INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

Preliminary Study on Paper Bricks as Affordable Building Units

Ogbodo, John Friday[1], Bako, Janet Omoyeni[2] and Oluyori, Raymond Taiwo[3]

[1,3]Department of Metallurgical and Materials Engineering, Kogi State Polytechnic, Lokoja, Nigeria.
[2] Department of Mechanical Engineering, Kogi State Polytechnic, Lokoja, Nigeria.

Received: 10 January 2023; Revised: 21 February 2023; Accepted: 24 February 2023; Published: 24 March 2023

Abstract: - This work focuses on the production of paper bricks as affordable building units. Sample preparation involved blending of cement at a proportion of 10 – 50wt.%, and sand at constant proportion of 20% in paper pulp and poured in a mould. The procedure describe in ASTM C942-99 was used for compressive, flexural and splitting tensile strength of the produced bricks using universal testing machine. Permeability test was carried out using capillary suction test in accordance with ASTM C 1585-13. Apparent porosity, water absorption and volumetric binding properties of the bricks were measured using mathematical relations. It was observed that increasing cement content brought about reduction in porosity of the paper bricks and promote dimensional stability of the bricks. The results also showed that capillary absorption reduced with increasing cement content while permeability decreased with cement content up to 40wt.%. The compressive strength of the bricks is enhanced with rise in cement content, the flexural strength increased with curing ages and splitting tensile strength increased with rising cement content at varying densities. The microstructural studies revealed significant closure of the pores thereby improved the mechanical properties and reduced water absorption capacity of the produced bricks. The research shows that there were enhanced properties in the produced composite bricks.

I. Introduction

Paper is an ecofriendly cellulose fiber, made from wood and other tree plants. It has been used for several years to pass written information and knowledge from one end to another. Paper occurs in different forms like office paper, newsprints, cardboards and others. Office papers and newsprints are used in documenting facts, recording events, and transferring information to end users. After the content (by way of writing/printing/typing) has been exhausted for the purpose they are meant for, they are discarded and disposed. One of the ways via which they are being disposed is by burning. Aside the fact that, burning constitutes environmental hazards, it also contributes to global warming. Paper materials are most times disposed not because they have degraded in structure, but because the written/printed/typed content are no longer needed. Scientists have developed ways of recycling the wastes which is by de-inking and reprocessing in the production of new forms of paper. Another way in which the papers have been reused is by its usage in the development and production of papercrete. Researches in the area of structural engineering employed paper as coarse aggregate in the development of lightweight concrete. According to, papercrete are concrete kind of materials made by the mix of sand, cement and paper in various proportion such that the paper is introduced as additive. Obtained composite is light weight, less energy consuming, ecofriendly, and economicalwhen compare with conventional concrete (Shermale, 2015).

Over the years, there has been clamor from different quarters for the reduction of prices of building materials which is rising beyond the reach of common man. The high cost is partly responsible for high housing deficit been recorded in most countries. Alternative materials are developed to tackle the challengeof which recycled pulp is a very good green alternative for construction of low-cost houses (Ajibola, 2014).

Similar kind of composite is paperbricks which are bricks composite made using paper pulp as matrix. The bricks, though not widely accepted, are made from the blend of paper (matrix), cement, sand and any other relevant additives. Utilization of such bricks in masonry for the construction of cost effective environmentally friendly structures (either partially or fully) provide a way of tackling national housing challenge. In realizing that, proper mix and combination must be achieved. Paper bricks are not commonly used attributed to no stipulated standards and legislations as touching their properties and usage. Hence, available standards for comparison of properties are the ones stipulated for sandcrete, fired bricks and fly ash bricks. Series of work had been done in recent years in the recycling of waste paper into paper bricks and the outcomes has shown great results (Moura, 2005).

Regardless, many of these researches were tailored onto evaluating mechanical and thermal properties, of which only few considered water absorption properties while fewer considered durability performance of such bricks as related to water medium. Knowing fully well that paper bricks are perceived to be susceptible to water attack which has brought about less patronage, there is need to access properties like porosity, water absorption, capillary suction, water permeability and volumetric swelling in order to ascertain the use of such bricks in the long term. One reason for the low reliability of paper for structural use is the tendency of degradation when exposed to water owing to hygroscopicity and hydrophilicity of pulp paper. High porosity and water retention

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

have been a major challenge faced in paper bricks. Understanding of this necessitate the initiative of adding a well graded building material (sand) as pore filler, giving impetus for pulverization and sieving of natural sand to -150 µm in the present investigation. Another objective of this study is to consider cement proportion that will yield optimum hydric performance in paper bricks (Zhang, 2020).

On that note, present study was conceived to design paper bricks with cement from 10 to 50 wt. % and fine sand at 20 wt. % and employ curing periods of 14, 28, 45 and 90 days. Hydric properties and mechanical were evaluated so as to ascertain the best cement proportion that will yield optimum performance and also to appraise adequate hydration periods to achieve the same feat.

II. Material Preparation

Waste office papers were collected from a book store and soaked in water for 4 days. Paper pulp grinder was utilized in grinding into slurry. The slurry was poured into a sack and compressed to allow dripping of water. This was followed by sun drying for another 14 days. Natural sand collected was washed and transferred into a plastic container half full of water. The mixture was left for 4 days to allow less dense impurities float after which the supernate was poured away. The process was followed the second time and the left-over sand was sundried (for 4 days) by spreading on a wooden platform. Sundried sand was further oven dried at 110ºC for 12 hours to reduce moisture content to the barest minimum. Following this was pulverization using laboratory pulverizer (model TMT 23KH6) and sieving, employing an electric sieve shaker. Afterwards, the sand sieved to -300 µm was collected and oven dried at 110^{O}C for 12 hours before been used in sample preparation. Ordinary Portland cement (grade 43) utilized as binder and strengthener which was procured from a local vendor was tested for some inherent properties.

Sample Preparation

Sample preparation involved blending of the cement (Fig. 1a) at 10, 20, 30, 40 and 50 wt. %, 20 % constant sand proportion as shown in Table 1.

Table 1: Mix Proportion

Cement (wt.%)	Sand (wt.%)	Paper Pulp (wt.%)
0	20	80
10	20	70
20	20	60
30	20	50
40	20	40
50	20	30

Sequel to this, was the vibratory compaction of samples at 2 MPa for 5 mins. The samples were left in the moulds for 24 hours before been ejection from the moulds. Fresh samples were cured for 14, 28, 45 and 90 days in polythene bags and tested after each curing age to access their properties in accordance with standard procedures.

Test evaluation and procedure

Preliminary tests were conducted on materials used to determine inherent properties and the result presented in Table 2-3.

Table 2: Properties of waste paper (WP).

