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PROPERTIES OF PAPERCRETE

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ABSTRACT

This paper studies the employment of waste, paper as an additional material in concrete mixes. Is simply a mixture, of paper and concrete? A composite made by adding waste paper as a partial addition by weight of cement. It is a sustainable, building material due to reduced amount of waste paper being put to pretty use. It gains inherent strength due to presence of hydrogen bonds in microstructure of paper. Papercrete has low cost as compared with alternative building construction material and energy absorption. It has good fire-resistant, sound absorption and thermal insulation. The percent of waste paper used (after treating) namely (5%, 10%, 15% and 20%) by weight of cement to explore the properties of the mixes (compressive strength, splitting tensile strength, flexural strength, density, thermal conductivity and scanning electron microscope (SEM)). As compared with references mixes, it was found that the fresh properties affected significantly by increasing the waste paper content. The compressive strength, splitting tensile strength, flexural strength, and density were decreased with increasing the percentage of waste paper addition. By using paper pulp with different weight percentages led to decreasing in thermal conductivity. The values of thermal conductivity at 28 days of all mixes range between (1.21 to 0.79 W/m.K).

Keywords: papercrete, compressive strength, splitting, strength, flexural, strength, sensity, water, absorption, thermal, conductivity, SEM.

INTRODUCTION

The use of waste paper has 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, According to Resource information system incorporated (RISI), paper recycling has been performed about 60% ~ 80% in many countries see (Table-1) (1). The waste problem considered as one of the most crucial problems facing the world as a basis of the environmental contamination. The waste is usually defined as all remains objects resulted from production uses and transfer processes, and in general all scattered things and resources that must dispose to prevent the danger on the health of the human and save the social environment in general (2).

Wastepaper has been used as building materials for decades, especially in cementitious matrices, and since then a lot of research has been conducted to develop the mechanical properties of the composite like compressive, tensile, flexural strength, and etc. (3).

Use of waste paper in structural concrete could become an economical and environmental friendly which helps to minimize harmful effects of construction process (4 and 5). Paper is the most frequent type of waste found in all actiity areas and exemplifies an important source of cellulous fibers.

In different forms (quality paper, mixed paper, newspapers and journals) paper exemplifies about 41% of all household waste produced today. Paper is a recyclable material that after reaching the garbage dumps has a biodegradation period of (3-12) months. That is why the benefits for nature through paper waste recycling are very important. Paper can be recycle in the technological flow that has produced it for the manufacture of paper or the produce of cardboard and pasteboard. waste paper could be only be recycled (6-10) times, with each recycling the length of cellulose fiber is reduced, that will cause a decrease in strength and quality (appearance, color) of the manufactured paper and an increase of technological losses.

Table-1. Recycling ratio of paper in some countries (1).

	Kor ea	Ja pan	Chi na	Taiw an	Hong Kong	U.S .A	Canad a	Germ any	U .K	Fra nce
Rec ycling Ratio (%)	75.4	72	34	68	80	52	68	75	65	64

Cellulose fiber insulation uses recycled newspaper as a raw material, from which raw fibers are extracted and subsequently treated with special additives for fire proofing, as well as for preservation against pests. The manufacture technology includes the application by injection of cellulose fibers. It can be applied for thermal insulation of walls, floors, as well ceilings and roofs enclose at the same time good sound insulation (2), more than 500 million tons of paper is generated worldwide per annum (6).

Papercrete was produced by blending sufficient amount of waste paper with Portland cement type I,

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water and aggregate, and then slump and strength values were contrast with the conventional concrete. The slump showed a decrease with higher amount of paper pulp content (having higher absorption ratio) with 5% replacement by weight of cement the slump show slight increase (about 5%), while adding paper pulp above 5% the slump was decreased. The results indicated that the mechanical strengths (compressive, splitting tensile and flexural) strength was 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 (7).

Paper is consist, mainly from wood cellulose, which is considered a fibrous material. Cellulose is a natural polymer, a long chain of associated sugar molecules made by the associating of smaller molecules. The links in the cellulose chain; are a type of sugar: ß-D-glucose. The cellulose chain bristles with polar-OH groups, these groups compose many hydrogen bonds with OH groups on approaching chains, bundling the chains together (Figure-1). The chains also pack orderly in places to form hard, stable crystalline regions that allow the bundled chains even more balance and strength. This hydrogen bonding produces the basis of papercrete strength (8). Paper sludge consist of silica and calcium oxide, in addition to alumina and magnesium oxide. Cement mixed with 1 0% and 20% waste paper shows less reduction in compressive strength than the control cement (9).

