

Preparation of Waste Paper Fibrous Cement and Studying of Some Physical Properties

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Abstract
Waste paper is available in environment from different sources, such as office, newspaper and markets. Waste papers are the abundant source of cellulose and may be used as landfill. Using of these wastes in building materials has two benefits, the first one has reduced the environmental pollution and the second improves the physical properties of concrete and building bricks (or blocks). Addition of waste paper cellulose to concrete at certain percentage improve its thermal insulation properties and affect its density to produce lightweight and insulating building materials. The material which produces by using waste paper is called papercrete. It is a mixture of waste paper pulp, sand, cement and water by replacing the cement by waste paper pulp at a certain percentage. Also fibrous cement could be produced by mixing of waste paper pulp with cement and water.
In the current work the waste paper was processed to obtain the raw materials of papercrete and fibrous cement. The processing method includes a sequence of processes which are shredding, soaking, mixing, dewatering and drying. In the dewatering process, a wet pulp was obtained and it can be used as it is in the mixtures of papercrete or fibrous cement. A dry pulp also could be used. It is observed that one kilogram of office paper and that of newspaper produces 3.24 kg and 3.26 kg of wet paper pulp respectively. The dry pulp, which is produced during the drying process is 0.954 kg and 0.949 kg for 1 kg of office paper and newspaper respectively. Design of mix proportion, test of water absorption, apparent porosity and drying curve of samples with different percentage of paper pulp were investigated in the present work.
Keywords: wastepaper, papercrete, fibrous cement, porosity, water absorption, bulk density

1. Introduction
Papercrete is a new composite material using waste paper as a partial replacement of Portland cement. This increase in the popularity of using environmentally friendly, low cost and lightweight construction materials in the building industry has brought out the need to investigate how this can be achieved by benefiting the environment as well as maintaining the material requirements affirmed in the standard. As a natural sources of aggregates are becoming exhausted, it turns out urgent to develop. The majority of abandoned paper waste is accumulated from the countries all over the world causes certain serious environmental problems (G. V. S. Siva Prasad *et al*, 2015)**.** In Saudi Arabia (KSA), according to a study prepared by the company “Frost & Sullivan” advisory, the waste paper size alone, more than 5 million tons per year, and includes office waste paper, household waste paper, newspapers and cardboard sheets. Despite the growing interest in locally to re-paper recycling only it is still about 90% of the paper waste buried or burned.

In Egypt, the waste paper pulp was used for a long time at countryside in bread preparation, but it has only recently been rediscovered. Papercrete is a scientific name of a mixture of waste paper pulp with cement and water. Cement and waste paper are blended with water to create a paper cement pulp, which can have poured into a mould, allowed to dry and be utilized as a durable building materials. Papercrete has three types of building materials, namely fibrous concrete, padobe and fidobe. The fibrous concrete is a mixture of paper, Portland cement and water. Padobe is a mix of waste paper, water and clay, sometimes it is called paperclay in which the clay was used as binding material instead if using the cement. Fidobe is like padobe, but it may contain other fibrous material. Papercrete is characterized by some physical properties beside low cost. These properties are lightweight, thermal insulation and appreciated mechanical properties

2. Objectives
The objective of the present work is to prepare the pulp from waste paper in wet and dry states to use it as a raw material of papercrete. Also a design mix proportion of papercrete was tested. Some physical properties of papercrete such as drying at room temperature with time, moisture content, total water absorption, apparent porosity, liquid absorption and bulk density were investigated in the current work.

3. Literature reviews
Papercrete is a tricky term. The name seems to imply a mix of waste paper and concrete; hence it is called papercrete. Different types of papercrete contain 50% to 60% of waste paper (K. Anandaraju *et al*, 2015). Up to now, there is no hard and fast rule, but recommended standard will undoubtedly be established in the future. The exact mix proportion was not known, so trial proportions were used. The standard mix proportion of papercrete

is determined according to the required physical properties such as density, mechanical properties, flame retarded and thermal properties. So the trick is finding the best mix for the application.

Design of mix proportion of papercrete was studied by several authors. In some investigations the mix proportions chosen is as follows by G. V. S. Siva Prasad *et al* (2015): Cement: Fine aggregate: paper sludge 1:1:1. The mix proportion of fibrous concrete is cement to waste paper is 1:1, 1:2 or 1:3. The papercrete forming by mixing Portland cement: white lime: paper sludge as 1:0.5:4. The amount of water added was enough to produce a workable papercrete. The workability was assessed using drop ball apparatus, where the ball penetration was 10±1 mm (Bashar S. Mohammed, 2009). Six mix proportion samples were considered in a research study by Saurabh Chandarana *et al* (2015), where waste paper to cement replacement ratio had been kept on increasing scale from 0.5 to 6.

J. Santamaria *et al* (2007) studies the compressive strength of papercrete samples of different composites. Theses composites are paper-cement, paper-clay, paper-cement-sand, paper-cement-fly ash, paper-cement-glass, paper-cement-lime with different mix proportions. Some conclusions and recommendations for the use of papercrete for building houses are also presented in this study. A compression of papercrete bricks, its thermal conductivity and water absorption were studied by Agilan V. (2015). The mix proportions of papercrete bricks as cement: rice husk ash: fly ash: paper pulp are 1: 2: 0: 4, 1:3:0:6, 1:1.5:0:4, 1:0:2:4, 1:0:3:6 and 1:0:1.5:4. It is concluded that the papercrete is a good thermal and sound insulation. Also the papercrete bricks are suitable for non-load bearing wall only and using the papercrete in the building will be reduced the cost from 20% to 50%.