Property	Value
Consistency	5.4 %
Density	0.61 g/cm^3
Water retention value	48.9 %
Specific gravity	1.28
Grammage	98 g/m^2
Drainage time	12 mins

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

Table 3: Chemical composition of pulp

Chemical composition	Amount (%)	Elemental Composition	Amount (%)
Cellulose	59.8	Oxygen	46.5
Hemicellulose	18.4	Carbon	38.9
Lignin	4.9	Hydrogen	8.2
Ash	9.3	Sodium	0.06
Others	7.6	Silicon	2.2
		Calcium	0.8
		Others	3.34

Properties of the paper pulp highlighted in Table 2 shows that paper pulp utilized in this study is light (0.61 g/cm^3) with high water retention value of 48.9 %. High content of oxygen and carbon indicated in the elemental composition value (Table 3) confirmed high content of cellulose in the pulp (Table 3). Other element present are hydrogen, silicon, calcium and others. Microstructural image of the pulp revealed inherent paper fibers which readily attach to hydrates products formed thereby enhancing bonding. In a view to enhance close packing and reduction of porosity within the matrix for enhanced properties, as received sand was processed and graded. Fineness modulus of 1.85 was achieved in the sand, via milling from the "as received state" and sieving to -300 µm before blending with the pulp.

Tests carried out on samples prepared (Fig. 2a) was to evaluate porosity, cold water absorption at 24 hrs. and water absorption at 5 hrs. boiling, volumetric swelling, capillary absorption and water permeability.

Characterization of samples

Porosity and water absorption

Porosity and water absorption was measured in accordance with ASTM C642-06 (24 hrs. and 120 days cold water immersion and boiling at 5 hrs.) were examined in line with using cylindrical samples with initial dry weight of sample measured in air while the weights of soaked samples after been suspended in water and air were measured. Evaluation was done with the use of equations 1 and 2 for porosity and water absorption respectively:

$$\text{Apparent porosity (\%)} = \frac{M_1 - M_2}{M_1 - M_3} \; x\, 100\ \% \qquad (1)$$

$$\text{Water absorption} = \frac{M_2 - M_1}{M_1} \; x\, 100\ \% \qquad (2)$$

Volumetric swelling

24hrs and 120 days volumetric swelling was assessed by measurement of dimensions (length, width and height) of the brick sample to obtain initial dry volume and final volume after 28 days water exposure to arrive at final volume. Assessment was done by the application of equation 3. Volume was calculated as length x width x height

$$\text{Volumetric swelling (\%)} = \frac{V_1 - V_2}{V_1} \; x\, 100\ \% \qquad (3)$$

Water permeability

Water permeability was examined by subjecting cube samples to constant pressure of 0.75 N for 72 hrs, as enshrined in A. C. (2013). With regards to ASTM (2013), capillary suction test was evaluated on cube sample (100 mm). One surface of the sample was exposed to water while the other sides were covered with wax and water sorption was measured at 6 hours interval for 7 days employing equation 4 in the evaluation of sorptivity coefficient.

$$\text{Capillary water suction (sorptivity) coefficient} = \frac{M_a - M_b}{At^{0.5}} \qquad (4)$$

Compressive strength

Evaluation of the compressive strength was done using a universal testing machine (U-H 1000B) in compliance with" Method of tests for strength of concrete" ASTM C942-99(2004) Cube (100 mm length) was utilized and examined at a loading rate of 30 KN/min.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

Flexural strength

Flexural strength was determined on brick samples of dimension 400 x 100 x 100 (mm^3) with span length of 300 mm employing universal testing machine "Method of tests for strength of concrete" ASTM C942-99(2004).

Splitting tensile strength

Splitting tensile strength was probed with the cylindrical samples in line with "Method to test splitting tensile strength" (1999).

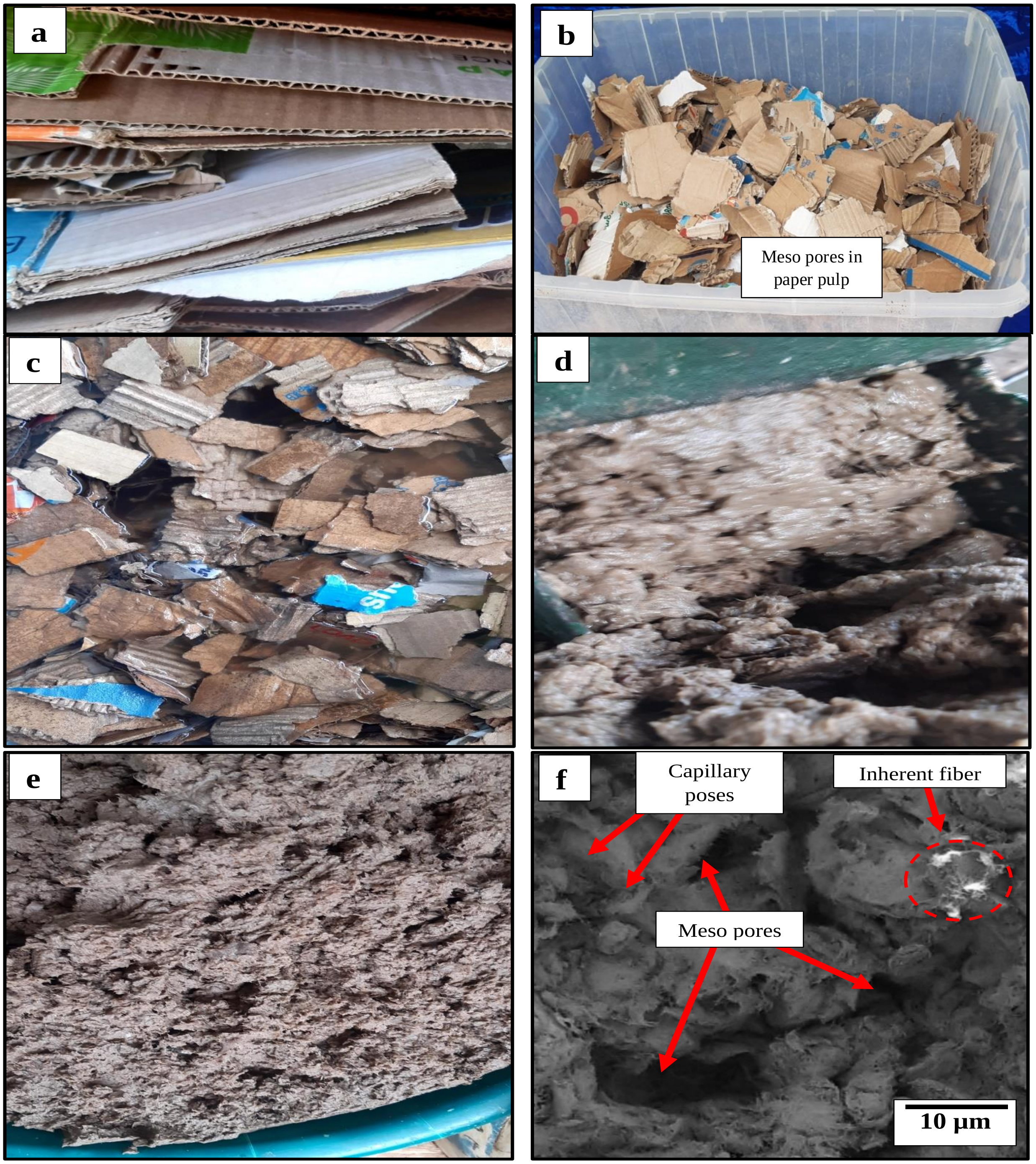
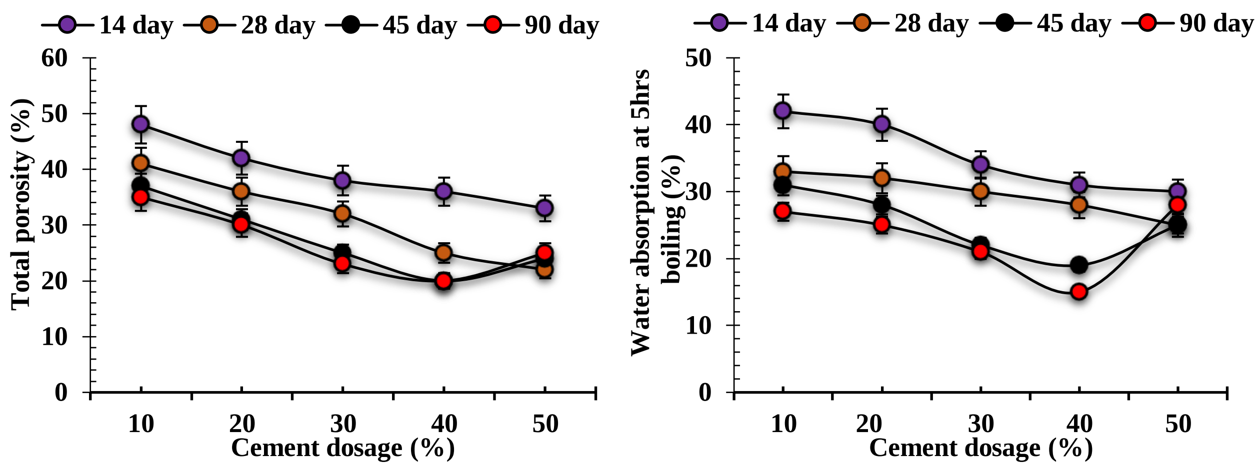