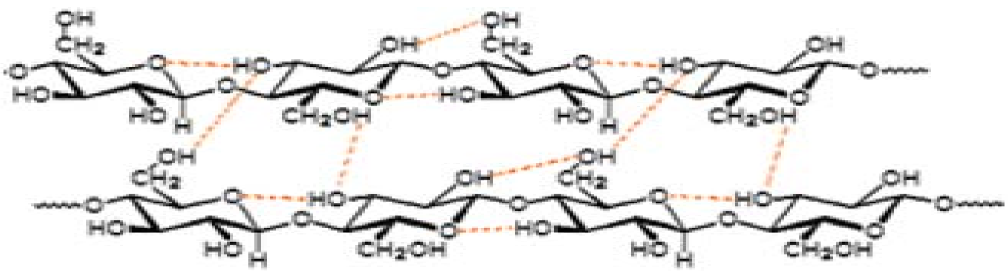

Figure-1. Chemical structure of paper (Cellulose hydrogen bond) (10)

Papercrete is a complex material comprising of Portland cement, waste paper, water and/or sand. Papercrete have been reported: to be cheap alternative building material; to have good sound absorption and thermal insulation; to be a light weighted and fire-resistant material. It should be noted that papercrete is a comparatively new concept with limited scope. Papercrete is known by alternative names such as fibrous concrete, Padobe and Fidobe. (11).

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

- Study the properties of Papercrete to define its potential as a sustainable building material.
- Limit the ideal papercrete mix.
- Formulate the samples of the locally available materials.
- Determine the strengths of various Papercrete mixes.

MATERIALS AND PROPERTIES

Cement

Ordinary Portland cement (Type I) manufactured by (Lafarge Company /Bazian) commercially famed as (Mass) was used throughout of the work. The physical properties are given in (Table-2), whereas the chemical composition and main compounds of cement are explained in (Table-3). The test results of cement present that the cement conforms to Iraqi Specification No.5/1984 (12). Tests were carried out by National center for Construction Laboratories and Researches (NCCLR).

Fine aggregate

Al-Ekhaider natural sand was used as fine aggregate throughout the experiment, al work. (Table-4) and (Figure-2) present physical and chemical properties of it. The tests results were presented the gradation of the sand lies in zone (2) and the sulphate content (0.37%) which are within the requirements of the Iraqi specification No. 45/ (198 4) (1 3). The tests were conducted at the construction materials laboratory at civil engineering department at university of technology.

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Coarse aggregate

Al-Soddor crushed coarse aggregate was used as coarse aggregate through the experimental work. It was tested to determine the sieve analysis, in addition to physical and chemical properties of gravel as shown in (Table-5). The tests results were presented the gradation of the gravel and the sulfate content (0.098%) which are within the requirements of the Iraqi specification No. 45/ (1984) (13).

Water

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

High-range water reducing admixture (Superplasticizer)

A High Performance Superplasticizer Concrete Admixture commercially known as Visco-Crete 5930 and produced by SIKA construction chemicals was based on modified Polycarboxylate which was used throughout the experimental work. The dosage recommended by the manufacturer is from (0.2-0.8) liters by weight of cement. This type of admixture conforms to ASTM C494 type G and type F (14).

Waste papers

Waste paper was collected from schools, administration offices, planning, and libraries. The physical properties of the waste paper are shown in (Table-6). The papers were cut into small pieces by using paper cutter as shown in (Figure-3). These small dimensions prevent the paper from clumping when waste paper is assorted with water so the paper expand evenly in the papercrete mix. The paper were then soaked in water for three days (Figure-4) and then the paper sludge was placed on non- absorbent plate for squeezing out extra water content, after that the paper submit to grinding by used blender to obtain the required size of paper sludge. The paper sludge was collected from the blender and stored in plastic bags for casting of papercrete specimens. (Figure-5) shows the paper mass after grinding in the wet grinder.

EXPERIMENTAL PROGRAM AND TEST PROCEDURES

Proportion of the mix

The mix proportion was designed to get appr ximately about (25) MPa compressive strength of normal concrete. Trial mixes were prepared for workable mix while adding waste paper. At last the mix proportion by weight was [1:1.9: 2.5] cement: fine aggregate: coarse aggregate, water cement ratio was kept constant as (w/c = 0.3 5) to keep the slump value the same by adding super-plasticizer called (Sika). The weight of cement, sand and gravel that used in all mixes were 400 (kg/m3), 760 (kg/m3) and 1000 (kg/m3) respectively. Four Papercrete mixes were then prepared by adding paper pulp by weight of cement as 5%, 10%, 15% and 20%.

