University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq
Number 4 Volume 25 April 2019

Civil and Architectural Engineering

Characteristics of Paper-cement Composite

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ABSTRACT

This study discusses the benefit of addition waste paper as a new cellulose material in mortar mixes. A partial addition of waste paper by cement weight was achieved to produce cement composite mortar. Pulp and paper is the third major industrial dumper of air, soil and water. In recent year, paper and paperboard constitute a greater portion of many countries' urban solid discarded generation. Beside, it increases characteristic strength due to existence of hydrogen links in the microstructure of paper. Furthermore, it consume better thermal protection. The addition percentages of waste paper used in this work were (5%, 10%, 15% and 20%) by mass of cement to measure and evaluate some properties of the mortar produced (compressive, direct tensile, and flexural) strength, thermal properties such as (thermal conductivity), and microstructure investigation like (scanning electron microscope (SEM)). The results indicated that the fresh mortar properties affected expressively with higher wastepaper percent. The mechanical properties (compression, direct tensile and flexural strength) were reduced by increasing the content of waste paper, it reduces to (74%, 50%, and 86%) respectively, with (20%) addition of waste paper than the reference mix. Moreover, using waste paper with different percentages led to noticeable decrease in thermal conductivity, especially with increasing addition percentages.

Keywords: compressive strength, tensile strength, flexural strength, thermal conductivity, SEM.

خصائص المركب الاسمنتي-الورقي

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الخلاصة

تناقش هذه الدراسة فائدة إضافة نفايات الورق باعتبارها مادة سيليلوزية جديدة في الخلطات الاسمنتية. ان هذا المركب الاسمنتي تم تصنيعه بإضافة نفايات الورق، كإضافة جزئية من وزن الاسمنت. وهي تعتبر مواد بناء مستدامة بسبب انخفاض كمية النفايات الورقية من مدافن القمامة أو المكاتب. كذلك انه يكتسب، مقاومة اساسها سبب وجود الروابط الهدروجينية في التركيب المجهري للورق. علاوة على ذلك ان الورق يمتلك عزل حراري جيد. ان نسب الاضافة الوزنية من الورق المستخدمة في هذه الدراسة كانت (5%، 10%، 15% و 20%) من

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2019.04.09

Article received: 5/8/2017
Article accepted: 2/1/2018

وزن الاسمنت لاستكشاف الخواص الميكانيكية للخلطات كمقاومة (الانضغاط، الشد المباشرة، الانثناء)، الخواص الحرارية مثل (معامل التوصيل الحراري)، و التحريات المجهرية مثل (المجهر الإلكتروني الماسح). وبالمقارنة مع الخلطات المرجعية، وجد أن خواص المونة الطرية تتأثر بشكل ملحوظ بزيادة محتوى النفايات الورقية. كذلك هناك انخفاض في مقاومة (الانضغاط ، الشد المباشرة و الانثناء) مع زيادة نسبة الورق لغاية الوصول الى (74%، 50% و 86%) على التوالي و عندما تكون نسبة الاضافة (20%) من مخلفات الورق بالمقارنة مع الخلطة المرجعية. علاوة على ذلك فان استخدام النسب المختلفة من المخلفات الورقية تؤدي الى نقصان ملحوظ في معامل التوصيل الحراري و خصوصا عند زيادة نسب الاضافة.

كلمات الرئيسية: مقاومة الانضغاط، مقاومة الشد، مقاومة الانثناء، معامل التوصيل الحرارية، المجهر الالكتروني الماسح.

1. INTRODUCTION

During the last recent years, many enhancements in our country have happened in all parts of life such as social, industrial, economical, etc. Utilization of the widely spread industrial wastes in the civil construction practice may cause a real possibility of significant decrease in the environment pollution and perceptibly economize the price of civil construction, **Mymrin, et al., 2009**. Papercrete can be used as a very good supplement of wood as it has strength comparable to wood. Papercrete is an experimental material which replaces an amount of cement with paper in the normal concrete mix, **Bukhari, et al., 2016.**

The use of waste paper; has a role in getting rid of their huge quantities which, constitute a fundamental environmental problem because of the difficulty of its degradation. Various attempts have been therefore made, in the building material manufactures to use waste material products. Ppaper recycling has been performed about 60% ~ 80% in many countries, **Table 1, Chung, et al., 2015.**

In this study, the paper pulp was used in mortar and concrete to study the mechanical properties of the produced mix some mechanical properties. It was possible to produce low cost concrete with better properties, incorporating paper pulps with cement.

1.1 Origination of Waste Paper and Papercrete

Papercrete is a composite primarily developed 80 years ago but it is only lately re-discovered. Moreover, it is a fibrous cementitious composition embraced Portland cement and paper pulp. These components are mixed with water to inspire a paper-cement pulp, which can then be cast into a mold, permitted to dry and be profited as a durable construction material, **Subramani, and Angappan, 2015**.

Paper is basically timber fiber, cellulose is nearly the second abundant substantial on earth after rock. Cellulose is a normal polymer, long chain of linked sugar particles made by the networking of smaller molecules. The links in the cellulose chain are a form of sugar: ß-D-glucose. The cellulose chain hackles with polar-OH assemblies. These assemblies form many hydrogen bonds with OH assemblies on adjacent fetters, pushing the chains together, **Plate 1**. This hydrogen connection forms the source of papercrete strength, **Khandelwal, et al., 2015.** The dry paper pulp mainly consists of calcium oxide and silica, followed by magnesium oxide and alumina. **Vegas, et al., 2009** showed that, adding 10% and 20% paper pulp by cement weight displays significant decrease in compressive strength than the reference mortar mix,

1.2 Applications of Papercrete

There are different applications that can be produced by using papercrete mortar or concrete **Khandelwal, et al., 2015**:

1. It can be used as a sound-proofing material.
2. Sufficient for roof floor loads in low-height buildings.

3. Load bearing construction block and brick units.
4. Papercrete can be used for simple furniture in homes provided that wire mesh is set into the papercrete for enhancing strength.
5. Different shapes to decorate houses, flower pots.