H. Yun *et al* (2007) study the mechanical properties of papercrete. Waste paper was used as replacement of Portland cement at 5%, 10% and 15% by weight. It is noted that the density of papercrete was decreased when the replacement ratio of waste paper of papercrete increased. The physical properties of papercrete were reported by Shivangni Khandelwal *et al* (2015). They reported that the density of the papercrete has a trend of decrease as a higher waste paper was included and the compressive strength is variously to be in the range of 140-160 lb/square inch. Papercrete has very good shear strength as a block, the R-value of papercrete is reported to be between 2.0 to 3.0 per inch and papercrete will not burn with an open flame. Density, water absorption, compressive strength and fire resistance of papercrete were studied by Isaac I. Akinwumi *et al* (2014). Two categories of papercrete were produced using either waste newspaper or waste office paper. For each of the waste newspaper and waste office paper mixtures, the ratios of cement: sand: wastepaper used were 1:1:0.2, 1:1:0.4, 1:1:0.6 and 1:1:0.8.

Six different proportions of papercrete were used by Ms. S. Suganya (2012) to study the feasibility of using waste paper in bricks. The mix proportion is designed as cement: rice husk ash: fly ash: sand: paper. The bricks are relatively light weight, good sound absorbent and more flexible but it has high of water absorption than conventional bricks. According to research of Joo-Hong Chung *et al* (2000), there was no formal mix design of papercrete, and effects of water to cement ratio on papercrete were not known. The exact mix proportion of papercrete was not known (T. Subramani *et al*, 2015), so trial proportions were used in several studies.

4. Methodology

4.1. Collection of materials

4.1.1. Waste paper collection

To attain the objectives, waste paper was collected from local sites. The materials that are used in this work should not be caused any pollution to the environment. In the study, paper is the main constituent material. The waste paper was collected from Department of Physics, Faculty of Science, King Khalid University, Greiger, Abha, Saudi Arabia. It includes office paper and newspaper. Different sheets of waste paper were weighed and the dimensions were measured before processing to obtain the waste paper pulp. Universities and schools have abundant quantities of waste paper.

In this study, paper is the main constituent material, which is principally wood cellulose and considered as fibrous material. Cellulose is the second most abundant material on earth after rock. Cellulose is a natural polymer which is a long chain of linked sugar molecules made by the linking of smaller molecules (S. V. Siva Prasad *et al*, 2015).

4.1.2. Cement

Cement is the important building material in today's construction world. In the present study Saudi Ordinary Portland cement of 53 grade was used to prepare the waste paper fibrous cement.

4.2. Generation of waste paper pulp

To obtain the waste paper pulp which is the raw material of papercrete, the waste paper processes in sequence steps which are shredding, soaking, mixing and dewatering. Waste papers were shredded manually in a small pieces, and then soaking in tap water at room temperature for 24 hours. The shredded soaked paper was mixed in a blender or mixer until a slurry was obtained, and then the slurry was dewatered until an excess water was drained. A waste paper pulp in wet state was obtained after these processes. The wet pulp can be used as it is in papercrete or it can be used in a dry state after drying at room temperature. Figure 1 shows the above processing steps.

Figure 1. Processing steps to obtain the waste paper pulp

4.3. Drying of waste paper pulp

After the waste paper pulp was obtained, it dried in ambient laboratory air. The pulp in the form of irregular lumps. Figure 2 shows the pulp after drying.

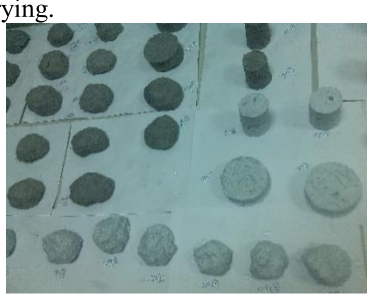

Figure 2. Pulp of office paper and newspaper

4.4. Water absorption test of dried pulp

The water absorption of papercrete is not related directly to the porosity owing to the nature of pores themselves (T. Subramani *et al*, 2015 and K. Anandaraju *et al*, 2015**)**. Some of Pores may be through pores which permit air to escape in absorption tests and allow free passage of water in absorption tests, but others are completely seated and inaccessible to water under ordinary conditions. For this reason, it is seldom possible to fill more than about three quarters of pores by simple immersion in cold water. The water absorption was determined from Equation (1) for various times.

$$WA\ \% = \left(\frac{W_s - W_a}{W_a}\right) x100 \qquad (1)$$

Where W_s is the weight is the weight of the sample after immersion and W_a is the weight of the sample before immersion.

The air dry sample was weighed, and the weight of the sample was determined before and after and after removing from water at various time intervals. After the sample was removed, it was gently blotted with filter paper to remove excess water on the surface, and the weight was recorded. The water absorption test was continued for several times until a constant weight was obtained.

4.5. Design of mix proportion of papercrete

The samples of papercrete (fibrous cement) were prepared by using a wet pulp in the form of fibrous cement of papercrete. Twelve samples were studied. Ten samples of them are fibrous cement which are a mix of cement and wet pulp with different percentage of waste paper pulp. In the remaining two samples, the first one is a waste paper pulp only and the other is cement only without any addition. The water of mixes is included in the wet dewatered pulp and the water cement ratio of twelfth sample is 0.4. The samples were prepared of the following mix proportions as the ratio of waste paper wet pulp to dry cement as shown in Table 1.