Table-2. Physical properties of cement.

Physical properties	**Test results**	**Limits of Iraqi specification No.5/1984 (12)**
Fineness (Blaine method), cm^2/gm)	3300	≥2300 cm^2/gm
Setting time (Vicate apparatus), a. Initial setting, hrs: min b. Final setting, hrs: min	 2: 10 4:30	 ≥ 45min ≤10hrs
Compressive strength, MPa For 3 days For 7 days	 19.63 28.93	 ≥15 MPa ≥2 3 MPa
Soundness Autoclave method%	0.09	<0.8

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Table-3. Chemical composition and main compounds of cement.

Oxides composition	**Composition content %**	**Limits of Iraqi specification No.5/1984** (12)
Lime, CaO	63.71	-
Silica, SiO_2	21.88	-
Alumina, Al_2O_3	5.00	-
Iron oxide , Fe_2O_3	3.29	-
Magnesia ,MgO	3.79	5.0 % Max
Sulfate, SO_3	2.33	2.8 % Max
Loss on Ignition, (L.O.I.)	3.16	4.0 % Max
Insoluble residue, (I.R)	0.14	1.5 % Max
Lime Saturation Factor, (L.S.F.)	0.96	0.66-1.02%
Main compounds (Bogues equations)		
C_3S	43.80	-
C_2S	29.42	-
C_3A	7.67	-
C_4AF	10.03	-

Table-4. Properties of fine aggregate.

Sieve size (mm)	**Passing by weight %**	**Limits of IQS (No.45/1984) Zone (2)** [13]
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 No.45/1984) (13)
Specific gravity	2.6	-
Bulk Density (kg/m^3)	1560	-
Sulfate content%	0.37	≤0.5
Absorption%	2.3	-
Fine materials %	3.7	≤5

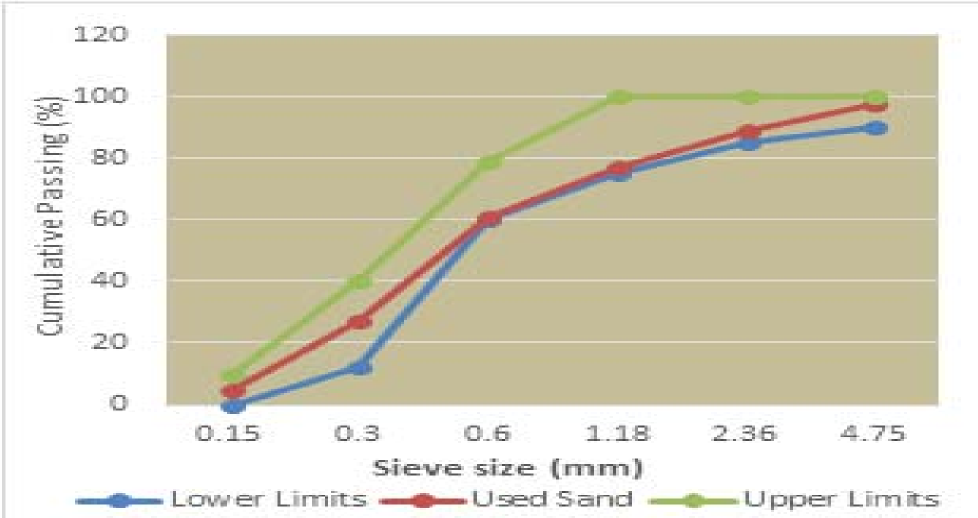

Figure-2. Gradingcurve for used fine aggregate.

Table-5. Properties of coarse aggregate.

Sieve size (mm)	Passing by weight %	Limits of IQS (No.45/1984)(13)
20	100	95-100
14	-	-
10	42	30-60
5	3	0-10
Property	Test Results	Limits of (IQSNo.45/1984)(13)
Specific gravity	2.68	-
Bulk Density (kg/m^3)	1680	-
Sulfate content%	0.098	≤0.1
Gypsum %	0.210	≤ 0.215
Fine material %	0.56	≤ 3
Absorption %	0.43	-

Table-6. Physical properties of waste paper.

Moisture Content %	2.6 7
Specific Gravity (SSD)	0.98
Density (kg/m^3)	80 0
Absorption %	8 9
Organic Materials %	7 0
In-organic materials %	3 0

Figure-3. Sample of paper shredder.

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Figure-4. Paper pieces soak in water.

Figure-5. Paper mass after soaking and grinding.