Papercrete can be used for plastering and can be given in any form, be panel or curved elements, **Tushar and Saransh, 2015.**

2. LITERATURE REVIEW

Higher than 450 million tons of paper is generated worldwide per annum and the expected demand for paper, will reach 500 million tons per annum by the end of 2020, **Ali, et al., 2013.** In spite of having more information about how to use papercrete as a building material, some researchworks have been done to determine their structuralsuitability, **Fuller, et al., 2006.**

Akinwumi, et al., 2014, investigated using waste paper to obtain their expediency for use as a construction building material. The percentages of cement: sand: wastepaper used were, (1:1:0.2, 1:1:0.4, 1:1:0.6 and 1:1:0.8), the bulk density results indicate that papercrete is a light-weight concrete. Papercrete has a high fire resistance, it should, not be used for external walls and near ground walls because of its higher ability to absorb water. While, **Asha, et al., 2017**, used recycled paper in construction field, a total of ten concrete mixes were created. Fine aggregate was replaced by waste paper accordingly in the range of 10% to 20%. As a result, it was found that the workability for both M20 and M25 grade of concrete decreases with the increase in percent replacement of paper pulp. The lower bulk density of papercrete refers that they are light-weight and can be used to produce of either hollow or solid blocks for buildings papercrete wall with good fire resistance.

Many studies have shown natural or lingo-cellulosic fibers, can beconsidered as one of the most important candidates for asbestos fiber in fiber-cement board because of the individual properties, availability and economic aspects, **Agopyan, et al., 2005.** Fiber reinforced cement board, products are compatible for most any light, load bearing or non-load bearing structures. Furthermore, they are suitable for a situation where characteristics of other materials are exceeded, such as resistance to lightness, durability, acoustics, and fire, **Olorunnisola, 2009.**
Tonoli, et al., 2009, studied the lingo-cellulosic fibers suggest that these fibers have the possibility for use as a reinforcing factor in cement composites. The first advantage of using lingo-cellulosic fibers as additives in cement are the low cost, low density, non-abrasive nature, high potential filling levels , lower consumption energy, and wide variety of fibers available throughout the world. It is better alternative waste material to substitute wood because it is abundant, widespread, and easily available. In addition to plentiful and renewability, employment of recycled paper has advantages for the economy and environment **Ren, et al., 2009.**
Salem, and Al-Salami, 2016, the addition of waste paper cellulose to mortar at certain percentage improves its thermal insulation properties and affect its density to produce light-weight and insulating building materials. However a much lower thermal conductivity than concrete was reported by, **Fuller, et al., 2006**, showing that its insulation value is much higher. This is because the R-value of papercrete is in between (0.078 - 0.12 per mm) with a thickness in walls (304.8 - 406.4mm) in one or two story house. Similarly, **Titzman, 2010**, reported the thermal conductivity of papercrete to be 0.10 W/m.K.

Seyyedalipour, et al., 2014, produced papercrete by replacing some amount of waste paper by weight of Portland cement type I and mix with aggregate and water. The workability and mechanical properties were studied and compared reference normal weight concrete. The slump results showed a decrease with increasing the percent of waste paper (having higher absorption ratio). The replacement of 5% waste paper by weight of cement shows a slight increase (about 5%) in slump value, while adding paper pulp above 5% the slump was decreased. The results indicated that the mechanical strengths (compressive, splitting tensile and flexural strength) were increased up to 10% addition of waste paper pulp and any increase in waste paper pulp cause the strengths to decrease. The most appropriate replacement of paper pulp was between 5 to 10% by weight of cement.

The new production technology comprises the application by injection of cellulose fibers, reused newspaper as a raw material, treated with special additives for fire proofing. It can be applied for thermal insulation of walls, floors, as well as ceilings and roofs enclose at the same time good sound insulation, **Aciu, et al., 2014.** Higher than 500 million tons of wastepaper are created global per year, **Ali, et al., 2013.**

Experimental works of this paper deals with the mechanical properties of mortar mixed with variable percent of waste paper pulp as (5%, 10%, 15% and 20%). The objectives are:

- Study the fresh and hardened properties of papercrete produced using locally materials.
- Limiting the optimum papercrete mix.
- Determining the possibility of producing non-structural elements from the optimum papercrete mix.

3. MATERIALS

3.1 Cement

The commercially cement calledas (Krasta) was used in this work, the physical and chemical properties are listed in **Table 2 and 3.** The results conform to ordinary Portland cement (type I) of the Iraqi Specifications, **IQS., No.5, 1984**.

3.2 Fine Aggregate

Natural sand of maximum size 4.76 mm was used in this investigation. It was brought from Al-Ukhaider region and its gradation lies in zone (2). The grading test results conform to Iraqi specification **IQS., No.45-1984**. **Table 4** and **Fig. 1** show the properties of fine aggregate.

3.3 Water

Tape water was used for both casting and curing of specimens.

3.4 High-Range Water Reducing Admixture (Superplasticizer)

A High Performance Superplasticizer concrete admixture commercially called as Visco-Crete 5930 and manufactured by SIKA Construction Chemicals was depended on modified Poly-carboxylate which was used in this study. The dosage suggested by the producer is from (0.2– 0. 8) liters for each (100) kilograms of cement. This admixture type confirms to, **ASTM, C494, 2015,** type G and type F. The technical description of superplasticizer is shown in **Table 5**.

3.5 Waste Papers

Waste papers were collected from many sources offices, schools, newspapers. **Table 6** and **Table 7** present their physical properties. The preparation process of the waste paper include many stages; first cutting to small pieces and soaking in water for three days then, put on non-absorbent filter for squeezing out supplemental water content as indicated in **Plates 2** and **3.** Lastly a kitchen blender was used to crush the waste till the required size of paper sludge. **Plate 4** shows the papers after crushing in the wet grinder.

