and tensile strength, while those with lower sand content are less dense but also weaker. Due to these characteristics, papercrete is recommended primarily as an in-fill material within frameworks of wood, metal, or poles rather than for structural components.

The papercrete's density decreases as the proportion of wastepaper increases [10]. At a 5% paper replacement, the density was 1.88 g/cm³, dropping further at higher replacement levels. Shrinkage also increased with higher paper content. Papercrete demonstrates potential for soundproofing, fire resistance, and decorative applications. It can be moulded into shapes for furniture, flowerpots, and lightweight construction components. Adding a wire mesh can enhance its strength for specific uses. Crustacean and protein biopolymers enhanced strength of organic soil. Casein-based biopolymer reduced compressibility and enhanced durability of organic soil. Plastic waste with fly ash lowered dry density and influenced clay soil strength.

The reviewed literature highlights the potential of papercrete to improve various mechanical properties, dimensional stability, and energy absorption capacity of construction materials. Studies show that combining paper mill residues, such as wastepaper sludge ash, with fly ash, rice husk ash, or blast furnace slag can significantly enhance the strength and durability of papercrete bricks. This research seeks to establish

papercrete as a sustainable and economically viable alternative for non-load-bearing construction applications, contributing to resource conservation and waste management.

3 Methodology

Papercrete bricks, composed primarily of recycled materials, offer a cost-effective alternative to conventional bricks. These bricks are lightweight, easy to mold into various shapes, and provide a smooth surface finish. Being nearly half the weight of traditional clay bricks, they help reduce the overall dead load of a structure, making them particularly suitable for earthquake-prone regions due to their flexibility and lightweight nature. However, papercrete bricks are limited to non-load-bearing applications, such as inner partition walls, as they are not suitable for waterlogged conditions or external walls.

3.1 Details of Mix Proportions

Wastepaper serves as the primary constituent material in this study. Various types of paper, such as record sheets, old newspapers, and magazines, are utilized. Paper primarily consists of wood cellulose, a fibrous material recognized as the second most abundant natural resource on Earth after rock. Cellulose is a natural polymer composed of long chains of β-D-glucose molecules. The cellulose chains contain numerous polar hydroxyl (-OH) groups that form hydrogen bonds with adjacent chains. These hydrogen bonds play a crucial role in bundling the chains together, providing strength and stability to the material.

Robo sand, also known as manufactured sand, is produced in stone quarries or derived from leftover sand in construction waste following demolition activities. It acts as a sustainable substitute for river sand in construction applications. For this study, mix proportions of cement, Robo sand, and paper pulp were adopted in various ratios: 1:1:1, 1:1:1.5, 1:1:2, and 1:2:2. The proportions were determined by the weight of each ingredient in the mixture. Bricks were cast using these ratios, and tests were conducted in accordance with standard procedures. Observations and results were recorded after 28 days of curing.

3.2 Paper Pulp Preparation

Papers were first torn into small pieces and soaked in water for four days, allowing them to degrade into a paste-like consistency. After soaking, the softened paper was removed from the water and ground into a pulp using a mixer. The resulting paper pulp was then placed on a non-absorbent surface, with excess water squeezed out to achieve the desired consistency.

For large-scale production, the use of mechanically operated tow mixers is recommended to reduce processing time and production costs. Fig. 1 illustrates the soaking process of wastepaper, Fig. 2 depicts the grinding of soaked paper, and Fig. 3 showcases the resulting paper pulp.

3.3 Mixing of Dry Ingredients

Robo sand and cement were dry-mixed until a uniform color and consistency were achieved. In this study, the mixing process was carried out manually. The prepared paper pulp was then incorporated into the dry mix to create the desired papercrete mixture.

Additional water was not introduced unless deemed necessary for achieving the required workability. Fig. 4 illustrates the final mix comprising cement, Robo sand, and paper pulp.

Fig. 1. Soaking of Wastepaper

Fig. 2. Grounding of soaked paper

Fig. 3. Paper Pulp

Fig. 4. Final Mix

3.4 Casting of Bricks

A conventional size metal brick mould was used for casting the papercrete bricks, as illustrated in Fig. 5. The mould features an extension to facilitate handling during the brick preparation process. The prepared papercrete mix was poured into the mould within 30 minutes of mixing. The material was compacted either manually using a tamping rod or mechanically on a vibrating platform to achieve uniform density. Excess material was levelled off with a metal strike to ensure a smooth surface. The bricks were then cured and allowed to sun dry for 14 days. The hardened bricks, ready for testing and application, are shown in Fig. 6.