Fig. 1. Overview of the preparation process (a) collection of waste cardboards (b) shredding (c) soaking (d) grinding (e) microstructural image of the pulp (f) some of the preparedcylindrical and (g) cube specimen.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

III. Results and Discussion

Porosity and water absorption at 5 hrs. boiling



(a) (b)

Fig. 2: Significance of variation in increasing cement dosage and hydration period on (a) porosity (b) water absorption (5 hrs. boiling)

Fig. 2a shows that with increasing cement dosage, porosity trended downwards even at lengthened hydration period, further reducing pore volume. The observation is linked to formation and accumulation of more hydrates in the matrix system. It was noted that porosity reduced from 44 % for 10 % cement mix (at 14 days curing) to the lowest 20 % at cement dosage of 40 % (curing ages of 28, 45 and 90 days), a reduction of 58.3 %. That notwithstanding, pore volume increased slightly on inclusion of 50 % for all curing periods except 14 days which reflected progressive depreciation in pore volume as cement content increased from 10 to 50 %. Porosity increase associated with cement content of 50 % cement for ages of 28, 45 and 60 days is attributable to internal defects within the matrix; possibly presence of micro-crack. Initial stage of hydration is symbolized with evolution of heat and high rate of chemical reaction of which at that high proportion of cement in the mix (50 wt. %), the fast reaction rate could be responsible for initiation of micro-cracks owing to excessive shrinkage within the matrix of cement ceramics.

Macro-cracks were not observed owing to ability of the inherent cellulose fiber of the pulp to arrest cracks within the matrix. As curing periods lengthened, rectification of micro-cracks is made within the system by repair of cracks and pores, through infilling with hydrates; which leads to decrease in water absorption even at higher curing ages. However, the amelioration process may not lead to complete repair of the cracks, leaving the matrix vulnerable to higher porosity.

Another reason may be caused by the existence of low water to cement ratio content. Cement content is high at 50 % cement relative to free/interstitial water content; hence, hydration process was unable to complete or halted at a point; effectuating lower pore volume refinement. Third reason may be on the dint of increased gel pores during hydration reaction. As hydration process increased with time, more hydrate gels are formed and in the course of hydration reaction, gases are evolved thereby creating gel pores. Also, there is micro shrinkage ensuing increasing capillary pores which has tendency of contributing to higher porosity at that cement portion of 50 wt. %. This insinuates that incorporation of cement up to 50 % by weight of waste pulp, may not be ideal for paper bricks or may require higher water: cement ratio for sufficient cement hydration.

In line with existing standard, brick samples which porosity are ≤ 30 % are fit for low cost masonry. In that case, samples composing 30 % cement (cured for 28, 45 and 90 days), 40 % cement (cured for 28, 45, 90 days) and 50 % (cured for 28, 45, 90 days).

Samples were exposed to boiling water for 5 hours and it was observed that water absorption at boiling reduced with higher cement content as well as higher curing ages (Fig. 2b). Throughout the process, none of the samples tested crumbled or collapsed, though some were characterized with dissociation of some sand particles in water. For specimen containing 10 % cement and cured for 14 and 28 days, it was noted that there was dissociation of sand particles in water. This can be attributedto the lower bond base within the matrix on account of lower proportion of cement to sand. This observation can be traced to gradual and

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

effective weakening of the pores through macro cavity in the pulp ensuing more water absorption. With lengthened days of curing, the value reduced and this can be due to stronger bond with higher curing ages. The blending of cement at 50 % produced a different response when compared with others. The value increased and this could be as a result of the presence of the micro cracks and increased capillary and gel pores at that proportion, which occurred on the dint of high rate of reaction, high amount of residual energy and high shrinkage induced within the system at high cement proportion but lower water (water-cement) content. This study denotes that lengthened curing ages favor lower value of water absorption while cement proportion of 50 % at water cement ratio of 0.26 may induce higher water absorption. Samples incorporated with 40 and 50 wt. % cement (cured for 28 days), 30, 40 and 50 wt. % cement (cured for 45 days) and 30 wt. % and 40 wt. % (cured for 90 days), met existing standardfor masonry applications. When comparing values obtained in this study with the ones reported in(interlocking clay bricks) values in this study is higher, however with increased curing ages, the values are at par.