4. EXPERIMENTAL WORKS

4.1 Mix Proportion

The mix was designed to get compressive strength of normal mortar approximately about (25) MPa. Workable trial mixes were done with waste paper by adding super-plasticizer called Sika. The mortar mix proportion was [1:2] by weight [cement equal 400 kg/m^3 and sand 800 kg/m^3] with (W/C) = 0.35. Prepared paper particles by weight of cement as (5%, 10%, 15% and 20%); were added to get four papercrete mortar mixes.

4.2 Mechanical Investigation

4.2.1 Flow test

A flow test according to, **ASTM, C1437, 2013** for determining the workability of all mortar mixes was done.

4.2.2 Dry density

Density (ρ) is the mass of a unit volume of hardened mortar expressed in kilograms per cubic meter. The cube specimens with (100mm) were tested according to **ASTM C567-2005a** and the average result of three samples at 28 days were calculated.

4.2.3 Total absorption

The total absorption test was concluded on (100) mm cubes according to **ASTM C642-2013**. The absorption at 28 days for all mortar mixes were prepared and the average of three cubes were determined.

4.2.4 Compressive strength

The compression strength for all mortar mixes was achieved using cubes with (50×50×50mm) which conform to **ASTM, C109/C109M, 2013.** The average of three cube strength at ages of (7, 28 and 60) days were gain.

4.2.5 Direct tensile strength

The test was done according to **BS, No.6319-Part:7, 1985**, the direct tensile strength of three briquette samples were gain at ages 7, 28, and 60 days.

4.2.6 Modulus of rupture

The flexural strength (modulus of rupture) was achieved using (40×40×160) mm prism that conform with, **ASTM, C348, 2014. C**entral point load system of three prisms were calculated at

(7, 28 and 60) days age for each mix. The flexural test was tested by ELE Digital Electric testing machine with 10 KN capacity.

4.3 Thermal Conductivity Test

Thermal conductivity (K) for all mortar mixes was determined by using Hot Disk method. Moulds with diameter of (50) mm and (10) mm thickness were prepared; two specimens for each mix were tested at (28 days). Awareness of locally thermal conductivity is essential in the evaluation of heat transfer rates.

4.4 Microstructure Investigation

This test requires to prepare a sample of test according to, **ASTM, C856, 2014** with the suitable dimensions (1*1*1) cm. All specimens were dried in an oven prior to testing at 60 ^{o}C for 7 days to avoid disturbance. The next step involves immersion of the sample in a low-viscosity epoxy resin. The epoxy was cured at 40 ^{o}C for at least 24 hrs. The final stage involves painting with thin layer of liquid gold to avoid the collection of electric charge when the electron ray looks at the sample by using scanning electron microscope (SEM).

5. RESULTS AND DISCUSSION

5.1 Fresh Mortar Properties

Table 8 presents the flow table test values. A reduction in flow values with increasing the content of waste paper pulp, this is due to greater water absorption of the paper. It requires more water to get the same flow, thus the flow of mortar containing paper pulp was enhanced by the addition of the super-plasticizer. The percent of super-plasticizer was higher with increasing in waste paper percent as indicated in **Table 8.** The requirement of flow table must be in the range of (100 $\pm$ 10)%.

5.2 Hardened Mortar Properties

The average dry density and water absorption results of all mortar mixes, are listed in **Table 9** and **Fig.2**. A decrease in dry density results was indicated, while water absorption was increased with the increasing of waste paper addition in the mixes, the higher amount of water absorption is due to the presence of cellulose resources that easily absorbs water, and keeps it for a period. Results of mechanical properties (compressive strength, direct tensile strength and flexural strength) at 7, 28 and 56 day's age for all mortar mixes are listed in **Table 9**. It indicated that there is an increase in all strengths with the progress of curing age due to continuing hydration process. All mortar mixes with waste paper show lower strength than reference mixes for all test ages except that mix with (5%). Mixture with (5%) shows slightly higher than the reference, this is due to considerable amount of alumina-siliceous material (presented in waste paper) which is combined with calcium and led to this slight increase in strength. Compressive strength results for all mixes are indicated in **Fig.3,** for all ages (7, 28, and 56 days). Direct tensile strength was indicated in **Fig.4,** which has same trend as in compressive strength. The reduction is due to the vanishing in cohesion with the binding of calcium- hydrate –silicate (C-S-H), gel on the cellulosic material is particularly weak. The modulus of rupture (flexural strength) results are drawn in **Fig.5,** indicate that mortar mixes with 5% paper pulp gave similar strength as reference mortar mix and the strength decreases as the content of paper pulp increases.

Thermal Conductivity test; is most important characteristics of the insulating mortar. Results of thermal conductivity at 28 days for all mortar mixes are listed in **Table 9**. Thermal conductivity results for mortar with (10%, 15%, and 20%) waste paper are less than refernce mortar. Due to the cellular nature of papercrete mortar which will produce a resistance to heat movement through papercrete and effect on the conductivity. Therefore, the paper pulp is the important factor to minimize the thermal conductivity. **Fig.6** demonstrates the relationship between dry density and thermal conductivity at 28 days age. The figure denotes that the dry density is the main factor disturbing the (K) value, improvement in density will cause an increase in thermal conductivity (K), due to minimizing of density, the gaps, and pores between the particles which block the passage of the heat through it. Because of increasing the number and size of pores and voids which cause to decrease in thermal conductivity as compared with mix without paper, the statement of lower density resulting in lower thermal conductivity was proven true and it is also supported by other researcher like, **Rehman, 2017.**

The scanning electron microscope observations of the transition zone; contrast the good bonding of cement paste with particles, that demonstrates in **Plate 5**. Also in **Plate 6**, the paper pulp surface is covered with the hydration products. So, it results in a decrease in porosity and small voids in the matrix. The compact matrix with pulp enhanced the mechanical strengths of composites. On the other hand **Plate 7**, **Plate 8**, and **Plate 9** illustrated a debonding between paper pulp and cement paste with a small content of $CaCO_3$ compared with reference symbols due to the transmigration of the carbonate composites. The results showed some micrograph of micro-cracks generated from bond zone between paper pulp and cement paste, because of weak bonding characteristic around cement paste and paper pulp. In addition to that, it was observed that increasing the content of paper pulp will produce closed pores in the specimens, the results also were reported by **Sangrutsamee, et al., 2012**.