Table 1. Mix proportion of papercrete

SN	Sample Code	Paper: Cement	Paper %	Cement %
1	P1C0	1.0: 0.0	100	0
2	P1C0.1	1.0: 0.1	90.9242526	9.075747
3	P1C0.2	1.0: 0.2	83.3089203	16.69108
4	P1C0.3	1.0: 0.3	76.9189422	23.08106
5	P1C0.4	1.0: 0.4	71.4017459	28.59825
6	P1C0.5	1.0: 0.5	66.6375503	33.36245
7	P1C0.6	1.0: 0.6	62.4987938	37.50121
8	P1C0.7	1.0: 0.7	58.8298042	41.1702
9	P1C0.8	1.0: 0.8	55.5641163	44.43588
10	P1C0.9	1.0: 0.9	52.6330102	47.36699
11	P1C1	1.0: 1.0	50.0152472	49.98475
12	P0C1	0.0: 1.0	0	100

4.6. Drying of the papercrete samples

The studied samples were prepared in cylindrical form and drying in room temperature (laboratory temperature, 20°C and humidity of 60%). The samples were handled pressed into cylindrical mould. The drying program continues during 30 days, and the weight and dimensions of the samples were measured each day approximately and in specific ages (1, 3, 7, 14, 21 and 28 days). The drying of samples at laboratory condition is called air curing. It involved no form of active curing by just exposing the specimens to ambient air in the Laboratory. The drying curves of the investigated samples were achieved by plotting the relationships between density and time at ages 3, 7, 14, 21 and 28 days. Figure 3 shows the investigated samples after drying

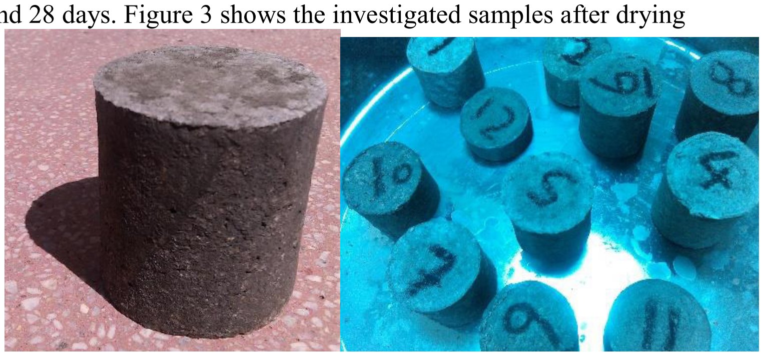

Figure 3. Cylindrical forms of papercrete

4.7. Density measurements of papercrete

The density of papercrete samples was determined according to ASTM C 642-06. The sample volumes, V and air dry weight, W_a were measured each day of investigation. The density by dimension method is given by:

$$\rho = \frac{W_a}{V} \quad (2)$$

4.8. Moisture content of papercrete

The total amount of moisture contained within the concrete, either as water or water vapor, is known as the moisture content and is generally expressed as a percentage of the mass of the concrete. Moisture in concrete is present in the capillary pores and smaller gel pores within the concrete matrix. Moisture may exist as either water (when the concrete is wet and the pores are saturated) or as water vapor which provides a level of relative humidity within the concrete material. The amount of water vapor and hence relative humidity within the concrete may vary significantly over time as water vapor moves in or out of the concrete in order to establish an equilibrium with the changing ambient conditions.

The moisture content was determined according to oven dry method (California Test 226, 1999). The moisture content of papercrete samples was measured after all samples are dried completely. The air dry weight (W_a) of the samples was measured, dried in oven at 105°C for 24 hours and weighed to determine the oven dry weight (W_o). There are two common ways in which the moisture content percentage (MC%) is routinely expressed. Air dry weight basis: In the method, the percent moisture in the sample is expressed as a percentage of the total weight of the papercrete sample, including both the dry papercrete. It is computed as follows:

$$MC\ \% = \left(\frac{W_a - W_o}{W_a}\right) x\ 100 \tag{3}$$

Oven dry basis**:** In the oven dry basis method, the MC% moisture in the papercrete samples is expressed as a percentage of the dry weight (W_o). It is determined by the formula:

$$MC\ \% = \left(\frac{W_a - W_o}{W_o}\right) x\ 100 \tag{4}$$

4.9. Apparent porosity, water absorption and bulk density of papercrete

Porosity refers to a fraction of the total concrete volume that is occupied by the pores in bulk cement paste. It is one of the major factors that control the strength of concrete. The porosity of concrete can be characterized into two forms – total and capillary or suction porosity (Md. Safiuddin, 2008). The total porosity is mainly comprised of capillary and air porosity. In contrast, the network of open pores mainly constitutes the capillary porosity of concrete. The capillary porosity has considerable effects on the transport properties and hence on the durability of concrete. Absorption is a process by which a liquid gets into and tends to fill the open pores in a porous solid body such as a component of concrete (ASTM C 125, 2004). The absorption is generally more significant in surface layer than the core of concrete due to strong capillary action. The rate at which a dry concrete surface absorbs a liquid can be taken as a predictor of the durability of concrete. Water is the most common liquid with which the concrete comes in contact. Hence, water absorption is widely used to indicate the absorptivity of concrete. It can be determined based on the increase in mass of a concrete specimen due to the penetration of water into its open pores. The water absorption of concrete is directly influenced by the porosity (Md. Safiuddin, 2008). The porosity controls the microstructure and thus the absorption of concrete, depending on the relative quantities of the pores of various types and sizes. When the porosity decreases, the water absorption is also reduced.

In the current paper a total apparent, total water absorption and bulk density of fibrous cement were investigated.