24 hrs.-water absorption and volumetric swelling

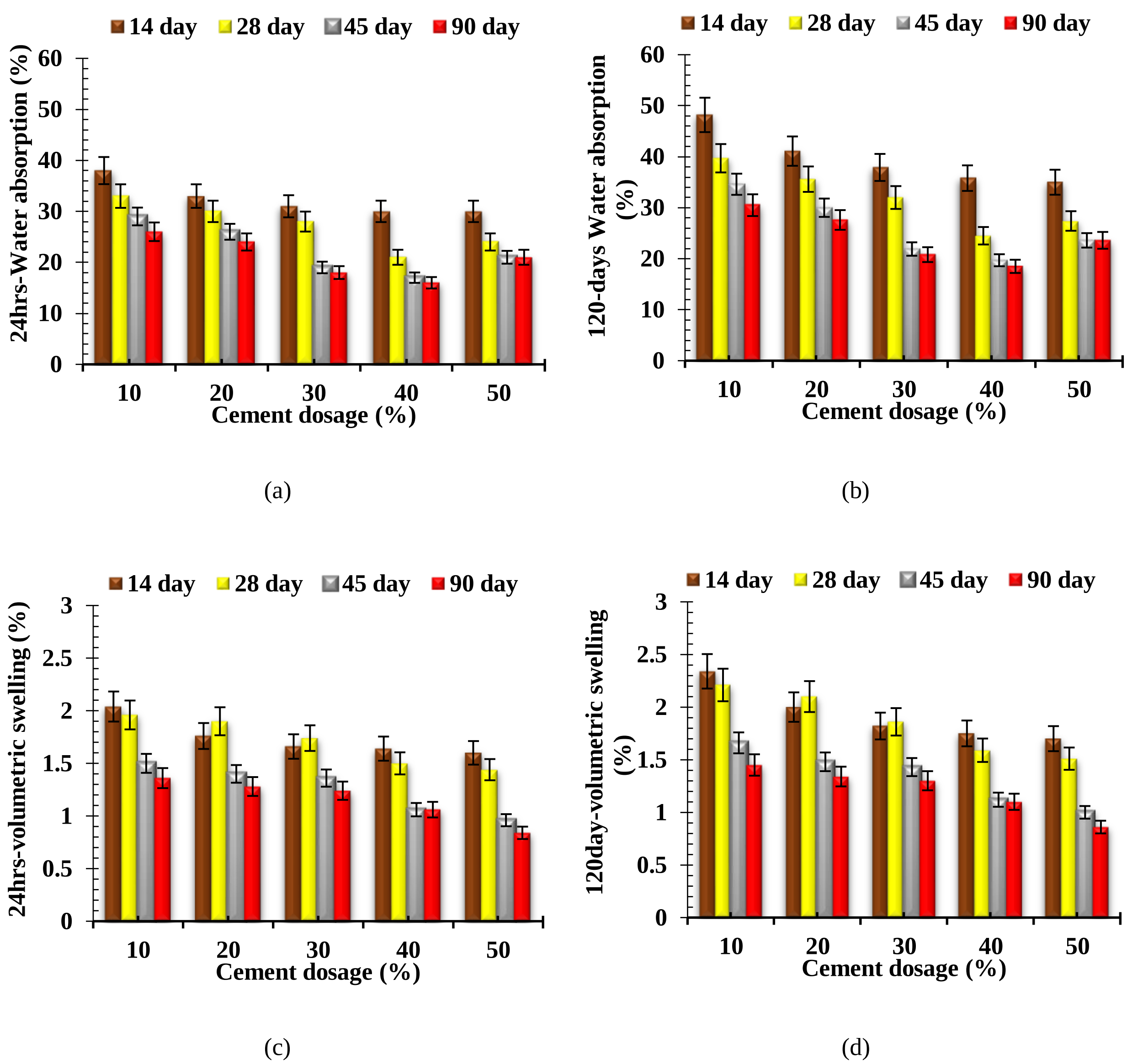


Fig. 3:Significance of variation in increasing cement dosage and hydration period on (a) 24 hrs cold water absorption (24 hrs. immersion) (b) 30 days water absorption (24 hrs. immersion) (c) 24 hrs. immersion volumetric swelling (d) 30 days volumetric swelling

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

Water absorption is dependent on porosity in that more cavities amounts to higher water absorption and vice versa. With reduction in total porosity, water uptake is bound to lessen which is depicted in Fig. 3b. As cement increased, 24hrs-water absorption trended down. Hardened cement hydrate coat over pores within the matrix prevents water penetration. Coupled with this, is the repulsion of water molecules from the cement-sand bond. Another reason linked to lower water absorption with increasing cement/sand ratio is reduction of paper pulp matrix down to 40 % as well as strong bond attachment between cement and paper fibers. From Fig. 5b, two specific observations are made; first of which is the progressive decrease in water absorption on increase of cement dosage from 10 % to 40 %. Within the frame, value of water absorption was observed to reduce from 44 % at cement mix of 10 % (cured for 14 days) to 16 % at 40 % cement (curing period of 90 days). This revelation implies that increasing proportion of cement between 10 to 40 wt. % for cement at water cement ratio of 0.26 effectuates lower water absorption on the consequence of depreciation in total porosity.

Second; at 50 % cement, water absorption was noted to change uptrend attributable to increase in capillary and gel pores as earlier discussed under porosity. The study therefore revealed a downswing in water absorption values as a result of increasing proportion of cement up to 40 % and longer curing ages.Tracz*et al*., (2019) signifies water absorption value (for 24 hours immersion) of ≤ 20 % for load bearing bricks, hence, samples containing cement 20 % (cured 90 days), 30 and 40 % (cured for 60 and 90 days) satisfiedTracz*et al*., (2019) requirement. Paper has been used as additives in the development of paper-concrete, named papercrete. In most of these studies water assimilation was observed to increase with increasing paper content. In other studies, where cement was used as binder in paper pulp for paper bricks, the uptake was noted to reduce with increasing cement content similar to the outcome of present study. Comparable work carried out in Kim(2010) and Andreola et al, (2005)affirms observations presented in this study. Values obtained for 24hrs. Water absorption is still higher than the ones of sandcrete as observedfor 28 days of curing, however, with increased curing duration, 24 hrs. Water absorption behavior are almost similar.