5. CONCLUSIONS

The following conclusions can be drawn from the experimental works:

1. Producing light-weight insulating papercrete mortar can be achieved by adding waste paper with low bulk density. The waste paper could be important material as alternative sustainable resources.
2. It was established that adding waste paper has a distinct opposed effect on the flow test. For which request “higher water or higher chemical “admixture dosages to keep the “flow values approximately the “same for all mortar “mixes. With increasing the addition of waste paper percentages causes more reduction in flow table test than the reference mixture.
3. Decrease in dry density was mentioned with increasing the content of waste paper added to the mortar mix. This is attributed to the absorbability of paper pulp causes a noticeable reduction in the unit weight of the mortar mixes as a result of the creation of voids and the porous structure of the paper, thus leading to an essential increase in the absorption in comparison with reference mix. The results of dry density demonstrate that light-weight “mortar could be created by adding waste paper.
4. Increasing waste paper led to an increase in the water absorption by about (14.5%, 32.9%, and 44.8%) for (M10, M15, and M20) respectively as compared with the reference mix. While the reduction in dry density was (6.7%, 22.8%, and 44.7%) for (M10, M15, and M20) respectively as compared with the reference mix.
5. Compressive strength, direct tensile strength and flexural strength for mixes with (10%, 15% and 20%) waste paper pulp content declined with the increase of the content of waste paper than reference mix except the mortar with (5%) which indicates nearly equal strength to that of reference mix.

6. Addition of paper pulp leads to reduced thermal conductivity, this reduction was an improvement with increasing the addition of paper pulp percentages. The thermal conductivity for (M20) was lower than reference mix by (65.5%).
7. The scanning electron microscope observations indicate that increasing the content of paper pulp will produce closed pores in the specimens

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Table 1. Recycling ratio of paper in some countries, **Mymrin, et al., 2009**.

	Korea	*Japan*	*China*	*Taiwan*	*HongKong*	*U.S.A*	*Canada*	*Germany*	*U.K*	*France*
Recycle Ratio (%)	75.4	72	34	68	80	52	68	75	65	64

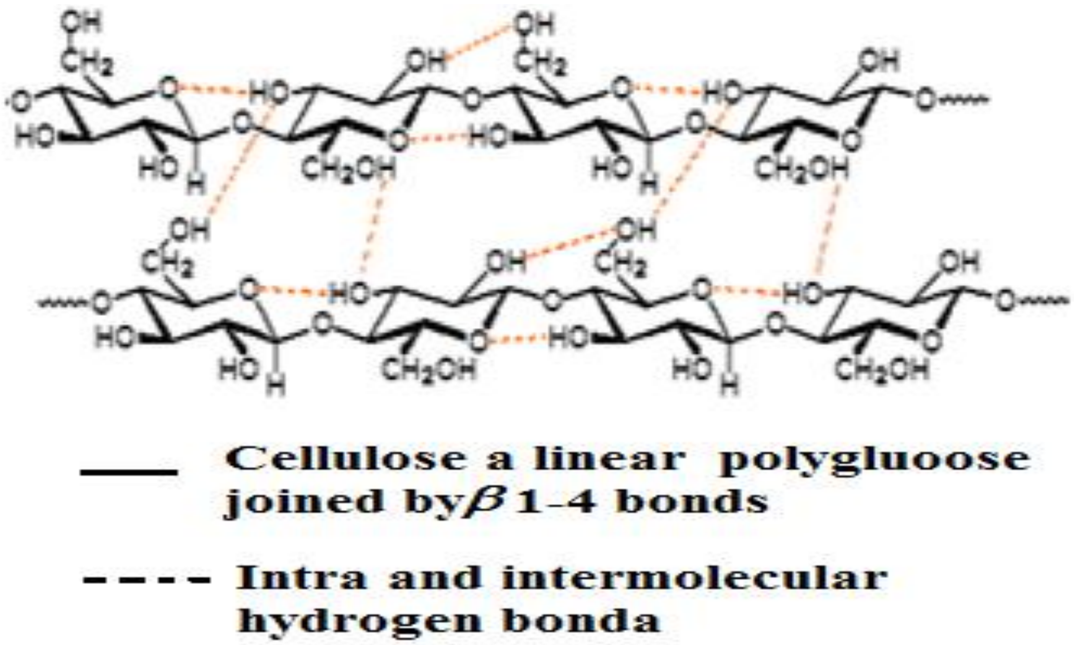

Plate 1. Chemical structure of paper (cellulose hydrogen bond), **Prasad, et al., 2015.**

Table 2. Physical Properties of Cement.

Physical Properties	*Test results*	*Limits of Iraqi specification* **IQS. No.5, 1984.**
Fineness (Blaine method), (cm^2/gm)	3760	≥2300 cm^2/gm
Setting time (Vicate apparatus), **a. Initial setting, hrs:min** **b. Final setting, hrs:min**	 2:05 4:00	 ≥ 45min ≤ 10hrs
Compressive strength, MPa **For 3 days** **For 7 days**	 20.0 25.0	 ≥ 15 MPa ≥ 2 3 MPa
Soundness Autoclave method%	0.12	< 0.8

Table 3. Chemical Composition and Main Compounds of Cement.