Apparent porosity (AP %), water absorption (WA %)) and bulk density (BD g/cm^3) of papercrete are determined according to ASTM C 20-0. For each sample of papercrete, its air dry weight (W_a) was determined, and then it dried in oven at 105°C for 24 hours to constant weight (Wo). The dried sample after cooling in desiccator was immersed in cold water at room temperature. It is soaked in water for 48 hours. Saturated weight of sample in air, W_s and saturated weight of sample immersed in water, W_i were measured by digital electronic balance. AP, WA and BD were calculated from the following formula (ASTM C642-06).

$$AP\ \% = \left(\frac{(W_s - W_o)\,\rho_w}{W_s - W_i}\right) x100 \tag{5}$$

$$WA\ \% = \left(\frac{W_s - W_o}{W_o}\right) x100 \tag{6}$$

$$BD\ (g/cm^3) = \frac{W_a\,\rho_w}{W_a - W_i} \tag{7}$$

Where ρ_w is the density of water at room temperature.

The accuracy of these properties depends on the accurate measurements of W_a, W_o, W_s and W_i. To obtain an accurate measurement, a digital camera was used to record these weights continuously to record a video of sample weights saturated in air and saturated immersed in water. The water bath was moved vertically to record these weights. The recorded video was analyzed manually or by an open source software "Kinovea" to obtain an average value of the required weights. Figure 4 represented the system for recoding the weights videos.

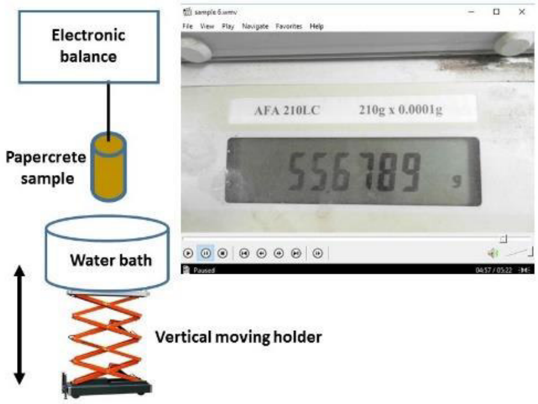

Figure 4. System to record the sample weights

5. Results and discussion

5.1. Properties of waste paper pulps

Waste paper pulp is the raw material of papercrete, thus in the current section its properties were reported and discussed. These properties are yield, drying and water absorption.

5.1.1. Yield of pulp from waste paper

The waste paper under investigation are office paper and newspaper of surface density equal to 79.868 and 54.084 g/m2 respectively. When generation of waste paper pulp, it is noted that 29.6481 g (6 sheets of area 614.46 cm2) of dry shredded office paper produce 95.93 g of wet pulp and 28.2847 g of dry pulp, while 31.8076 g (6 sheets of area 995.89 cm^2) of dry shredded newspaper produce 113.2732 g of wet pulp and 30.1954 g of dry pulp. Therefore, the wet pulp yield of office paper and newspaper is to be 323.562% and 356.1199%, respectively, and the dry pulp yield of that is equal to 95.40139% and 94.9314% respectively.

The results of generation of waste paper pulp are that 1 kg of shredded dry office paper would be produced 3.2355 kg of wet pulp and 0.954 kg of dry pulp, while 1 kg of shredded dry newspaper produced 3.5612 kg of wet pulp and 0.949 kg of dry pulp. The increasing of wet pulp weight is due to the pulp absorbed a lot of water during the processing, and a slightly decreases in dry pulp weight because of cellulose particle passed through a cloth mesh during dewatering process. Figure 5 shows the cellulose suspension of the dewatering process.

Figure 5. Cellulose suspension

5.1.2. Drying of waste paper pulp

The wet pulp of office paper and newspaper were dried at room temperature (ambient air of laboratory of 20°C and humidity of 60%). Figure 6 shows the drying curves of office paper and newspaper wet pulp. It is observed that the two curves have the same behavior, but the newspaper absorbs water larger than office paper because of the surface density of office paper (79.86769 g/m^2) is larger than that of newspapers (54.08378 g/m^2).

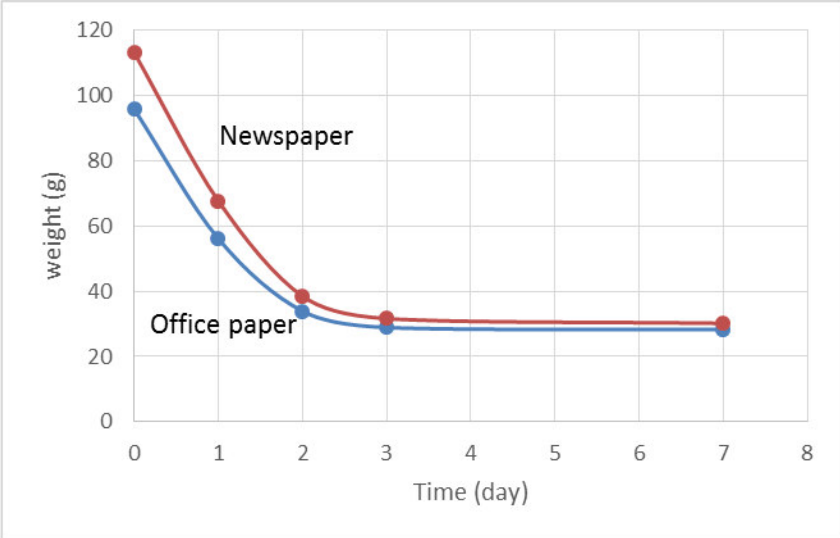

Figure 6. Drying curves of wet pulp of office paper and newspaper

5.1.3. Water absorption of waste paper pulp

Because of the yields of pulp form office paper and newspaper did not differ, thus it could be use one of them to test the water absorption. The water absorption test was carried out on office paper. Figure 7 represents the trend of water absorption of air dried office paper pulp.

