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DEVELOPMENT AND PERFORMANCE OF PAPERCRETE AS AN ECO-FRIENDLY CONSTRUCTION MATERIAL

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Abstract- In view of the increasing need for environmentally friendly building materials, this research examines the impact and features of papercrete (a mixture of shredded recycled paper added to concrete) as a green and innovative partial substitute for conventional concrete. The study investigates the material's feasibility for sustainable construction, with a primary focus on replacing sand. To evaluate compressive strength, different replacement levels containing 2% and 5% replacement levels of sand and cement were tested under standard curing ages, 5% cement replacement proved the remarkable decrease in compressive strength, pointing towards a deteriorated matrix and weak bonding of particles. In contrast, replacing 2% of the sand had minimal effects on compressive strength, indicating that wastepaper serves as a good lightweight filler material. But sand replacement of 5% started negatively influencing the compressive strength. The results encourage partial use of wastepaper, which can result in a sustainable, lightweight, and economical concrete appropriate for non-structural components such as partition blocks, interior walls, and plastering. The research contributes to the development of green building technology through reframing waste as a precious material.

Keywords- Eco-Friendly Concrete Mix, Papercrete, Sustainable Construction, Waste Paper Reuse

1 Introduction

The construction industry is the largest polluter, utilizing enormous natural resources and generating significant waste products. Among all the biggest building materials made up of cement, water, and sand, i.e., mortar, is among the biggest offenders for the issue. Sand digging in construction has resulted in riverbed stripping, water body alteration, and loss of biodiversity, while cement production is the biggest carbon dioxide emitter in the environment. To tackle this destruction of the environment, researchers and engineers are now turning to developing less destructive materials for use in construction, which will be able to counter environmental pollution. Papercrete is such a novel material where wastepaper is mixed with mortar as a mixture to be added to cement and sand. That 244 million metric tons of wastepaper are generated globally throughout [1], of which the bulk is destined for landfills. Recycling waste paper in construction saves waste and conserves the environment efficiently. Papercrete not only renders an individual independent of traditional materials but also provides functional benefits like lighter material weight, better thermal insulation, and reduced cost of construction. Microstructural development, which was brought about through the incorporation of paper fibers, influences the mechanical and physical behavior of mortar and must be adequately investigated for incorporation into applications.

This study is focused on waste paper as a replacement for sand and examines the physical and mechanical characteristics that are resultant from it, i.e., compressive strength. Although other past research has focused broadly on cement replacement, this study concentrates more on sand replacement as its primary agenda, a topic of great concern given the unsustainable use of sand mining worldwide. Environmental effects of over-sand quarrying, including erosion, groundwater loss, and habitat destruction, disconnected floodplains are demonstrative of the need for alternative materials[2], [3]. Through the use of waste paper in mortar, the study seeks to minimize the use of natural sand and paper wastage. Partial cement replacement is a minor aspect of the study that explores other environmental benefits. The ultimate aim is to support sustainable and green construction activities through waste management activities and the circular economy. Papercrete can suppress building waste, save natural aggregates, and make greener construction activities on a large scale viable if the product itself is good.

This study addresses the application of papercrete, a combination of mortar and shredded waste paper, as an environmentally friendly product in the building industry. The study aims at the effect of sand with processed paper in mortar. It also addresses the dual problem of environmental degradation resulting from sand excavation as well as the emerging problem of paper waste disposal. Compressive strength was tested to analyze the material's suitability for structural purposes. Cement is the major source of the carbon footprint[4]. The study also explores restrained substitution with cement to quantify additional environmental benefits. Papercrete is able to reduce the weight of the material and improve thermal performance. It aligns with the circular economy rules and promotes the conservation of resources. The study is able to make green building techniques available. The study proposes the possibility of recycling waste in a real application. Papercrete can be a strong green innovation toward sustainable and cost-effective building practice.

2 Literature Survey

The recent studies reviewed the viability of papercrete (an eco-friendly building material made of shredded waste paper, cement, and additives) in replacing conventional concrete. A researcher investigated the properties of the papercrete from a physical and mechanical perspective, stating that waste paper's viability as a construction material is dependent on waste paper decreasing material weight and increasing heat insulation, leading to an advantage [5]. However, the papercrete still does not dominate in compression, which hampers its use. The study highlighted additional refinements that needed to be made. Similarly, another researcher approved paper mills' effluent sludge as a partial substitute for lime in cement mortars with replacement rates of $5\,\% - 20\,\%$ [6]. Their findings showed that the structural strength of the mortar was not impaired with replacement up to 10%, making the material suitable for use in wall and ceiling coatings. However, this leads to lower strength from low heat of hydration, making such mixes suitable only for minor masonry repairs.