Oxides Composition	***Composition Content %***	***Limits of Iraqi specification* IQS. No.5, 1984.**
Lime, CaO	66.11	-
Silica, SiO_2	21.93	-
Alumina, Al_2O_3	4.98	-
Iron oxide , Fe_2O_3	3.10	-
Magnesia ,MgO	2.00	5.0 % Max
Sulfate, SO_3	2.25	2.8 % Max
Loss on Ignition, (L.O.I.)	2.39	4.0 % Max
Insoluble residue, (I.R)	1.29	1.5 % Max
Lime Saturation Factor, (L.S.F.)	0.93	0.66-1.02%
Main compounds (Bogues equations)		
C_3S	58.16	-
C_2S	19.00	-
C_3A	7.95	> 5%
C_4AF	9.43	-

Table 4. Properties of Fine Aggregate.

Sieve size (mm)	***Passing by weight %***	***Limits of IQS Zone (2)* IQS. No. 45, 1984.**
9.51	100	100
4.75	98	90-100
2.36	89	75-100
1.18	77	55-90
0.6	55	35-59
0.3	21	8-30
0.15	5	0-10
Fineness Modulus =2.8		
Property	***Test Results***	***Limits of IQS* IQS. No. 45, 1984.**
Specific gravity	2.6	-
Bulk Density (kg/m^3)	1712	-
Sulfate content%	0.37	≤0.5
Absorption%	3.2	-

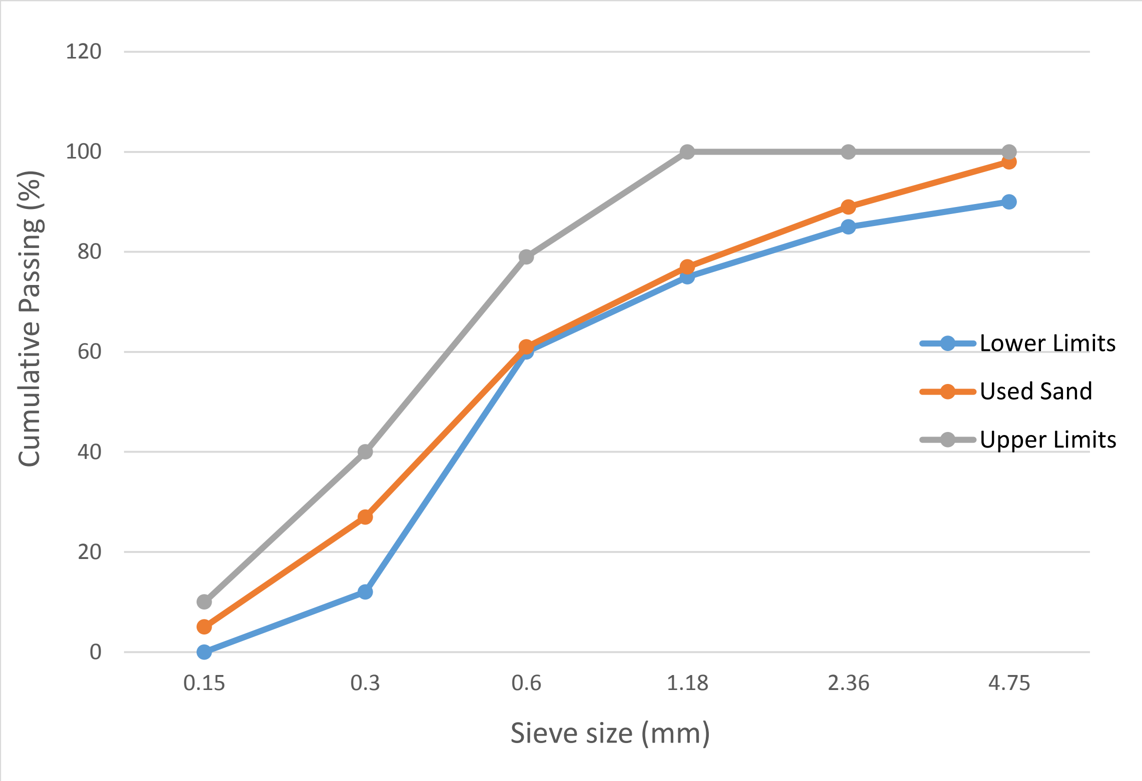

Figure 1. Grading curve for used fine aggregate.

Table 5. The technical descriptions of superplasticizer.

Properties	***Technical Description***
Appearance	Turbid liquid
Color	Transparent
Density	1.095 kg/lt. at 20° C
pH value	6.6
Recommended Dosage	(0.5-0.8) litter for 100 kg of cement
Storage	Should be stored from direct sunlight and frost at temperatures between + 5 °C and + 35°C. Shelf life at least 12 months from date of production.
Dosage	0.2 – 0.8 % by weight of cement
Chloride Content	Nil
Transport	Not classified as dangerous
Viscosity	128+/-30 cps @20°C
Packaging	5 Kg, 20 Kg pails 200 kg drums Bulk Tanks are available upon request
Labeling	No hazard label required

Table 6. Physical properties of waste paper.

Moisture Content %	2.67
Specific Gravity (SSD)	0.98
Density (kg/m^3)	800
Absorption %	89
Organic Materials %	70
In-organic materials %	30

Table 7. Grading of Paper Pulp.

Sieve Size (mm)	***Passing by Weight %***
9.51	100
4.75	88
2.36	18
1.18	2
0.6	0

Plate 2. Sample of paper shredder.

Plate 3. Paper pieces soaked in water.

Plate 4. Paper mass after soaked and grinding.

Table 8. Results of flow table and percentages of super-plasticizer addition.

