Performance analysis of Papercrete in presence of Rice husk ash and Fly ash

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Abstract. Papercrete is a modern composite material, that uses waste paper as a partial replacement to Portland cement, and is a renewable medium to construction owing to the reduction of the volume of waste paper as well as cement. Papercrete has strong sound absorption, thermal insulation and a low-cost alternative; light weight and fire-resistant building material. However, its low mechanical strength needs to be compensated by incorporation of supplementary cementitious materials. The work discusses the potential for the partial replacement of cement (by weight) with waste paper pulp in presence of Rice husk ash (RHA) and fly ash (FA) in ternary blends. For tests, the levels of replacement for RHA and FA were 10%, 15%, 20% and 25% and for waste paper, the rates of replacement were maintained at 10%. A reference mix was also prepared for the comparative purposes without substitution by RHA, FA and paper pulp. The flow, compressive strength, split tensile strength, water absorption and dry density studies were performed for all the specimens. The findings revealed decreased the flow of specimens compared with the reference mix along with reduction in strength that was well compensated by RHA and FA particles. The optimal content for RHA blends was 20% and that of FA was 15% with maximum strength among the mixes. The study signifies that the waste paper can be used to prepare papercrete in presence of optimal content of supplementary cementitious materials to have desired mechanical properties.

1. Introduction

The emerging market for building materials needs to satisfy all the challenging demands for short-term and long-term structural efficiency [1]. The building materials of tomorrow will have to meet more stringent performance standards than those in practice today, as they will be more elaborative and more complex [2]. A huge amount of money is required for large housing construction activity in developing countries. Building materials account for about 70% of the total cost to build housing [3]. The growing popularity in the construction industry of renewable, inexpensive and lightweight building materials has led us to explore ways to accomplish this through the conservation of the environment and the preservation of standards-supported material requirements [4]. Bricks are the most frequently used building materials in building construction worldwide as one of the oldest building materials [5]. The bricks are moulded into rectangular blocks in uniform size, and the blocks are dried and burned. The bricks can be arranged correctly as they are uniform in size. But it does have two main disadvantages, self-weight and fragility. The brick-making method has not changed in India...
for decades, except for a few minor refining steps. In our country, there was little effort to improve the process of making bricks to improve brick quality. The structures were also not drastically modified in view of their compressive strength, structural stability and relatively low costs [6].

Initially developed 80 years ago, Papercrete was only recently re-discovered as a small-scale concept. Papercrete is a cement fiber paste made of Portland concrete and waste paper combined with water to produce a pulp of paper cement, which can then be poured into a mold to dried and then used for long term building [7]. The processing of Papercrete does not contain hazardous by-products or an unnecessary use of energy. Papercrete can be either fibrous, padobe or fidobe type. A mixture of paper, portland cement and water is a fibrous papocrete. Padobe has no cement and is a blend of paper and water in presence of clay as a binding medium [8]. The standard brick can crack during drying when the clay content is too high, but with paper fibres in the earth mix the drying block strengthens. This offers stability to avoid cracking. Fidobe is like padobe, but other fibrous material may be found there. Paper is a natural polymer consisting of the most plentiful organic compound in the planet i.e. wood cellulose. Cellulose is water insoluble, although it contains many hydroxyl groups. The reason is because the chains are rigid and hydrogen bonds are present in adjacent chains between two OH groups [8]. The chain gets coiled consistently in places, forming strong, stable crystalline regions that increase stability and strength in coiled chains. The strength of papercrete is founded on this hydrogen-bonding. Applying force on the surface, breaks the hydrogen bonding between the water and cellulose molecule. Coating of Portland cement on cellulose fibres produces a cement matrix to give the blend extra strength [9].