120 days water absorption followed the same trend as that of 24 hrs. in that, its value decreased progressively from 10 to 40 wt. % cement while 50 days initiated slight increase (Fig. 3b). For samples cured for 14 days, percentage rise in water absorption from 24 hrs. to 120 days. are 21.5, 18.5, 15.9, 13.2, and 9.7 % for 10, 20, 30, 40 and 50 % cement respectively. It shows that increasing cement content displayed lower level of water absorption between 24 hrs. and 120 days. 28th day curing resulted in 14.3, 11.9, 8.3, 6.6, 5.8 % rise with regards to the cement content respectively. 45 days curing ensued 12.5, 7.8, 4.7, 3.9, 3.0 % increase while 90 days hydration yielded 9.6, 6.7, 4.2, 2.7, 2.5 % appreciation in the water absorption at 120 days exposure to water. From these observations, samples cured for 14 and 28 days showed significant increase in 120 days water absorption as compared with that of 24 hrs (since increase > 5 %). In the same way, samples containing 10 and 20 % which were cured for 45 and 90 days had significant rise in 120 days water absorption relative to 24 hrs water absorption. Meanwhile, samples of 30, 40 and 50 % cement cured for 45 and 90 days displayed insignificant rise, hence are said to maintain water absorption capacity over 120 days period. Consequently, 30 to 50 % cement and curing days of 45 and 90 days are recommended for bricks which may be exposed to moist environment. The slight increase experienced is attributed to gradual widening of the capillary pores of the water. As cement content increased from 10 to 50 %, the rise in water assimilation trended downwards, a feat linkable to the impermeable bond engendered by hydrates.

Volumetric swelling of paper bricks when exposed to water is a crucial parameter to be assessed in order to ascertain the dimensional stability in water for 24hrs and 100 days; a factor that determines the serviceability and reliability of the brick in a wet environment. Absorption of water affects volumetric swelling in that higher water absorption portends higher tendency of volumetric swelling, however, not in all cases. Water absorption is dependent on pore volume while volumetric swelling is a function of cohesion between matrix at water saturation. As espoused in Fig. 3c, the value was observed to decrease progressively with rising cement proportion on account of strong bond created within matrix. Equally, higher curing duration ensued enhanced dimensional stability within water content. This implies that increasing cement and curing duration enhance dimensional stability when immersed in water over 24 hrs. Adopting values lesser than 6 % standard as prescribed for dimensional stability of bricks, cement proportion up to 40, and 50 wt. % with curing ages of 45 and 90 days suffice.

Fig. 3d illustrates the 120 days volumetric swelling which is percentage rise in volume of samples on exposure to water for such duration. As noted, volumetric swelling reduced as cement proportion increased while curing days also led to lowering of the value, similar to the occurrence of 120 days water absorption. Increasing cement proportion from 10 to 50 % spawned progressive reduction in 120 days volumetric swelling assignable to the strong bond with increasing cement content. In comparison, percentage increase in 120 days volumetric swelling relative to 24 hrs. swelling is 15.1, 11.3, 8.6, 6.3, 5.4 % at 10, 20, 30, 40 and 50 % cement content respectively for samples cured for 14 days while for 28 days, the increase is 12.6, 9.2, 6.4, 5.2, 4.6 %; implying that 50 % cement content in paper brick composite showed insignificant increase in volumetric swelling at 100 days immersion. 10, 20, 30, 40 and 50 % cement in the composite kindled 10.5, 7.4, 4.6, 3.7, 3.1 % increase in swelling for samples cured for 45 days. By implication, cement content of 30, 40 and 50 % reflected dimensional stability at 120 days swelling for curing period of 45 days. In the same vein, the same dosage of cement in samples cured for 90 days resulted in 7.1, 4.8, 4.1, 3.1 and 2.8 % rise in swelling

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

for 120 days. Hence, samples cured for 90 days, 20 to 50 % cement maintained dimensional stability in paper bricks for 120 days swelling. **Deduction**; increasing cement content promote dimensional stability of paper bricks when immersed in water for 120 days period.

Capillary absorption and water permeability

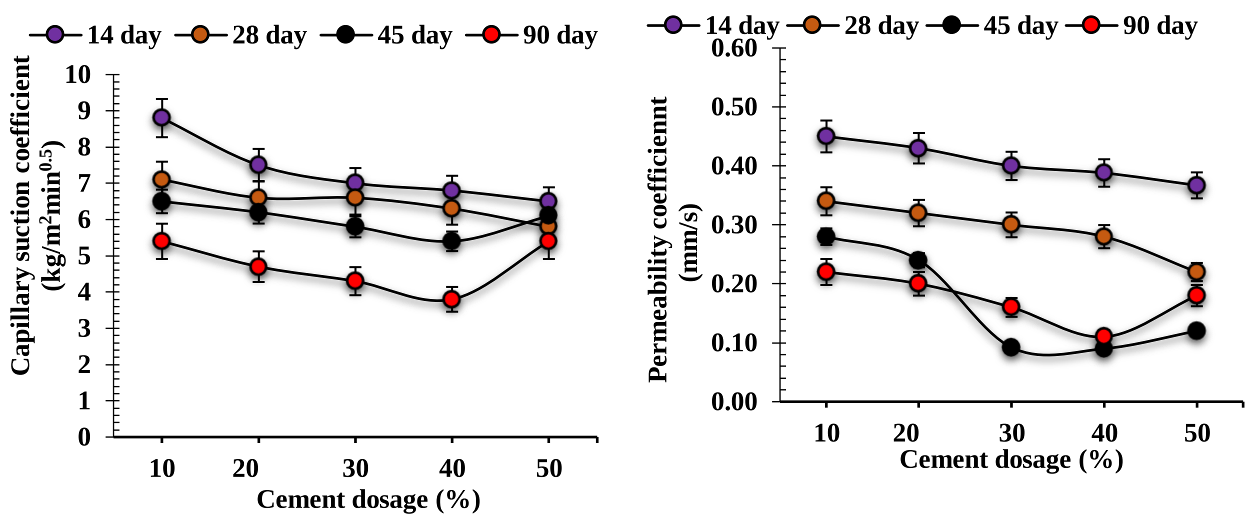


Fig. 4: Significance of variation in increasing cement dosage and hydration period on (a) capillary suction(c) water permeability coefficient