Mix ID	*Pulp paper mass by weight of cement (%)*	*Admixture (Sika) by weight of cement (%)*	*Flow table (%)*	*Fresh density (kg/m^3)*
R	0	1	103	1668
M5	5	1	99	1850
M10	10	1.25	101	1594
M15	15	1.5	98	1413
M20	20	2	96	1225

Table 9. Properties of hardened papercrete mortar Mixes.

Mix ID	**Dry Density (kg/m^3)**	**Thermal Conductivity (W/m.K)**	**Water absorption (%)**	**Compressive Strength (MPa)**			**Direct Tensile Strength (MPa)**			**Flexural Strength (MPa)**		
				7 days	*28 days*	*56 days*	*7 days*	*28 days*	*56 days*	*7 days*	*28 days*	*56 days*
R	1586	1.24	5.9	22.3	28.4	30.4	1.7	1.8	1.9	7.4	8.4	8.9
M5	1755	1.32	4.3	25.4	31.2	32.5	1.5	1.6	2	6.8	7.7	8.3
M10	1487	1.17	6.9	21.5	25.5	28.1	1.4	1.5	1.6	5	5.9	6.9
M15	1291	0.72	8.8	13.8	19.5	21.3	1.2	1.3	1.4	4.7	5.4	6.3
M20	1096	0.53	10.7	11.7	16.3	17.5	1.1	1.2	1.3	3.7	4.5	5.1

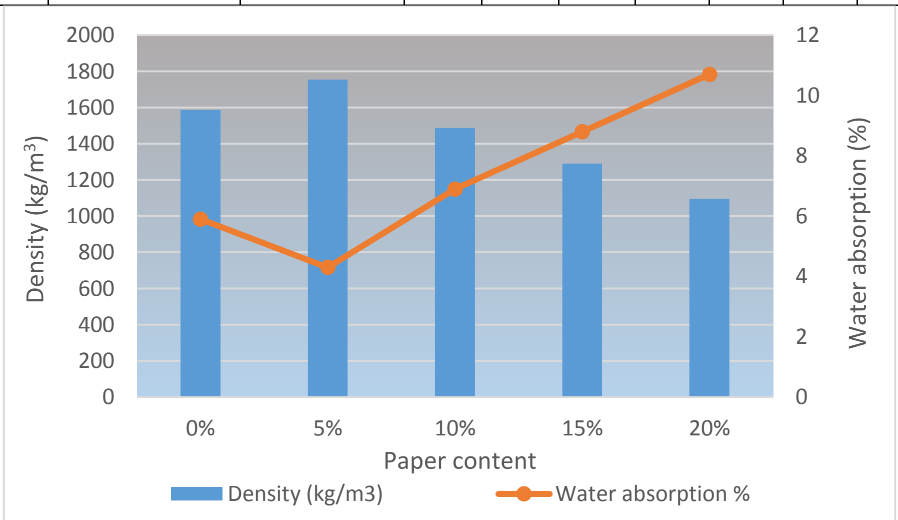

Figure 2. Variation in density with water absorption.

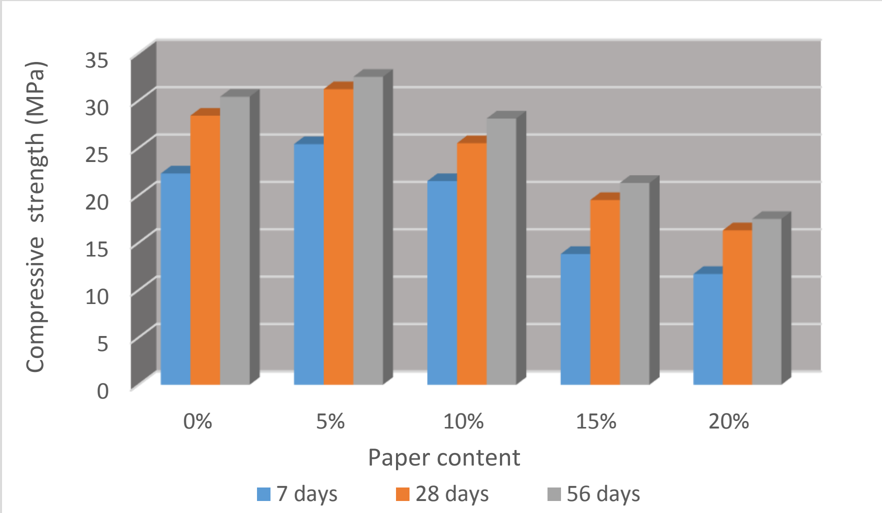

Figure 3. Results of compressive strength of papercrete mortar.

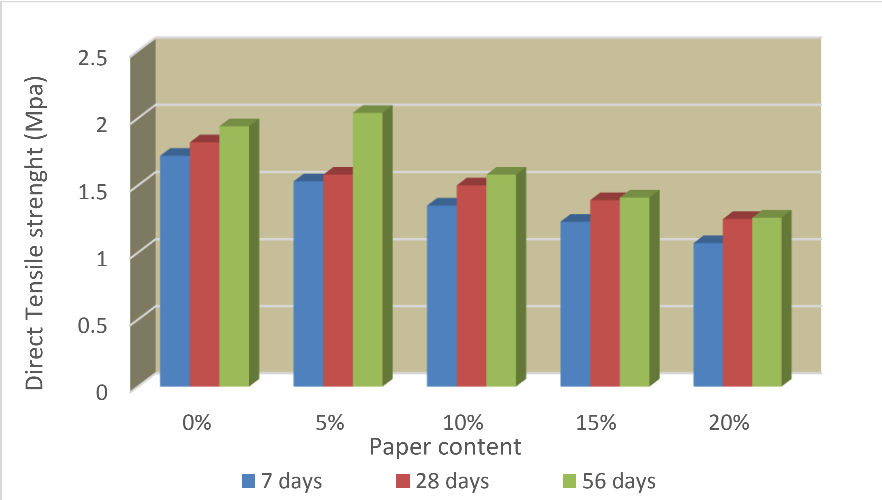

Figure 4. Results of direct tensile strength of papercrete mortar.