The use of industrial waste of various forms for production of building materials is a new era for building technology in the construction industry. In the last few years waste rubbers, glass powders, fibres, waste sawdust and calcareous waste in powder have been taken into greater account for manufacturing buildings [6]. This is fully comprehensible because the economic progress of construction is becoming more and more recognized as more dependent on intelligent use of materials and constant improved materials. In the last decade, a great demand has been placed on the construction materials industry because of the increasing population which causes a chronic shortage of building materials [10]. The situation has posed a challenge to civil engineers to turn industrial wastes into usable construction and building materials. Increased environmental concern also resulted from an accumulation of unprocessed waste in developing countries [11]. In addition to the problems of pollution, the economic design of buildings can be dealt by using waste in building material as a viable option. The existing knowledge pool of papercrete reveals very little existing research and further studies are required to explore further potential [12]. The literature analysis indicates that the amount of paper significantly affects the mechanical properties, dimensional durability and structural integrity of papercrete [13]. The analysis also reveals that the inclusion of residual paper mill waste including waste paper sludge and ash, greatly gives the necessary strength and longevity to the bricks [9]. In most of the studies, the industrial and natural waste such as fly-ash, rice husk ash, and blast furnace slag has been used to improve the strength and other properties, including durability, usability, water absorption capacity, etc [5].

Fly ash is a combustion by-product of coal in thermal stations, removed as fine particle residue from gases before being released into the atmosphere [14]. The tests on fly ash-based bricks demonstrate their suitability to meet the requirements for traditional clay brick specified in ASTM C 216. The cemented brick in the ASTM C 55 and the standard specification for papercrete structural brick also fall within the acceptable shrinkage limits. The process used in fly ash-based bricks is estimated to reduce almost 90% of the construction energy [6]. RHA is another excellent pozzolan used in construction materials. Adding RHA to the concrete mix even in low replacement will dramatically increase the workability, strength and impermeability of concrete mixes, and making the concrete durable to chemical attacks and abrasion [15]. The aim of the present analysis is to manufacture new
type of environmentally friendly papercrete bricks by the use of waste materials such as paper, fly ash and rice husk ash to study the strength and durability of papercrete bricks for commercial use in construction works. An experimental program was conducted to investigate the strength and other technological properties of fly ash based papercrete bricks such as dry density, water absorption percentage and tensile strength.

2. Materials and Methods

The main materials for the papercrete are paper and cement. Waste papers from nearby places were collected, and any foreign materials such as pins or threads etc. were removed. Table 1 provides the physical properties of paper. In this study, the entire work was made of 43 grade Ordinary Portland Cement. In addition, fly ash and/or rice husk ash were added in presence of sand. In this study, fly ash was collected from nearby thermal power plant while rice husk was procured from the local supplier and converted to ash. The chemical and physical properties of cement, fly ash and rice husk ash are given in Table 2 and Table 3 respectively. The natural sand used in the study confirmed to zone-II. After chopped in small pieces, the paper pulp was obtained by pulverizing the chopped pieces after dipping in water for 15 days. Excess water was removed by filtration under pressure. The details of the mixed proportions used during the study are given in Table 4. The dry components were sprinkled and uniformly mixed manually over the required amount of paper pulp and then transferred to the mechanical mixer. The wooden mold lined with machine oil on the inner surface were used. Papercrete fibrous mix were poured into the mold in three layers and were hydraulically compressed to obtain bricks with 230 mm x 110 mm x 70 mm in thickness. The specimen was tested for the metallic sound on the brick surface after 15 days and coated externally with waterproofing admixture after having been dried in the air. The compressive strength and split tensile strength were examined according to IS:3495-1992 recommendation. Test for percentage of water absorption and dry density was performed according to ASTM C-67 standards.

| Properties | Values |
|------------|--------|
| Weight     | 47 GSM |
| Thickness  | 0.06 mm|
| Moisture   | 7.5%   |
| Bursting Strength | 168 kPa |
| Tearing resistance | 12.6 kg |
| Tensile Strength   | 1.13 kg |
| Porosity       | 475 mls/minute |

Table 2. Chemical Composition of Binder Materials

| Oxides | OPC | FA | RHA |
|--------|-----|----|-----|
| % by mass | % by mass | % by mass | % by mass |
| SiO₂  | 19.46 | 61.65 | 91.81 |
| Al₂O₃ | 4.22  | 25.86 | 2.23 |
| Fe₂O₃ | 3.56  | 9.56  | 1.95 |
| CaO   | 65.92 | 13.78 | 0.97 |
| MgO   | 1.08  | 2.33  | 1.92 |
| K₂O   | 0.67  | 1.57  | -   |
For all papercrete blends, the flow results are shown in Figure 1. The RHA and FA presence decreased the flow rates as compared to the reference mix. The percentage decreased for flow was observed as 10%, 17%, 23%, 30% respectively at 10%, 15%, 20% and 25% of RHA. Paper fibres can retain water being composed of hydrophilic cellulose. This results in an increased thickness and compact matrix of the papercrete [2]. Addition of RHA has been reported to result in a decline in the workability of the concrete [15]. Results also demonstrate that with the RHA rise, the flow rate declined continuously for all the specimens as compared to the reference mixture [16]. Hence, the combined effect of RHA and paper pulp result in an overall decrease in the flow of the papercrete.