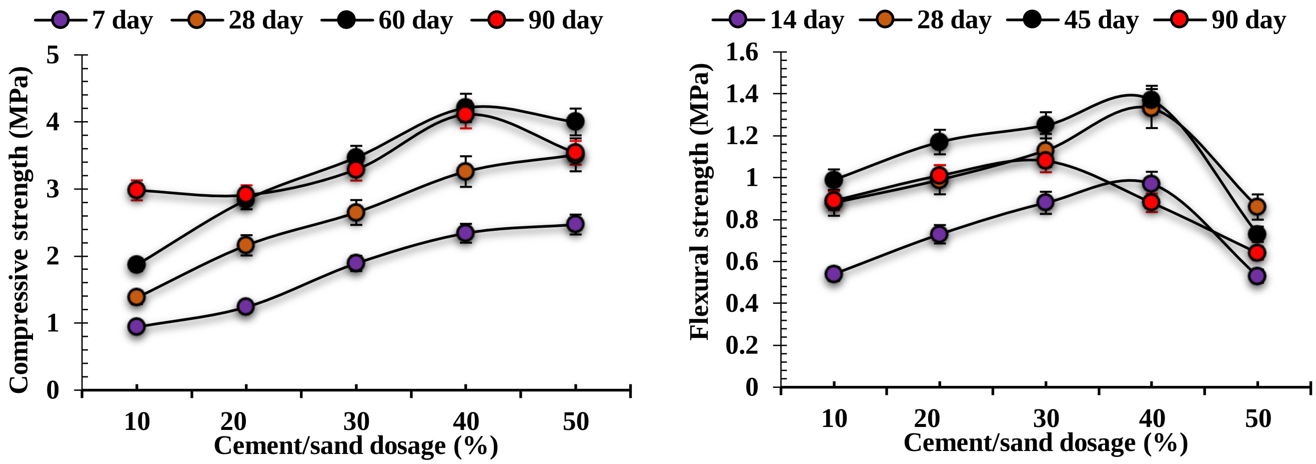
Capillary moisture absorption in bricks is an important parameter based on the effect of moisture on durability of bricks especially since paper matrix has tendency to exhibit hygroscopic and hydrophilic behavior. Moisture absorption must be minimized to ascertain long term performance of paper bricks. As observed, capillary absorption reduced progressively with increasing cement proportion from 10 to 40 wt. %. The performance can be linked to reduced capillary pores based on formation of C-S-H gel which filled and cover pores. Also, formation of water impermeable bond between cement and sand aid reduction of capillary pores consequence of which led to lower moisture absorption as cement increased. Significance of curing duration on capillary suction is exhibited in Fig.4a. With prolonged curing duration, capillary suction coefficient reduced significantly. As curing duration increases, more stable water impermeable coats are formed within the matrix which results in lowering of moisture absorption.

Conversely, it was observed that the value increased for samples containing 50 % cement proportion cured for 45 and 60 days. This might be due to rise in capillary voids as discussed previously. Results realized under capillary suction observed in this study is higher than the values realized owing to discrepancy in matrix.

Permeability relates to the rate at which fluid permeates the pores of the bulk material. It depends on pore sizes especially the ones of sizes 120-160 nm and their connectivity. Already filled pores has less permeability. It is affected by water to cement ratio, degree of compaction and curing duration. Under 14 and 28 days (Fig.4b), permeability coefficient was observed to reduce progressively with cement loading on account of reduced porosity and capillary micro pores. This is further boosted by hydration period in that increasing hydration period led to further reduction in the permeability. Formation of water impermeable coats which increase in volume with curing periods played important role in lowering permeability coefficient. At 45 and 60 days, permeability reduced with rising cement content up to 40 wt.% cement, and at 50 wt. % cement, there was steady rise. The rise is associated with possible defects initiated in the matrix at that weight percent. Values recorded in this study is higher the ones recorded for concrete inwhich is linked to the fact that permeability is lesser in concrete bricks than paper bricks. Only samples containing 30 and 40 wt. % cement cured for 45 days satisfiedstandard requirement for bricks.

Compressive and Flexural strengths

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023



(a) (b)

Fig. 5: Effect of variation in cement: sand ratio and curing days on (a) compressive strength (b) flexural strength.

Compressive strengths of paper brick composite developed with varying proportion of cement proportion of 10 to 50 % cement are as presented in Fig. 5a. The chart is characterized by two features with respect to fraction of cement portion, first of which is improvement of compressive strength observed when cement dose increased from 10 to 40 % and the second which is the depreciation observed on infusion of 50 cement. The increase in strength is as a result of more hydrates produced which strengthens internal bond, resulting in rise in compressive strength. The decrease in strength at 50 % fraction could be traced to residual stress effectuated by the heat of hydration leading to distortion (enhancing brittleness) within the matrix.

With respect to curing days, results of the compressive strength expressed in Fig.5 can be categorized into 3 regions. Region 1 is between 14 and 28 days of curing, second between 28 and 45 days where the strength values for samples reached their crescendo and the third is between 45 and 90 days. Gradual increase in strength from 14 – 28 days (first region) can be interrelated with gradual acceleration period and gradual formation of C-S-H on the surface of C_3S. The percentage rise between 14-day compressive strength and 28 days value is between 39 and 73 %. It was noted that at cement portion of 50 %, the percentage increase was the highest 62 and 79 % respective increment as compared with others owing to high cement content undergoing fast acceleration rate. Between 28 and 45 days, percentage increase in strength was 9.3, 13.8, 20.1, 21.6, 11.6, 5.2 for cement content of 10, 20, 30, 40, 50 % respectively. The increment was gradual but slower than what was obtained in region 1 attributable to slower rate of hydration process in the deceleration period. This stage is characterized by lower proportion of water which consequently affected hydration, slowing down reaction. It was observed that between cement content of 10 to 40 %, percentage increase rose gradually, however, at cement proportion beyond 50 %, there was a fall. The decrease can be linked to reduction in free water within the system at cement of 50 %. Implication is that at cement proportion of 50 % experienced appreciable enhancement at the acceleration period but reduced enhancement at deceleration period opining more water will be

Flexural strength relates to resistance to bending in a given structure. Hardened matrix is noted to have lowering effect on flexural strength of ceramic bricks. The strength was observed in Fig. 5b to appreciate with increasing fraction of cement which is provoked by stronger bond strength. It should however be noted that at cement fraction of 40 to 50 %, flexural strength reduced as compared with what was attained at cement fraction of 30 %, owing to brittle nature of matrix. Values appreciated with increasing curing ages as a consequence of stability in hydrate phases formed amounting to stronger bond strength. Flexural strength is aided by the inherent fibrous nature of the matrix which forms a strong bond with cementious material. Flexural strength rose in high proportion between 14 and 28 curing days in the range of 28 to 132 %, based on the higher rate of formation of hydrates which ensued stronger bond with inherent fibers of the base material. Between 28 and 45 days, the increment in strength was in the range of 4 and 24 % lower than what was obtained under 14 to 28 days. This is spawned by the steady but slower formation and accumulation of hydrates which formed strong bond with cellulose fibers. The slow action transpired as a result of depletion in the free/interstitial water within the system. Having emphasized that, it was noted that maximum value of flexural strength was attained with 40 % cement fraction under 28 days, serving as region in which point of inflection is realized. Considering what happened between 45 and 90 days, there was no increase observed, instead there was reduction varying between -24 to -7 %, insinuating that there was reduction in strength between 45 and 90 days, accruable to the brittle nature of the matrix at that point. It can be inferred that for optimum value in flexural strength, curing should be between 7 and 28 days. Results obtained in this study agrees that; flexural strength

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

increase with curing ages. In line with all samples fit in for masonry as per flexural strength except samples incorporated with cement fraction of 10 and 50 % (cured for 7 days), 50 % (cured for 45 days), 40 and 50 % (cured for 90 days).