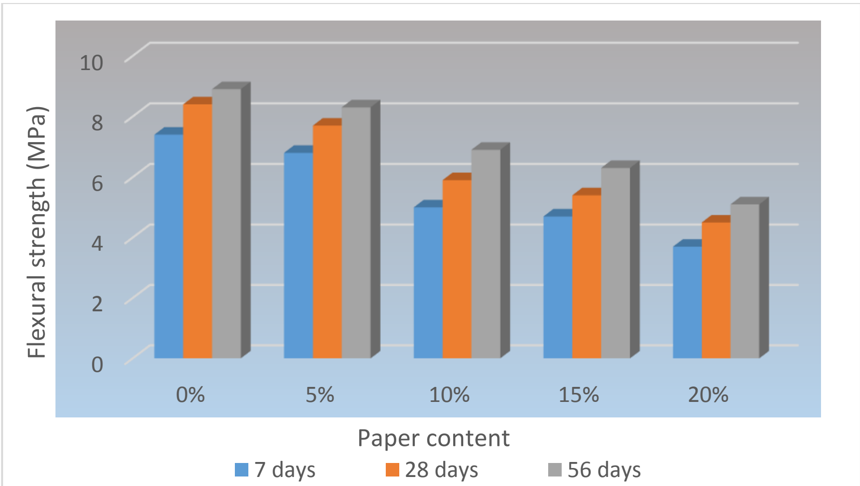

Figure 5. Results of flexural strength of papercrete mortar.

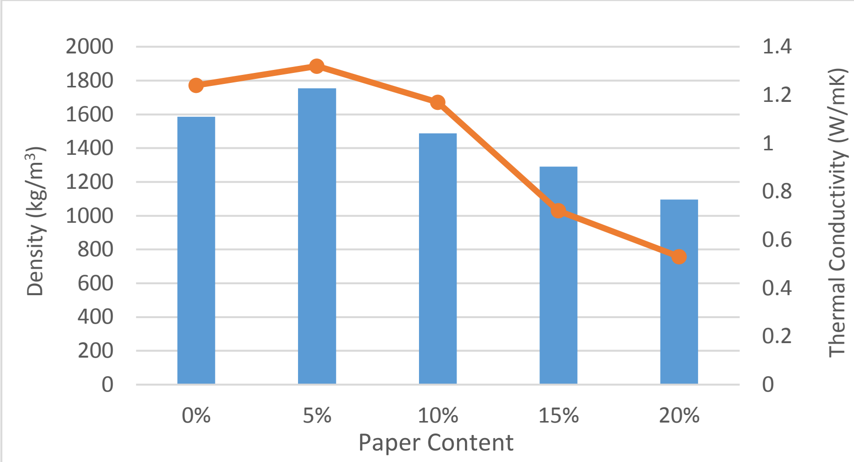

Figure 6. Variation in dry density with thermal conductivity.

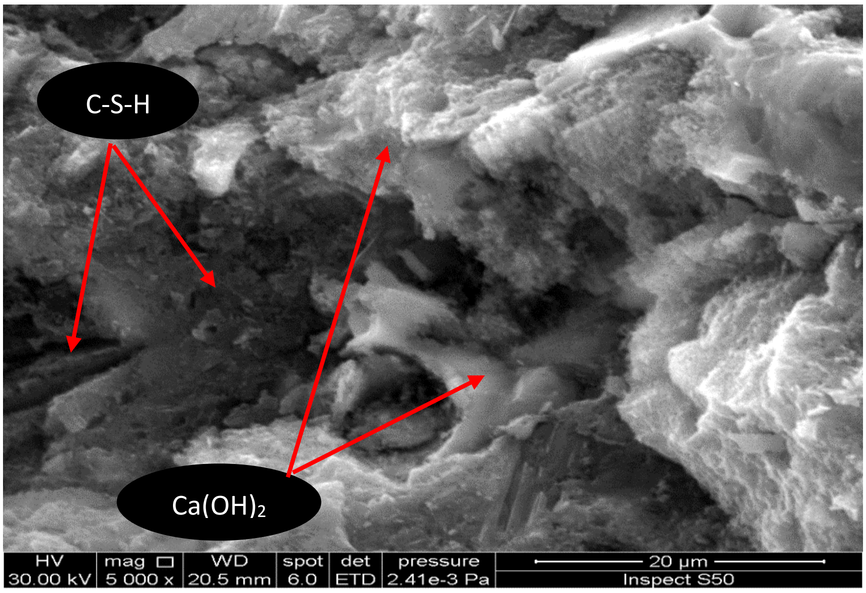

Plate 5. SEM Micrograph of the Specimen with 0% Re-Pulped Paper.

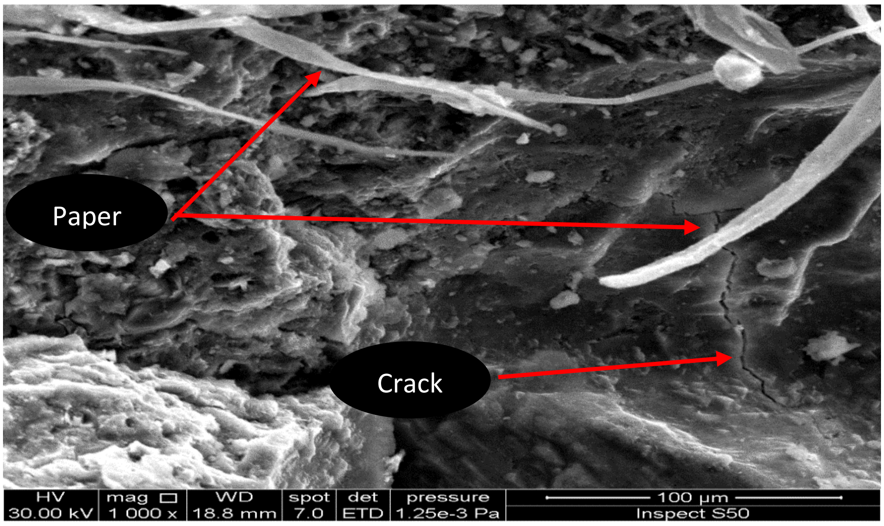

Plate 6. SEM Micrograph of the Specimen with 5% Re-Pulped Paper.