With FA at 10%, 15%, 20% and 25% substitution levels, the reductions in flow were 7%, 7%, 14%, 18% and 24%, respectively. This drop in flow levels is compatible with results reported in literature indicating that although FA has been reported to improve the workability of the concrete, yet the presence of waste paper fibres reduce the slump because the extra water absorbed by the paper fibres compensate the effect [14]. The literature reports that paper fibres absorb water more quickly and effectively than ordinary Portland cement particles resulting in a significant decrease in flow [2]. Moreover, as shown in Figure 1, the FA blends show comparatively more workability than the RHA blends. The finesse of FA in comparison with RHA particles results in better enmeshed structure that can attribute to this behavior [17].

3. Results and Discussions

3.1. Flow
3.2. Compression Strength

Figure 2 demonstrates the compressive strength measurements of the 7-and 28-day specimens. For RHA mixtures, it has been shown that the compressive strength decreased by 24% and 35% at 7 and 28 days respectively in comparison to the reference mixture, with cement being substituted by 10% RHA in presence of 10% paper pulp. This decrease can be due to the role of paper fiber waste which degrades compressive strength due to poor cohesive forces between CSH gel and cellulose particles and decreased amount of cementitious material [8]. By comparison, substitute dosage greater than 10% (15%, 20% and 25%) the compressive strength declined by 16%, 9%, and 13%, respectively and by 19%, 8% and 13% at 7 and 28 days, relative to the reference mix. Literature reports that inclusion of RHA results in enhancement of compressive strength that compensates the negative effect of paper pulp addition and comparatively lesser decrease is obtained in the strength [16]. However, the slight decrease in compressive strength at 25% RHA can be attributed to the increase in friction among the particles at high dosage of RSH [15].

Results revealed that the substitution of 10% of cement with FA provided better results as compared to the RHA blends. Such results have been in line with the literature [17]. At a substitution level of 10%, the strength for FA blends, decreased by 22% and 19%, respectively, at 7 and 28 days. Literature also reports similar results [4]. This degradation can be explained by the loss of cemented activity of the FA in presence of paper due to loss of proper binding. In comparison, at substitution levels of 15% to 20%, the compressive strength levels have been reduced by lesser amount. The reduction rates at 7 and 28 days were 3% and 2% (for a replacement of 15%) and 9% and 6% (for a replacement of 20%). The findings of this analysis are consistent with the pozzolanic effect of FA that produces the strength enhancing CSH gel occupying the cement matrix and compensates the decrease in compressive strength contributed by the low level of silica in paper pulp [14]. However, as the substitution amount of FA was enhanced further to 25%, a slight decrease in compressive strength was observed that may be attributed to the better pozzolanic action of FA at an optimum content and after that satisfactory results are not obtained [18].
3.3. Split Tensile Strength

Figure 3 shows the effects of the RHA and FA incorporation on the split tensile strength of specimens at 7 and 28 days. For RHA, the substitution of cement with 10% RHA resulted in a degradation in the tensile strength of the cement mortar in consistence with the compressive strength analysis. The results are coincidental to that of the earlier studies reporting that the tensile strength decreased with introduction of paper pulp. The effect has been assigned to the weak binding between cellulosic fibers and CSH gel [9]. Compared with the reference mix, the reduction was 20% and 16% at 7 and 28 days in presence of 10% paper pulp. Increased cement replacement ratios with RHA to 15%, 20%, and 25% resulted in 14%, 10%, 12%, and 14%, 10%, and 11% decrease in tensile strength at 7 and 28 days, respectively, as compared to the reference mix. Addition of cellulose fibres from the paper pulp has been reported to result in a decreased split tensile strength as compared to reference mix [8]. However, the addition of RHA introduces the fibres that counterattacks the strength deterioration effect of cellulose fibres. This effect is aided by the fine microparticles of RHA that strengthens the binding between the binder particles and regulates the matrix cracking tendency [15]. Fiber intervention will work in two ways: first by space filling, where it is properly designed to avoid the breakage of microcracks in large amounts, and second, by “bridging” the microcracks, which increases the bonding between the two sides of a crack and therefore increases the tensile strength [19].