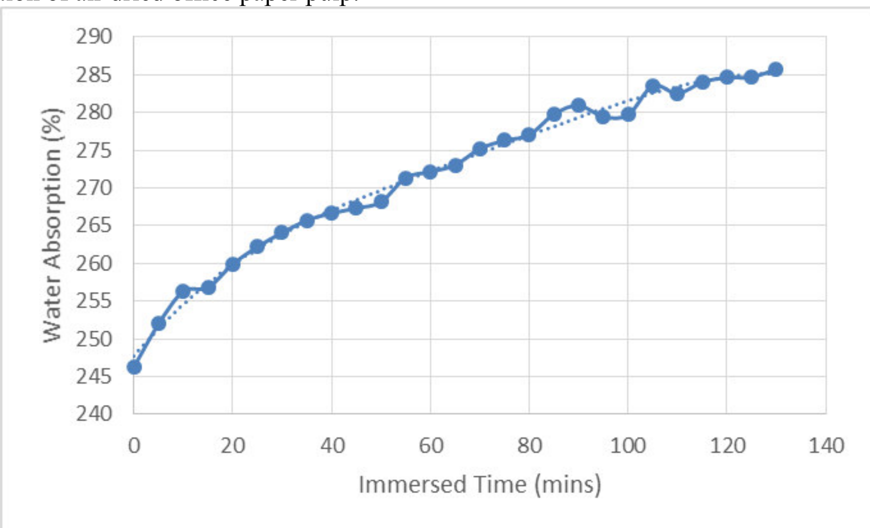

Figure 7. Water absorption of dry pulp

It is clear that water absorption increases with immersion time. Waste paper pulp showed rapid uptake of water over the first several minutes due to its nature as a cellulosic material, enabling the pulp to take up a high amount of water. When the pulp has been immersed in water for a long time, the capillarity action conducts the water molecules in the material and fills in the voids.

5.2. Properties of papercrete

After the properties of raw material waste paper pulp) of papercrete were presented and discussed in the previous section, a papercrete was prepared according to the mix proportions showed previously and the properties of papercrete were discussed in this section. These properties are drying, moisture content and Apparent porosity, water absorption, bulk density, which are discussed in the following.

5.2.1. Drying of papercrete

The papercrete samples with different content of waste paper pulp were drying after preparation at room temperature (ambient atmosphere of laboratory, 20°C and humidity of 60%). This process is called air curing for 30 days. The samples were dried to a constant weight and the density was determined at ages 1, 3, 7, 14, 21 and 28 days of air curing. Figure 8 shows the change of papercrete density with the content of waste paper pulp at different ages. The relationships at all ages are linear. The linear relationship between pulp content and density was shifted toward low density when samples are drying.

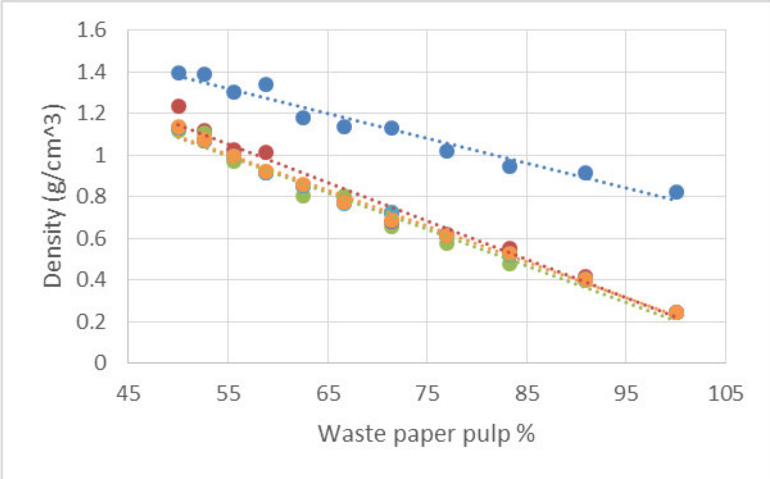

Figure 8. Change of papercrete density with pulp content at different curing times

The correlation coefficient of density-pulp content relationship increases nonlinearly with increasing curing times (1, 3, 7, 14, 21, 28 days) as shown in Figure 9, this is due to increasing of papercrete density with curing time. Table 2 presents the regression equations of density-pulp content relationship and correlation coefficients

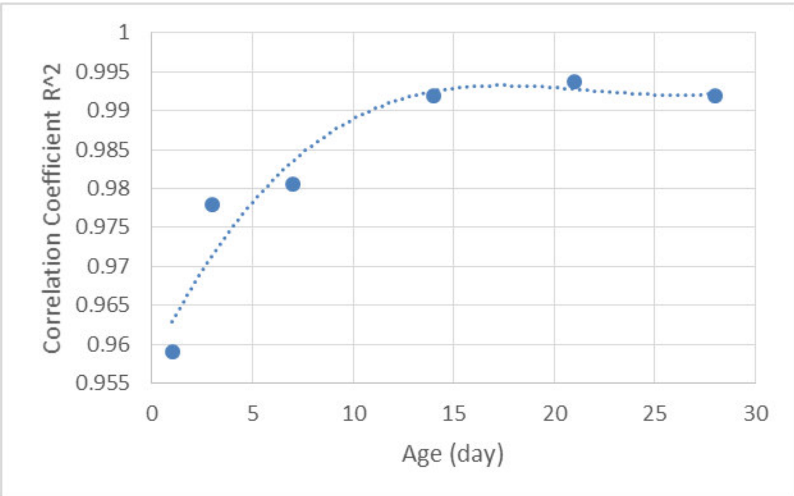

Figure 9. Increasing of correlation coefficient (R^2) with curing time of papercrete

Table 2. Regression equations and correlation coefficients of density-pulp content relationships

Air curing time (day)	Regression equation	Correlation coefficient (R^2)
1	Y = -0.0120X + 1.983	0.959
3	Y = -0.0189X + 2.079	0.978
7	Y = -0.0176X + 1.962	0.981
14	Y = -0.0172X + 1.948	0.992
21	Y = -0.0172X + 1.952	0.994
28	Y = -0.0173X + 1.956	0.992

Figure 10 shows the decreasing of papercrete density with increasing the air curing time for the sample of 50% pulp content. It is noted that in the first stage of drying in air (7 days), the density decrease rapidly and in the second stage (7-28 days), the density remains constant approximately at 0.9896 g/cm^3 with a standard deviation of 0.00528.