It is highly expressed that they had similar support through identical findings regarding the investigations they conducted on the papercrete composites of repulped paper fiber, cement, and sand soil. They argued that papercrete has a low density (1.07 gm/cc) and therefore is lightweight, but simultaneously ground such properties like shrinkage of 8-9% and water absorption of 30% or thereabouts [7]. Despite these limitations, the work demonstrated, to some extent, environmental sustainability due to minimizing waste and having a lower carbon footprint through the production of papercrete, as long as proper drying protocols and other measures are undertaken to increase the durability. In addition, a researcher investigated the use of waste paper pulp as a partial replacement for sand and cement in mortar cubes as an effort to reduce both the consumption of sand and the disposal of paper waste. They concluded that a 50% substitution of the sand by paper pulp achieved a 28-day compression strength of 6.6 MPa, lower than traditional mortar, but acceptable for non-bearing applications like partition walls and insulating panels [8].

Another researcher went a step further to define papercrete properties, confirming its lightness and ductility, making it more flexible and less prone to cracks. They also said its compressive strength remains inferior to traditional concrete, thereby restricting the application of this green concrete to non-load bearing structures, such as ornamentation panels, temporary shelters, and sound insulation [9].

This study nicely touches upon multiple important points that were lacking in the former studies on papercrete. Although previous research [5], [7] concentrated on the possibilities that papercrete offered as a light and green material, they provided only anecdotal confirmation of the mechanical strength using different composites. By studying and comparing

five different mortar mixes, as 2% and 5% cement and sand were partially replaced with waste paper powder, this exploration gives further clarity to the benefits of the individual material reserves, showing that it is possible to keep the structural integrity without any problems in the case of partial sand replacement. Former studies [8], [9], while agitating some failings in the area of compressive strength and humidity receptivity, were silent about relative tests with the reference blend. In this study, the experimenters do this, they lay the root for the performance evaluation being carried out. The other exploration [6] concentrated on the operation of paper sludge in mortars, but the focus was on the issue of waste operation, which wasn't covered at low relief rates. This is what the current study has accepted. This study has incompletely answered the standardization issue raised in the former workshop, as they have now easily defined the blend rates, and they have completely explained the mixing, molding, curing, and testing processes.

3 Research Methodology

3.1 Paper Fibers preparation

Waste paper from offices is collected and soaked in water for a whole day and then blended in a domestic blended until it becomes like a paste which is named as paper pulp as shown in figure 1(a). Paper pulp is dried for 24 hrs in lab oven at 100^0c as a result it comes in a form of small hard balls and then grinded in a domestic grinder to make it a powder. As a result, the paper comes in form of small fibers as shown in figure 1(b).

a)  b) 

Figure 1: Paper fibers preparation, a. Blending paper, and b. Final product

3.2 Materials

Once the recycled paper components were ready, papercrete specimens were prepared by mixing the following components:

1. Ordinary Portland cement.
2. As defined in ASTM-C109/C109M utawa sand is used[10].
3. Paper powder for which preparation is already defined is used.
4. Simple tap water is used for hydration purpose.

Table 1:Mix Proportions

Mix Name	Cement (g)	Paper (g)	Sand (g)	Water (g)
Mix 1 (A)	250	0	687.5	121
Mix 2 (B)	245	5	687.5	121
Mix 3 (C)	250	13.75	673.75	121
Mix 4 (D)	237.5	12.5	687.5	121
Mix 5 (E)	250	34.375	653.125	121

3.3 Specimen preparation

The mortar mix's proportions were predetermined, and waste paper was added as needed. These mixes were prepared using mechanical mixer as shown in figure 2(a) in accordance with ASTM C109/C109M[10], which describes the standard procedure for testing hydraulic cement mortars. The quantities of materials used for the different mix variations are listed in Table 1. In accordance with ASTM C109/C109M[10], 2-inch mortar cubes were cast for testing as shown in figure 2(b). Before casting, the cube molds were cleaned and lightly oiled to facilitate demolding. The mortar was then poured into the molds in two layers, each of which was compacted using thirty-two tamping strokes to ensure proper consolidation and uniformity.

The mortar cubes were left at room temperature for 24 hours following casting in order to facilitate the initial setting. After the initial setting period, the cubes were carefully demolded and transferred to a curing environment. Over the course of the seven-day curing period, the mortar was adequately hydrated and strengthened. The cubes were removed from the curing chamber and left outside for an additional twenty-four hours following the curing period. This step allowed excess surface moisture to evaporate, ensuring the specimens were dry before further testing and analysis.

a)  b) 

Figure 2: Casting the molds, a. Mechanical mixing, and b. Casted cubes

3.4 Testing Procedure

In compliance with ASTM-C109/C109M[10] specifications, mortar cubes were tested for individual compressive strength using a compression testing machine (CTM) after three days of curing as shown in figure 3(a). The test was conducted under strict supervision to ensure accuracy and consistency in the findings. The cube was carefully inserted into the machine, and the load was progressively increased until the mortar cube failed as shown in figure 3(b). Using the measured compressive strength values, the impact of substituting cement and sand in the mortar cube on compressive strength was evaluated.