Splitting tensile strength

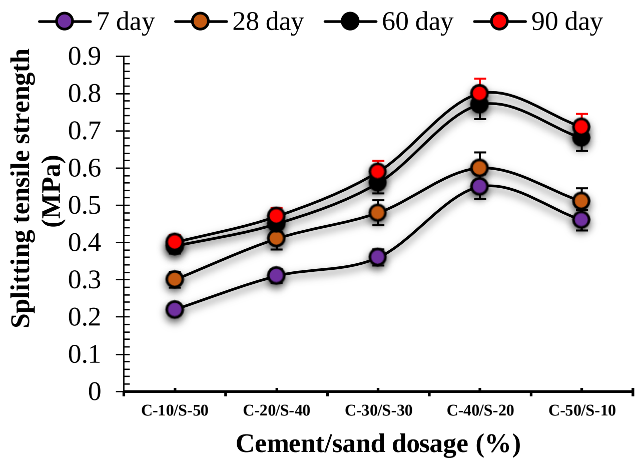


Fig. 6: Effect of variation in cement: sand ratio and curing days on the splitting tensile strength

It's an indirect tensile strength evaluation of cement composites. Proportion of cement had influence on tensile strength as the value was enhanced with cement dose from 10 to 40 wt. % for all curing ages. This may be attributed to enhanced bond strength and reduced proportion of sand.Addition of 50 wt. % cement reflected decrease in strength relative to value attained at 40 wt. %. This may be probably due to brittle matrix as a result of storage of residual stress.

Effect of storage duration on the property is also unveiled in Fig. 6. Increasing curing age from 14 to 90 days led to progressive enhancement of the strength for all proportion of cement. Splitting tensile strength of concrete developed shows increasing value with lengthened curing days. Similar study also follow the same trend as observed in this investigation as splitting tensile strength was enhanced over curing days. Studies showed increasing splitting tensile with rising cement content from density of 850 to 1150 kg/m^3 of which 1200 kg/m^3 cement addition led to decrease. At 45 days of curing, 85, 90, 92, 92 and 96 % of the 90-day splitting tensile strength was attained for cement proportions of 10, 20, 30, 40, and 50 wt. % respectively yielding average of 90 % for all cement proportions.

Microstructural Analysis

In order to observe influence of hydration period on the microstructure of developed composite, microstructural examinations of samples containing 40 wt. % cement cured for 14, 28, 45 and 90 days were examined. The images are represented in Fig. 7 a, b, c, d respectively. As observed, Fig. 9a indicate inherent pores in the structure of the sample cured for 14 days. Equally, hydrate phases are observed which occurred on account of hydration reaction within 14 days. In Fig. 7 b, c and d, observation made is in the increment in hydrate phases identified within the matrix. Higher curing ages effectuate higher hydration reaction resulting in increased proportion of hydrates. Increased hydration enhances pore refinement, over curing ages leading to property improvement which led to reduction in porosity and water absorption. Reduced porosity aided reduction in capillary pores leading to lowering of capillary suction and water permeability. Distinct features are the hydrate phases which increased with curing days owing to increased hydration reaction with storage days. The hydrates enhanced bond within matrix resulting in lowering of volumetric shrinkage as curing days increased. Consequence of this was reflected in the enhancement of compressive, flexural and splitting tensile strengths. Sand particles, were also observed to fill pores as highlighted in Fig. 7 b, c, d which also contributed to reduction of water susceptibility of the bricks.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