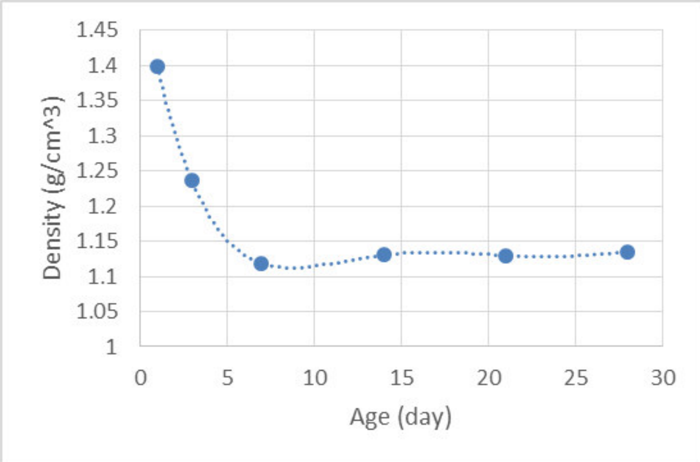

Fig (10): Variation of papercrete density with air curing time

5.2.2. Moisture content of papercrete

The result obtained for moisture content of papercrete with different percentage of paper pulp is presented in Table 3. Where SN is the serial number of samples, P (%) is the percentage of paper pulp in the sample, W_a is the air dry weight and W_o is the oven dry weight.

Table 3. Percentage moisture content of papercrete samples

SN	P (%)	W_a (g)	W_o (g)	Moisture content %	
				Oven dry basis	Air dry basis
1	100	12.7885	11.9261	7.231198799	6.743558666
2	90.92425	17.8655	16.7755	6.497570862	6.101144664
3	83.30892	29.7382	27.8888	6.631335877	6.218937259
4	76.91894	52.9387	49.8995	6.090642191	5.740979661
5	71.40175	55.1727	52.1981	5.698674856	5.391434532
6	66.63755	62.0073	58.8516	5.362131191	5.089239493
7	62.49879	61.074	58.0404	5.226704158	4.967089105
8	58.8298	74.7898	71.1456	5.122171997	4.872589578
9	55.56412	59.8302	57.0577	4.859116298	4.633947404
10	52.63301	63.3877	60.6497	4.514449371	4.319449988
11	50.01525	66.9048	64.1321	4.323419941	4.144246751
12	0	59.8906	58.1737	2.951333678	2.866726999

The highest percentage moisture content is 7.231% for sample 1, which is without cement (paper pulp only), and the moisture content decreased with decreasing the percentage of paper pulp in the papercrete samples. The change of moisture content of papercrete with percentage of waste paper pulp is presented in Figure 11.

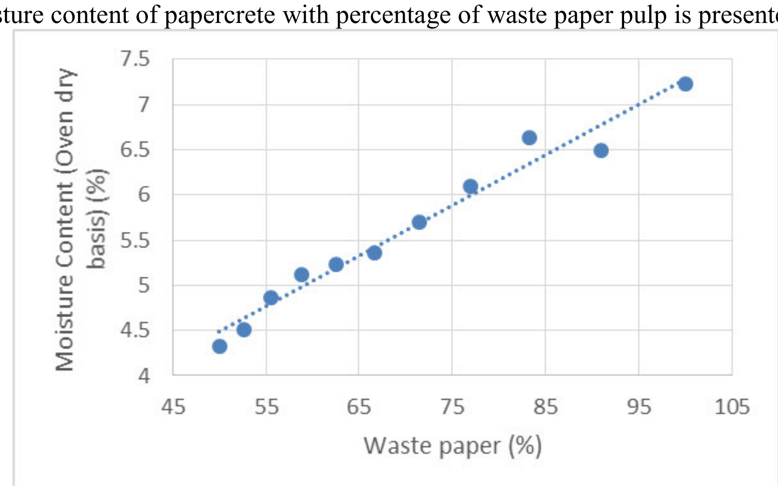

Figure 11. Variation of moisture content of papercrete with percentage of pulp

5.2.3. Apparent porosity, bulk density and water absorption of papercrete

Table 4 presents the apparent porosity (AP%), water absorption (WA%), and bulk density (BD (g/cm^3)) of papercrete with different content of waste paper pulp from approximately 90% to 50% with two samples, one of them is waste paper pulp only and the other is cement only.