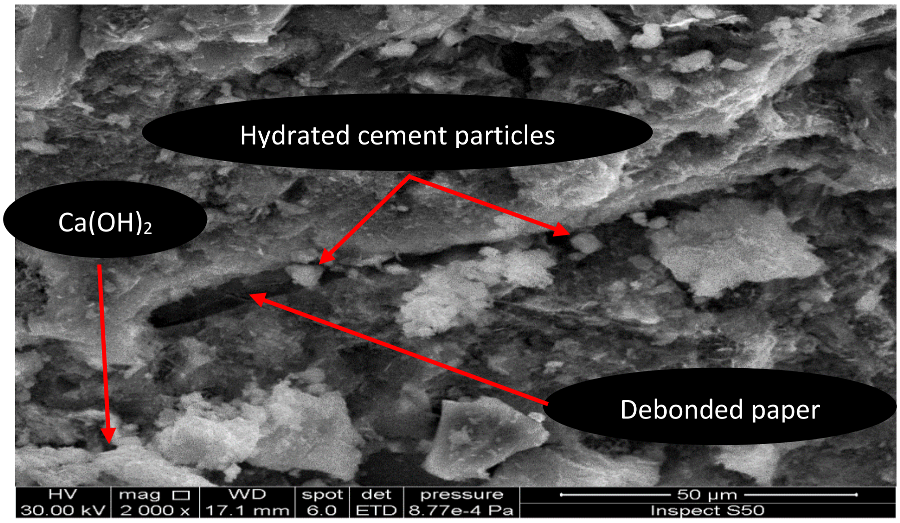

Plate 7. SEM Micrograph of the Specimen with 10% Re-Pulped Paper.

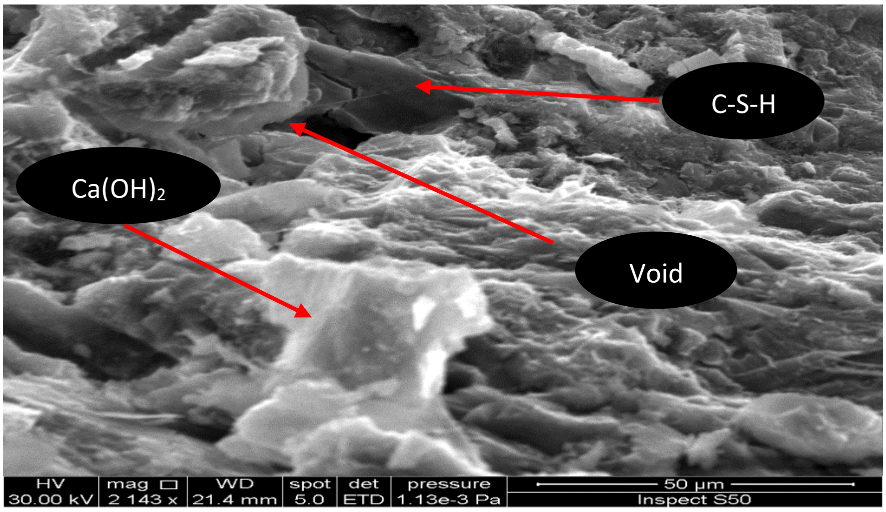

Plate 8. SEM Micrograph of the Specimen with 15% Re-Pulped Paper.

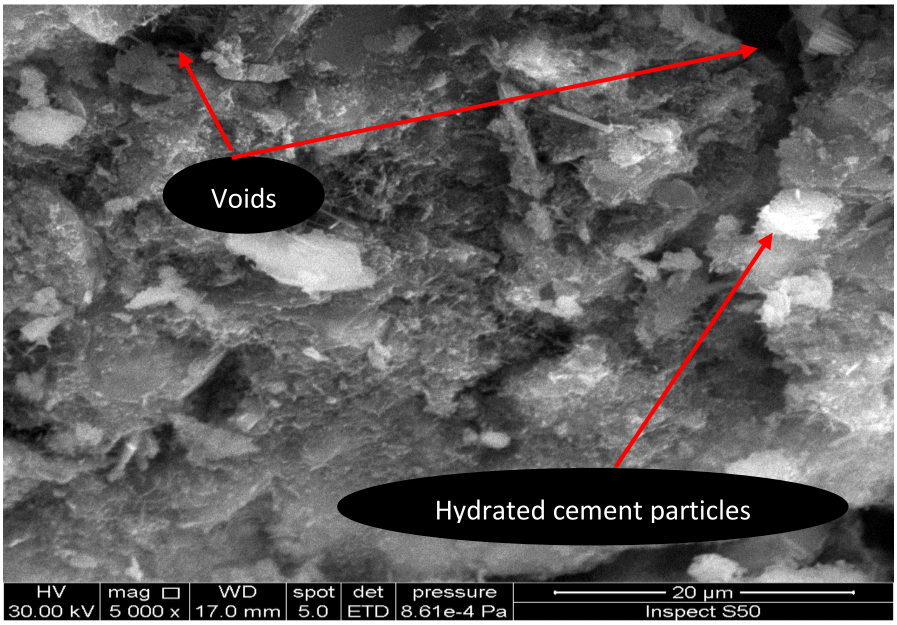

Plate 9. SEM Micrograph of the Specimen with 20% Re-Pulped Paper.