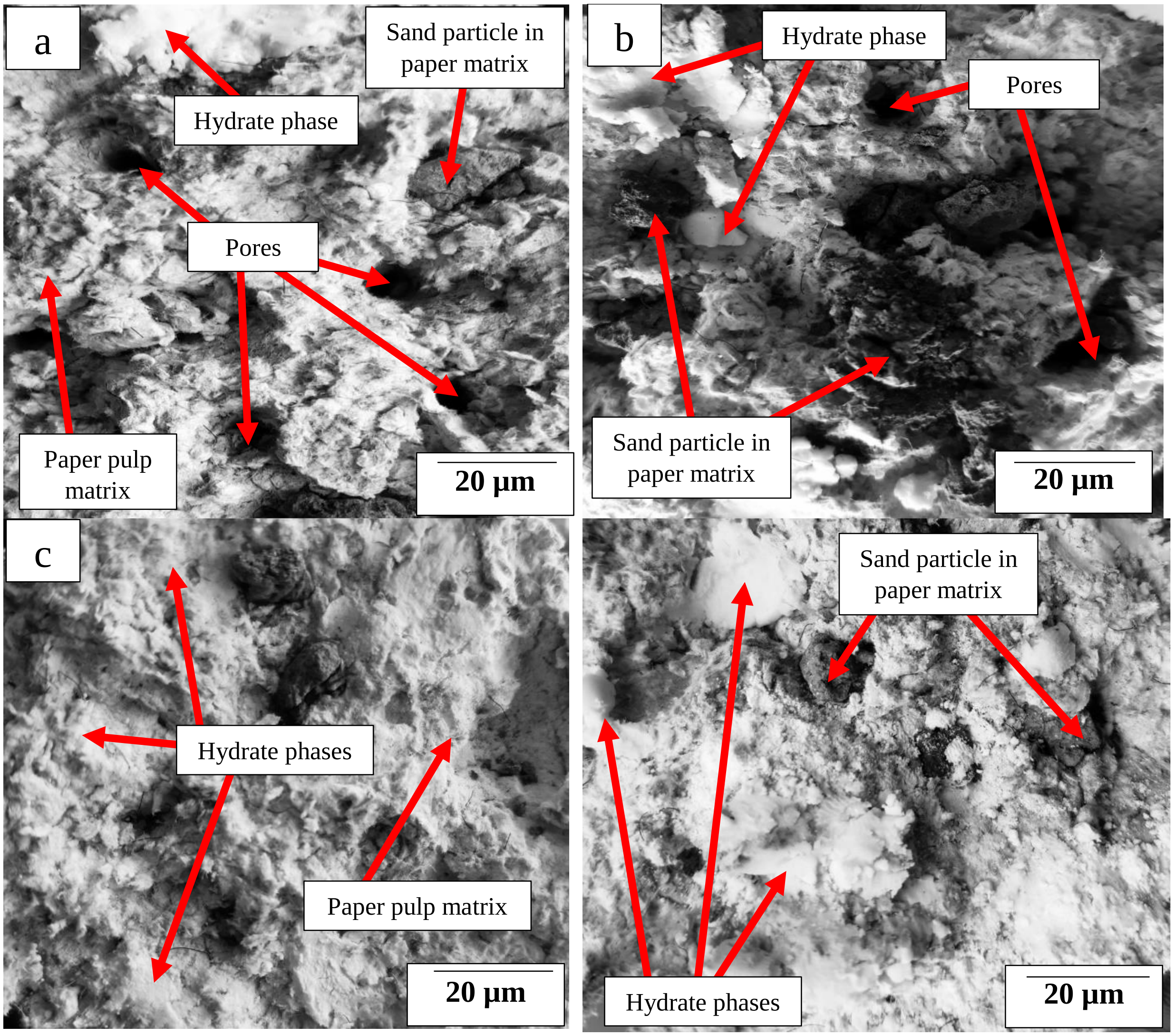


Fig. 7. SEM images of samples containing 40 wt. % cured for 14, 28, 45 and 90 days.

IV. Conclusion

The following conclusions can be drawn from this work:

1. Paper pulp was successfully incorporated into sand and cement to form a composite
2. Porosity of the paper brick reduced with increasing cement content
3. Mechanical properties of the paper bricks were enhanced with excellent mixture of the sand and cement ratio
4. The excellent microstructural properties obtained lowered the water susceptibility of the

References

1. Akinwande A. A. (2020). Cement and Bricks: Property Evaluation and Performance-Cost Analysis. Term Paper, Federal University of Technology, Akure. Nigeria.
2. Apebo, S., Shiwua, A., Agbo, A., Ezeokonkwo, J. and Adeke, P. (2013). Effect of Water-Cement Ratio on the Compressive Strength of Gravel-Crushed Over Burnt Bricks Concrete. Civil and Environment Research. 3(4), 74-81.
3. ASTM. C. 1585-13, "Standard test method for measurement of rate of absorption of water by hydraulic-cement concrete,"

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XII, Issue III, March 2023

ASTM Int. West Conshohocken, PA, 2013.
4. ASTM C642-06, Standard Test Method for Density, Absorption, and Voids in Hardened Concrete
5. B. Alabi and J. Fapohunda, "Effect of increase in the cost of building materials on the delivery of affordable housing in South Africa," *Sustainability*, vol. 13, no. 1772, pp. 1–12, 2021.
6. C. M. Ikumapayi and S. L. Akingbomire. Effect of elevated temperature on splitting tensile strength of OPC and BLA pozzolanic concrete and mortar. FUOYE Journal of Engineering and Technology. 2(1), 124-128.
7. D. Chesta, A., Tofanica, B., Puitel, A., Nicu, R and Gavrilescu, "Environmentally friendly cellulosic fibers from corn stalk," *Environ. Manag. J.*, vol. 17, pp. 1765–1771, 2018.
8. E. C. Mpakati-Gama, "The use of alternative building materials in developing countries: Addressing challenges faced by stakeholders.," in *Global challenges in construction industry*, 2012, pp. 266–275.
9. F. Andreola, L. Barbieri, I. Lancellotti, and P. Pozzi, "Recycling industrial waste in brick manufacturing," *Water Constr.*, vol. 55, no. 280, pp. 5–16, 2005.
10. G. Kim, "Effect of heat generation from cement hydration on mass concrete placement," *MSc Diss. IOWA State Univ.*, 2010.
11. G. M. Ajibola, "Promoting the use of alternative building technologies in Nigerian construction industry: The problems and recommendations," *Int. J. Adv. Res. Technol.*, vol. 3, no. 11, pp. 69–73, 2014.
12. IS 516. Method of tests for strength of concrete. Burea of Indian Standard. New Delhi, 2004.
13. IS 5816. Method to test splitting tensile strength. Burea of Indian Standrad. New Delhi, 1999.
14. K. K. S. Thangavel, S. and Reddy, "Ozone layer depletion and its effect: A review," *J. Environ. Sci. Dev.*, vol. 2, pp. 30–37, 2011.
15. M. B. Shermale, Y. D. and Varma, "Papercrete: A lightweight concrete," in *National Conference on Technical Revolution*, 2016, p. NCTR-2016.
16. M. Shermale, Y. and Varma, "Papercrete: An efficient use of waste paper," *Recent Trends Civ. Eng. Technol.*, vol. 5, no. 3, pp. 54–59, 2015.
17. N. Shah, I., Amjed, S. and Alakthiri, "The economics of paper consumption in offices," *J. Bus. Econ. Manag.*, vol. 20, no. 1, pp. 43–62, 2019.
18. O. Hubbe, M., Venditti, R. and Rojas, "What happens to cellulosic fibers during papermaking and recycling? A review," *BioResources*, vol. 2, no. 4, pp. 739–788, 2007.
19. P. O. Akanni, A. E. Oke, and O. J. Omotilewa, "Implications of rising of building materials in Lagos State," *SAGE Open*, vol. 4, no. 4, pp. 1–7, 2014.
20. R. Arya, R. K. AND Kansal, "Utilization of waste paper to produce ecofriendly bricks," *Int. J. Sci. Res.*, vol. 5, no. 8, pp. 1–5, 2013.
21. R. M. and A.-S. A. E. Salem, "Preparation of waste paper fibrous cement and studying of some physical properties.," *Civ. Environ. Res.*, vol. 8, no. 3, pp. 42–54, 2016.
22. S. Sheth, J. and Joshi, "Papercrete: A sustainable building material," in *Energy Technology, Power Engineering and Environmental Sustainability*, 2015, pp. 85–90.
23. S. Zaki, H., Gorgis, I. and Salih, "Mechanical properties of papercrete," in *MATEC Web of Conferences*, 2013, vol. 162, p. 02016.
24. T. Tracz and T. Zdeb, "Effect of hydration and carbonation progress on the porosity and permeability of cement pastes," *Materials (Basel).*, vol. 12, no. 192, pp. 1–20, 2019.
25. Y. Amberber, M. and Addis, "Paper burning and associated problems in higher educational institutions of Ethiopia; the need and potencial of recycling," *Int. J. Waste Resour.*, vol. 7, no. 3, p. 1000290, 2017.
26. Y. Y. Kim, K. M. Lee, J. W. Bang, and S. J. Kwon, "Effect of W/C ratio on durability and porosity in cement mortar with constant cement amount," *Adv. Mater. Sci. Eng.*, vol. 2014, no. 273460, pp. 1–11, 2014.