The 10% cement substitution ratio for FA produced comparable results at 7 and 28 days to that of RHA blends. In addition, there was a decrease of 3%, 6%, 8% at 7 days and 3%, 6%, 9% at 28 days for 15%, 20%, and 25% FA substitution. A similar behavior has been found in past studies with pozzolanic activity of FA particles [14]. The presence of fine particles fills the voids and the production of CSH gel increases the bonding, thereby increasing the density and the tensile strength. Further, as the number of voids in the matrix reduces, it increases the tensile strength [18]. However, best results were obtained at 20% RHA and 15% FA in presence of 10% paper pulp that can be amounted as the optimal content of the supplementary cementitious materials.
3.4. Water Absorption %

Figure 4 shows the effects of RHA and FA in presence of 10% paper pulp on water absorption % at 28 days. For RHA, tests have shown that these mixtures were having significantly lower water of absorption than the reference mix but for the substitution dosage of 10% RHA, the results were similar. The presence of cellulose fibres from paper has been reported to decrease the water absorption [20]. Further, higher the level of substitution by RHA, lower the water absorption % was observed. At the replacement dosage of 20% RHA with 9% lower value than the reference mix, the maximum decrease was reported. The large number of voids got occupied in the presence of high quantities of fiber that consequently lead towards a increased density leading to decrease in absorption of water [21]. Studies revealed that water absorption was not improved even in the case of FA mixtures. Water absorption decreased by 5% for the 10% FA dosage, compared to the reference mix. However, the water absorption of the specimens decreased more with the increase in the replacement dosage by 15%. These results are consistent with past studies and have been attributed to the pore filling effect and pozzolanic action of FA [22].
3.5. **Dry Density**

Figure 5 illustrates the results of dry density tests for all blends at 28 days. For RHA, the findings showed that the 10% substitution resulted in approximately 1.2% increase in density relative to the reference mix. This increase may be due to the fibrous properties which enable water to be absorbed and retained in the sample during mixing and thus boost the sample density [3]. In comparison with the reference mix, substitution levels above 10% resulted in density increase of 4%, 11% and 8%, respectively, for the replacement content of 15%, 20% and 25%. This is because increased microparticles of RHA occupy the voids in the matrix which increases the density [16]. The results on FA blends have demonstrated that presence of FA particles in the mix increased the density of the papercrete. The increase obtained was 6%, 9%, 7% and 7%, respectively, compared with the reference mix for 10%, 15%, 20% and 25% substitution content of FA. These results coincide with that reported in the literature with increase in density of the matrix by replacement of air voids by microparticles of FA [17].
4. Conclusion
Based on the study, the following conclusions can be drawn:
1. Replacing cement with RHA and FA in presence of 10% paper pulp has a detrimental effect on the flow of the papercrete. With the rise in the replacement percentages, the flow of all mixes decreased relative to the reference mix.
2. As compared to the reference mix, the compressive and split tensile strength was found lesser for all the mixes at 7 and 28 days of curing. However, among the RHA mixes, maximum compressive and split tensile strength was obtained for 20% RHA in presence of 10% paper pulp. On the other hand, among the FA mixes, maximum compressive and split tensile strength was obtained for 15% FA in presence of 10% paper pulp.
3. The substitution of cement by 10% paper pulp in presence of RHA and FA decreased the water absorption of all the mixes as compared to the reference mix. However, minimum water of absorption was obtained at 15% FA in presence of 10% paper pulp followed by 20% RHA in presence of 10% paper pulp.
4. Maximum dry density was obtained for the strengthened samples. Hence, 15% FA in presence of 10% paper pulp and 20% RHA in presence of 10% paper pulp can be stated as the optimal content for improved properties of papercrete that can be used for practical applications.