Fresh concrete test

a) Slump test

A slump test is a suitable test to determine the workability for all types of concrete mixes; the test was performed according to ASTM C143-12 (15).

b) Fresh density

This test is conducted according to ASTM C567-14 (16). The average of three cubes of (100) mm is considered to determine the fresh concrete density.

Hardened concrete test

A. Density of hardened concrete

Is determined using air dried cubes of, sizes (100x100x100) mm according to B.S 1881: part 114: 1989 (17). The specimens were tested after picking, the cubes out of the curing water after drying their surfaces by a piece of cloth. Density (ρ) the mass of a unit volume of hardened concrete expressed in kilograms per cubic meter.

B. Compressive strength

Is determined according to B.S 1881: part 116, 1983 (18). Average compressive strength of three cube specimens was recorded at the age of (7, 28 and 56) days.

C. Splitting tensile strength

Isdone according to ASTM C496-11 (19) and the average splitting tensile strength of three cylinder specimens was recorded at ages (7, 28, and 56) days.

D. Modulus of rupture (Flexural strength)

Is determined by using (100×100×400) mm prism specimens in conformity with ASTM C78 -15 (20) the prisms were subjected to two- third point loading system. The loading was applied at a rate of 0.02 MPa/sec, the specimens were tested at age of (7, 28, and 56) days. The average of two specimens in each age was adopted.

E. Absorption test

Is determined using cubes of sizes (100x100x100) mm to determine the absorption capacity in accordance with the ASTM C642-13 (21).

F. Thermal conductivity

Thermal properties such as thermal conductivity and specific heat may vary locally with temperature, humidity, material composition, direction ...etc. Knowledge of local thermal conductivity is important in the evaluation of heat transfer rates. A special mold was prepared to produce the required specimen with diameter of (50 mm) and (10 mm) thickness; two specimens were used for each mix and tested at (28 days). Hot disk method was used for determining the thermal conductivity (K).

G. Scanning electron microscope (SEM)

This test requires to prepare a sample of test according to ASTM C-856-14 (22) with the suitable dimensions (10*10*10) mm. All specimens were dried in 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 h. The final stage involves coating with a thin film of conductive material (Liquid gold) to prevent the buildup of electric charge when the electron beam scans the specimen.

RESULTS AND DISCUSSIONS

Fresh concrete

(Table-7) present the slump test values and fresh density results. A higher content of waste paper pulp cause a reduction in slump values and fresh density due to higher water absorption of the paper. It requires more water to get the same slump, thus the workability of concrete containing paper pulp was improved by the addition of the super-plasticizer. While density decreased by the addition of paper. The percent of super-plasticizer was increased with increase in waste paper pulp content as indicated in (Table-7).

Table-7. Results of slump and fresh density.

Mix ID	% of pulp paper mass by weight of cement	Admixture (Sika) by weight of cement (%)	Slump (mm)	Fresh density (kg/m^3)
R	0	0. 75	4 5	2334
M5	5	1	48	2310
M10	10	1. 5	5 0	2103
M15	1 5	2. 25	4 6	2083
M20	2 0	2.5	4 2	2040

Hardened concrete

The results of dry density and water absorption test of the papercrete are shown in (Table-8) and (Figure-6). It was noted that the dry density shows a decrease in results; while water absorption was increased with the increasing of waste paper content of the mixes. High amount of water absorption is due to the presence of cellulose materials that easily absorbs water and retains it for long time. The average test results of compressive strength, splitting tensile strength and flexural strength at (7, 28 and 56) days age are recorded in (Table-8). The test results indicated an increasing in strength with progressing of curing ages due to continuing of hydration process. The results of strengths (compressive, splitting tensile and flexural)strength of concrete mixes with waste paper pulp were less than reference mix for all test ages except that mixture with (5%) of paper pulp addition. Mixture with (5%) shows slightly higher than the reference mix, since waste paper contains considerable amount of alumina-siliceous material that is combined with calcium, leading to the improvement in its strength. The advancement of this strength is predominantly inferable to the hydraulic and pozzolanic activity of waste paper that is activated by the alkalis and to some extent, $Ca(OH)_2$ which is released from the hydration process. Compressive strength results for all mixes are indicated in (Figure-7) for all ages (7, 28, and 56 days). The same trend was seen in (Figure-8) for splitting tensile strength. This is because of loss in cohesion and also the binding of calcium- hydrate - silicate (C-S-H) gel on cellulosic material is extremely poor. Beside adding waste paper to the concrete mix will hold volume in the specimens and any expansion will weaken the concrete. On the other hand the flexural strength results showed in (Figure-9) which indicates that concrete mixes with 5% paper pulp gives same strength as reference mix for all ages and the strength decreases as the content of paper pulp increases. Thermal Conductivity test is one of the important properties of the insulating concrete. The test results of thermal conductivity of all papercrete mixes at (28) days are listed in (Table-8) and (Figure-10). The results show that thermal conductivity for concrete containing (10%, 15%, and 20%) of waste paper is less than that without paper pulp. Due to the cellular nature of papercrete, it resists the heat flow through papercrete and effect on the conductivity, Therefore, the paper pulp is the main factor to decease the thermal conductivity. (Figure-11) shows the relationship between thermal conductivity and dry density at (28) days. This figure indicates that the density is the major factor affecting on thermal conductivity values, increases in the density lead to increase thermal conductivity (K), due to reduction of density the pores and gaps between the particles which prevents the passage of the heat through it. Due to increasing the size and number of voids and pores that led to decrease in thermal conductivity as compared with reference mix, the statement of lower density resulting in lower thermal conductivity was proven true and it is also supported by other researchers such as Tuqa (23), Bassem (24), Al-Jailawy and Gajin (25).