Table 4. Apparent porosity (AP%), water absorption (WA%) and bulk density (BD g/cm^3) of papercrete

SN	P%	AP%	WA%	BD(g/cm^3)
1	100	79.880537	385.15462	1.028696684
2	90.924253	74.591782	197.19323	1.44565103
3	83.30892	71.043575	146.88125	1.603522139
4	76.918942	68.123718	118.8067	1.719950486
5	71.401746	65.059133	97.834643	1.814816825
6	66.63755	61.73086	79.809512	1.921303978
7	62.498794	57.932073	69.381414	1.892271227
8	58.829804	54.358727	59.48987	1.908823387
9	55.564116	52.389531	53.391041	1.964399281
10	52.63301	51.0628	46.755507	2.118951751
11	50.015247	41.02206	41.41674	1.633402018
12	0	30.153208	15.892534	2.58901011

Figure 12 shows that the apparent porosity of papercrete samples increased with waste paper pulp addition. Apparent porosity increase from 41% to 74.6% when pulp content increase from 50% to 90.9%. The larger the pulp content, the larger apparent porosity, therefore a higher pulp addition ratio increases the open pore volume and decreases the bulk density of papercrete samples as shown in Figure 13 of decreasing the bulk density with increasing of pulp content. The maximum bulk density on average of 2.12 g/cm^3 with the sample of 52.6% of pulp content. The comparison of bulk density of papercrete of 52.6% pulp with a control sample (sample 12), it is noted that the bulk density decrease by approximately 18%. Increasing the waste paper pulp addition from 0% to 51.3% decreased the bulk density from 2.59 g/cm^3 to 1.88 g/cm^3, and increasing from 51.3% to 83.3%, the bulk density decreased from 1.88 g/cm^3 to 1.6 g/cm^3.

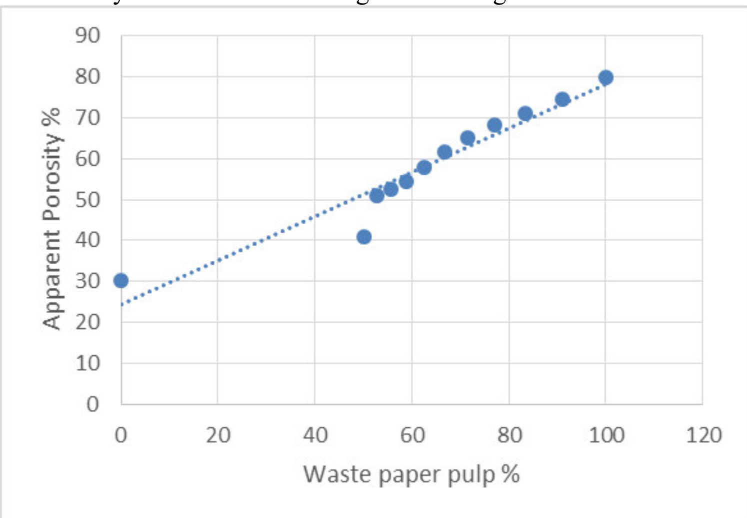

Figure 12. waste paper pulp addition effect on apparent porosity

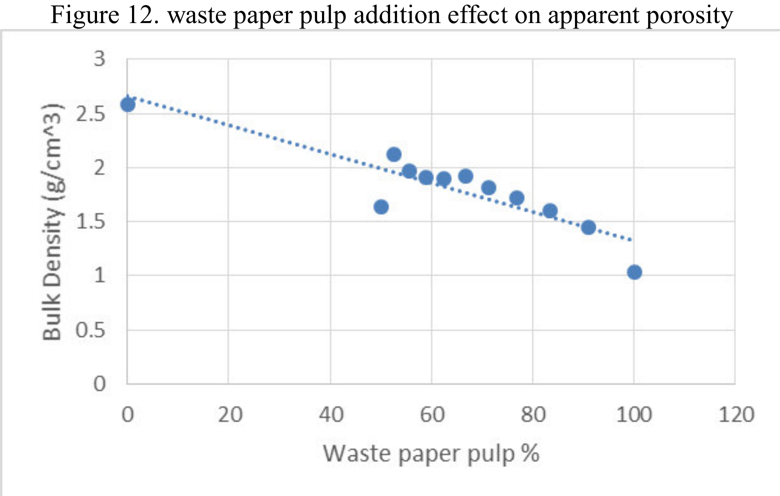

Figure 13. Variation of bulk density of papercrete with waste paper content

The relationship between waste paper pulp content and apparent porosity is meanwhile linear (R^2 value of 0.925). The relationship using Microsoft Excel is given as y = 0.538 x 24.48. The increase in porosity with increasing pulp content can be explained by the fact that pulp particles in addition to being porous can absorb water. The high value of porosity with an increase in pulp content may be due to the tendency of the particles to clump together while mixing, entrapping water filled spaces, which consequently turn into voids. The correlation coefficient (R^2) of relationship between waste paper pulp content and bulk density is to be 0.81 and the relationship is given by y = -0.0134x + 2.6606, it is less correlated than the apparent porosity-pulp content relationship. The waste paper pulp addition effect on water absorption is shown in Figure 14. Water absorption increases from 41.4% to 146.9% when the content of waste paper pulp increases from 50% to 83.3%.