a) 

b) 

Figure 3: Compression Testing, a. Testing setup, and b. Tested cube

4 Results

4.1 Compression test results

Compressive tests validate the impact of sand and cement replacement with waste paper on mortar cube strength. The control mix with no replacement exhibited the highest compressive strength because it reiterated the importance of traditional cement and sand for achieving structure and integrity in building materials. When waste paper replaced cement at even 2% replacement, there was sure loss of strength, that is, binding tendency of cement is necessary for providing the load-carrying ability of mortar supply. When there was a replacement of cement with 5%, there was dramatic fall-off, that is, high levels of replacement lower matrix strength and lower particle-to-particle bond. But 2% replacement of sand had minimal impact on compressive strength as shown in table 2, thus waste paper in small percentages can be utilized as a filler without affecting performance. But in 5% replacement of sand, strength started to decrease, but not as much as when cement was replaced. This suggests that although paper-like materials can replace some of the sand with minimal loss of structure, cement replacement has a far greater adverse effect.

Table 2: Compressive Strength

Mix Name	Replacement	Compressive strength (MPa)
Mix 1 (A)	No Replacement	7.95
Mix 2 (B)	2% cement	4.1
Mix 3 (C)	2% sand	7.3
Mix 4 (D)	5% cement	1.1
Mix 5 (E)	5% sand	3.95

Graphical representation of effect on compressive strength of mortar shown in figure 4. Red color is representing compressive strength of reference mix and blue color is representing compressive strength of mortar cubes with replacement.

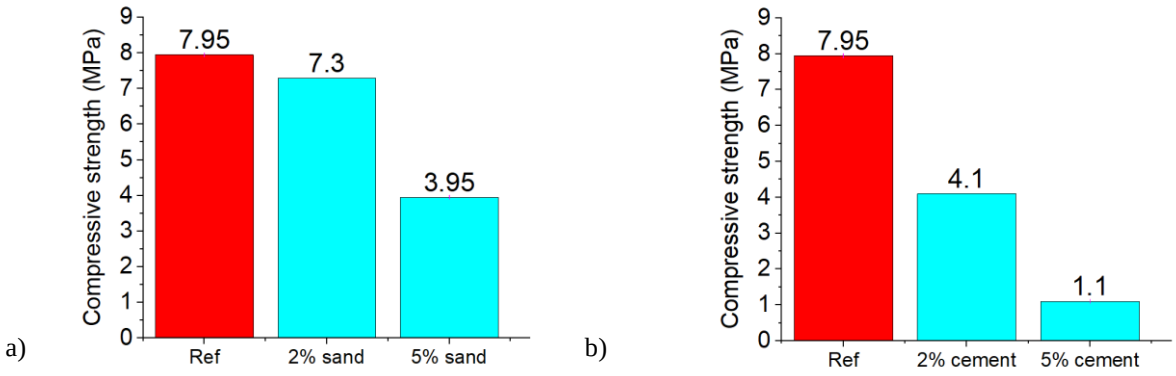

Figure 4: Effect of replacement on compressive strength, a. Sand replacement, and b. Cement replacement

5 Practical Implementation

Papercrete developed by partial replacement of sand and cement with waste paper in mortar is a highly promising approach for sustainable building. It can be successfully used in many non-load-bearing element like partition wall, internal plastering, and boundary wall especially where high structural strength is not the major consideration. The applicability of papercrete can be highly increased by optimizing the materials with further research. Improving its water resistance, durability, and mechanical properties might unlock the potential for more extensive uses. With advances in material science the production of paper-based composite blocks and prefabricated panels might become a viable reality for modular

construction in the near future. While with increasing global focus on climate change and sustainable development, papercrete emerges as the building material of the future combining a distinct eco-friendliness like waste elimination with practical advantage in construction.

6 Conclusion

On the Basis of the above experimental work results in this investigation, the following conclusions can be drawn:

- Substitution of sand had minimal impact on papercrete compressive strength demonstrating that waste paper in small quantity can serve as a filler without affecting performance.
- Waste paper increase results in compressive strength decrease.
- 2% and 5% cement replacement cause a high reduction in compressive strength which makes it unable for non-structural use also.
- 5% sand replacement also reduces the compressive strength by 50% which can be used for non – structural elements only.
- 2% sand replacement had a minimal effect on compressive strength and can be used for load bearing structures with slight modifications.

More research, though, is needed on the following areas:

- Admixtures can be used to improve setting and bonding qualities.
- Alteration in the proportion of the mix in order to realize optimum qualities.
- Incorporation of silicon, sealer concrete or epoxy resin would make papercrete waterproof.
- With additional investigation into durability water resistance and volume production processes, papercrete also stands the opportunity of being widely adopted as an element of green building processes.
- Papercrete should be assessed for the long-term performance and resistance to environmental degradation before use as paper-based materials notoriously susceptible to moisture and biodegradation.

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