Fig. 5. Metal Mould

Fig. 6. Hardened Bricks

4 Results and Discussions

4.1 Water Absorption Test

The test was performed according to IS:3495 – Part 2 standards. A dry brick was weighed, then immersed in water. After 24 hours of immersion, the brick was weighed again, and the difference in weight indicated the amount of water absorbed. The test results are summarized in Table 1. According to the standard, water absorption should be less than 20% of the dry weight of the brick.

Water absorption significantly impacts the bond between brick and mortar. If bricks absorb excessive water and are not adequately soaked before masonry work, they may extract water from freshly laid mortar. This can compromise mortar strength, as insufficient water would be available for the hydration process. The test results showed that water absorption increased with a higher paper pulp content in the mix. Based on the findings, it is ideal to use paper pulp in proportions of 1 to 2 parts, as these mixes meet the required standards.

4.2 Soundness Test

The soundness test evaluates the behavior of bricks under sudden impact. Two randomly selected bricks were struck against each other. A good-quality brick should produce a clear, bell-like ringing sound and remain intact. The results indicated that all mix ratios produced a clear bell-like sound when two bricks were struck together. None of the bricks showed signs of breaking, confirming their good quality.

4.3 Hardness Test

A high-quality brick should resist scratches from sharp objects. To assess this, a sharp tool was used to scratch the surface of the brick. If no visible scratch impressions appeared, the brick was considered hard. The results showed only very light scratch impressions on the brick, indicating it has a reasonable level of hardness.

4.4 Fire Test

A construction brick should not be flammable when exposed to an open flame. The brick was first wiped clean to remove any foreign materials. Then, flammable sticks were lit in an open area, and the brick was placed directly in the open flame for 30 minutes. After exposure, the brick was inspected for any changes in size or shape. No changes were observed, confirming that the brick is fire-resistant.

4.5 Structure Test

The fractured surfaces of broken bricks were examined for any structural defects, such as holes, lumps, or inconsistencies. The results indicated that the papercrete bricks had a homogeneous structure, were compact, and were free from defects.

4.6 Compression Strength Test

The compressive strength or crushing strength, of the brick was determined using universal compression testing machine. The compressive strength values for different mix proportions are presented in Table 1.

Table 1. Percentage of Water Absorbed and Compressive Strength Values

S. No.	Mix Proportions	Percentage of Water Absorbed	Compressive Strength (N/mm^2)
1	1:1:1	11.4%	4.22
2	1:1:1.5	16.2%	3.318
3	1:1:2	18.45%	2.533
4	1:2:2	17.13%	2.21

From the above results we observed that the compressive strength of papercrete bricks is little lesser than the compressive strength of conventional bricks. The compressive strength of papercrete brick is decreasing with increase in paper pulp ratio. So, it is ideal to use up to 30% to 35% of paper pulp which gives good compressive strength.

5 Conclusions

- The papercrete brick is sound (all mix ratios produced a clear bell-like sound when two bricks were struck together), hard (very light scratch impressions on the brick), and exhibits good resistance to fire (No changes were observed in shape and size).
- The water absorption is from 11 to 18% with increase in pulp content still less than the permissible limits of 20%.
- The compressive strength of papercrete bricks varies from 4.22 to 2.21 MPa is considerable, though slightly lower than that of conventional bricks.
- The fire test conducted for 30 minutes showed no change in the shape or size of the brick. However, the bricks will eventually turn to ashes after prolonged exposure to fire. To prevent burning, applying interior plaster and exterior stucco on the fibrous concrete brick can offer additional protection.
- Papercrete bricks are lightweight, i.e. High strength-to-weight ratio making them ideal for reducing the dead load of a building, particularly beneficial in earthquake-prone areas, helping reduce both life and property losses.

- About 55% of paper waste globally still goes unrecycled and is directly disposed of. A significant portion of this waste can be used in the manufacturing of papercrete bricks, contributing to waste reduction and environmental sustainability.

6 Future Scope

This research represents an initial exploration into the use of papercrete. Further studies are necessary to modify mix proportions to achieve optimal properties, enhancing the performance and durability of the bricks and to improve color and texture to enhance the aesthetic appeal and design versatility of papercrete for broader applications in construction.

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