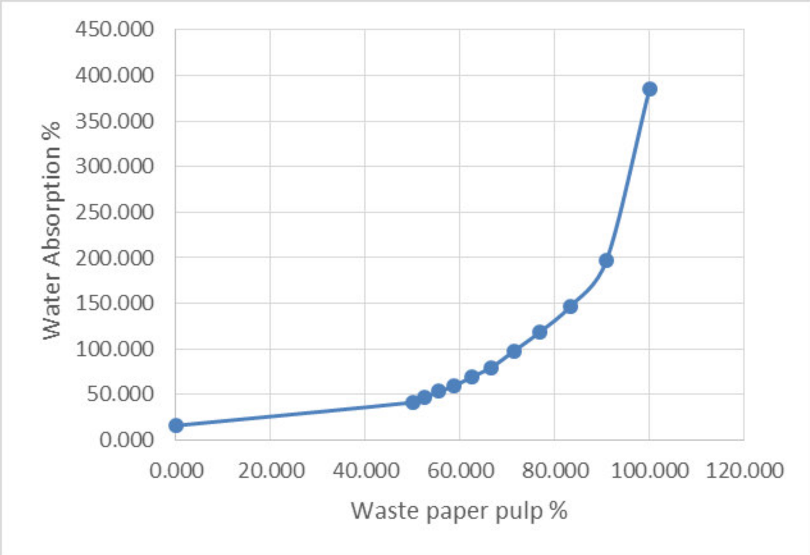

Figure 14. Effect of waste paper pulp content on water absorption

Bulk density of papercrete is a function of water absorption, waste paper content and porosity. The results indicate that the bulk density due to water absorption for papercrete with waste paper pulp is higher as compared with that control sample without pulp. The relationship between bulk density, water absorption and apparent porosity are shown in Figure 15 and Figure 16. The higher water absorption capacity of papercrete with high content of pulp may be attributed to the amount of water absorbed by the cellulose fibers of the pulp, which is influenced by void volume and the amount of cellulose material present, and both of these parameters effect bulk density.

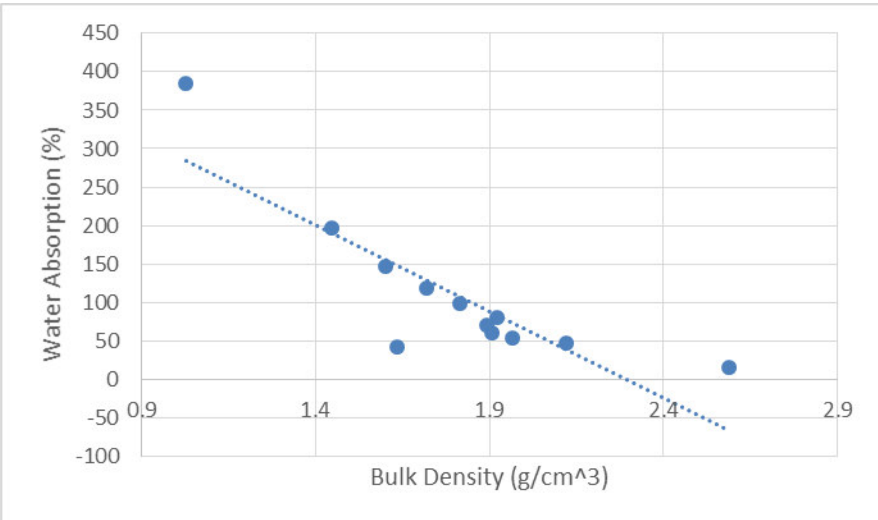

Figure 15. Relationship between bulk density and water absorption of papercrete

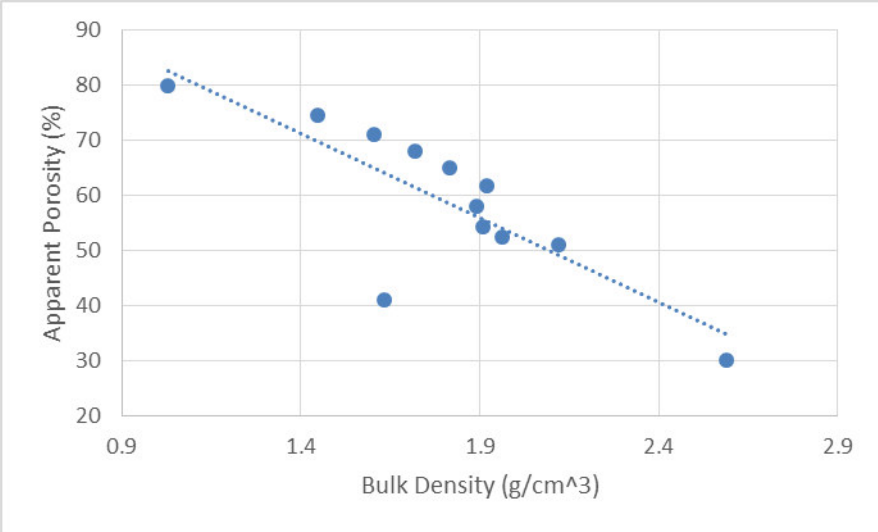

Figure 16. Relationship between bulk density and water absorption of papercrete

6. Conclusions

The following conclusions were drawn on the basis of the results obtained during the experimental study: (1) The waste paper was available at urban area and it is useful to use it in building materials instead of landfill. (2) The waste paper could be processed easily to obtain the waste paper pulp as addition to cement for improvement the physical properties. (3) The prepared waste paper pulp in dry state absorb more water in mixing with cement. (4) The yield of pulp from office paper and newspaper had the same percentage. (5) A fine waste paper cellulose could be obtained in dewatering process of waste paper slurry. (6) Preparation of wet waste paper pulp was required more water and this water could be recycled in mix proportion of fibrous cement mix. (7) The mix proportion of fibrous cement was designed by increasing the waste paper pulp from 50% to 100% by weight, and it is noted that by increasing of waste paper pulp in fibrous cement, its density decreased. (8) Addition of waste paper pulp to cement improves its physical properties like density and increase water absorption. (9) The mix proportion was used cement and waste pulp to produce the papercrete, fibrous cement, with low cost. (10) Papercrete, fibrous cement, was dried linear with waste paper content, and the relationship became more correlated by increasing the air curing age. (11) By increasing the waste paper pulp percentage in fibrous cement, the moisture content was increased linearity. (12) Apparent porosity, water absorption and bulk density of fibrous cement were affected by the waste paper content, where apparent porosity and then water absorption were increased while bulk density was decreased by increasing the content of waste paper pulp.

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