References
[1] Stevulova N, Schwarzova I, Hospodarova V and Junak J 2016 Implementation of waste cellulosic fibres into building materials Chem. Eng. Trans. 50 367–72
[2] Hospodarova V, Stevulova N, Briacinc J and Kostelanska K 2018 Investigation of Waste Paper Cellulosic Fibers Utilization into Cement Based Building Materials Buildings 8 43
[3] Chen M, Zheng Y, Zhou X, Li L, Wang S, Zhao P, Lu L and Cheng X 2019 Recycling of paper sludge powder for achieving sustainable and energy-saving building materials Constr. Build. Mater. 229 116874
[4] Shibib K S 2015 Effects of waste paper usage on thermal and mechanical properties of fired brick Heat Mass Transf. und Stoffuebertragung 51 685–90
[5] Muñoz P, Letelier V, Muñoz L and Bustamante M A 2020 Adobe bricks reinforced with paper & pulp wastes improving thermal and mechanical properties Constr. Build. Mater. 254
[6] Vashistha P, Kumar V, Singh S K, Dutt D, Tomar G and Yadav P 2019 Valorization of paper mill lime sludge via application in building construction materials: A review Constr. Build. Mater. 211 371–82
[7] Yun H, Jung H and Choi C 2011 Mechanical properties of papercrete containing waste paper ICCM International Conferences on Composite Materials pp 1–4
[8] Zaki H, Gorgis I and Salih S 2018 Mechanical properties of papercrete ed T S Al-Attar, M A Al-Neami and W S AbdulSahib MATEC Web Conf. 162 02016
[9] Kubba H Z, Nasr M S, Al-Abdaly N M, Dhahir M K and Najim W N 2020 Influence of Incinerated and Non-Incinerated waste paper on Properties of Cement Mortar IOP Conf. Ser. Mater. Sci. Eng. 671 012113
[10] Malaiskienne J, Kizinievic O, Kizinievic V and Boris R 2018 The impact of primary sludge from paper industry on the properties of hardened cement paste and mortar Constr. Build. Mater. 172 553–61
[11] bin Mohd Sani M S H, bt Muftah F and Rahman M A 2011 Properties of Waste Paper Sludge Ash (WPSA) as cement replacement in mortar to support green technology material 2011 3rd International Symposium & Exhibition in Sustainable Energy & Environment (ISESEE) (IEEE) pp 94–9
[12] Ahmadi B and Al-Khaja W 2001 Utilization of paper waste sludge in the building construction industry Resour. Conserv. Recycl. 32 105–13
[13] Dalmay P, Smith A, Chotard T, Sahay-Turner P, Gloaguen V and Krausz P 2010 Properties of
cellulosic fibre reinforced plaster: influence of hemp or flax fibres on the properties of set gypsum. *J. Mater. Sci.* 45 793–803

[14] Bui N K, Satomi T and Takahashi H 2019 Influence of industrial by-products and waste paper sludge ash on properties of recycled aggregate concrete *J. Clean. Prod.* 214 403–18

[15] Molaei Raisi E, Vaseghi Amiri J and Davoodi M R 2018 Mechanical performance of self-compacting concrete incorporating rice husk ash *Constr. Build. Mater.* 177 148–57

[16] Chopra D, Siddique R and Kunal 2015 Strength, permeability and microstructure of self-compacting concrete containing rice husk ash *Biosyst. Eng.* 130 72–80

[17] Rukzon S and Chindaprasirt P 2009 An Experimental Investigation of the Carbonation of Blended Portland Cement Palm Oil Fuel Ash Mortar in an Indoor Environment *Indoor Built Environ.* 18 313–8

[18] Kearsley E P and Wainwright P 2001 The Effect of fly ash content on the compressive strength development of concrete *Cem. Concr. Res.* 31 105–12

[19] Fapohunda C, Akinbile B and Shittu A 2017 Structure and properties of mortar and concrete with rice husk ash as partial replacement of ordinary Portland cement – A review *Int. J. Sustain. Built Environ.* 6 675–92

[20] Gomes L M, Aroche A, Schafer M, Erhart R, Moraes C A M, de Campos Rocha T L A and Brehm F A 2014 Influence of Cellulose Pulp Waste in Plastering Mortar *Key Eng. Mater.* 634 222–34

[21] Siddique R, Singh K, Kunal P, Singh M, Corinaldesi V and Rajor A 2016 Properties of bacterial rice husk ash concrete *Constr. Build. Mater.* 121 112–9

[22] Mardani-Aghabaglou A, Inan Sezer G and Ramyar K 2014 Comparison of fly ash, silica fume and metakaolin from mechanical properties and durability performance of mortar mixtures view point *Constr. Build. Mater.* 70 17–25