The SEM observations of the interfacial transition zone contrast the good bonding of particles with cement paste, that demonstrate in (Figure-12). Also (Figure-13), the paper pulp surface is covered with the hydration products. Thus, it results in a decrease in tiny voids and porosity in the matrix. The compact matrix with pulps improved the mechanical strength of composites. On the other hand (Figure-14), (Figure-15), and (Figure-16) show a de-bonded between paper pulp and matrix with less $CaCO_3$content compared with reference specimen 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. Moreover, it was noticed, that there are presence of closed pores in the specimens with increasing the percentage of paper pulp addition. The results also distinguished by (26).

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Table-8. Properties of hardened concrete mixes.

M ix ID	Air d ry density (Kg/m^3)	Thermal Conductivity (W/m.K)	Water absorption (%)	Compressive strength (MPa)			Splitting 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	2140	1.13	6.3	32.6	39.7	48.7	2.5	3.3	3.5	4.4	5.5	5.8
M 5	2159	1.21	5.9	33.2	42.1	49.9	2.7	3.5	3.6	4.3	5.4	5.7
M 10	2015	1.08	8.4	31.7	31.4	37.3	2.2	2.8	3.3	3.4	4.4	4.8
M 15	1989	0.92	12.4	17.4	22.2	26.9	1.8	2.4	2.7	3.2	4.1	4.3
M 20	1894	0.79	14.6	11.3	16.8	21.2	1.5	1.9	2.4	2.4	3.4	3.6

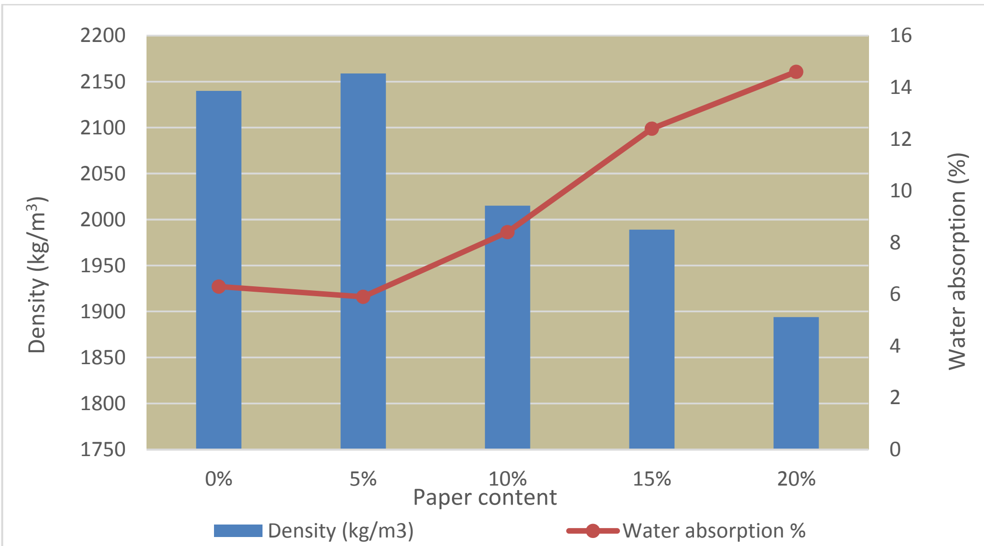

Figure-6. Variation in density with water absorption.

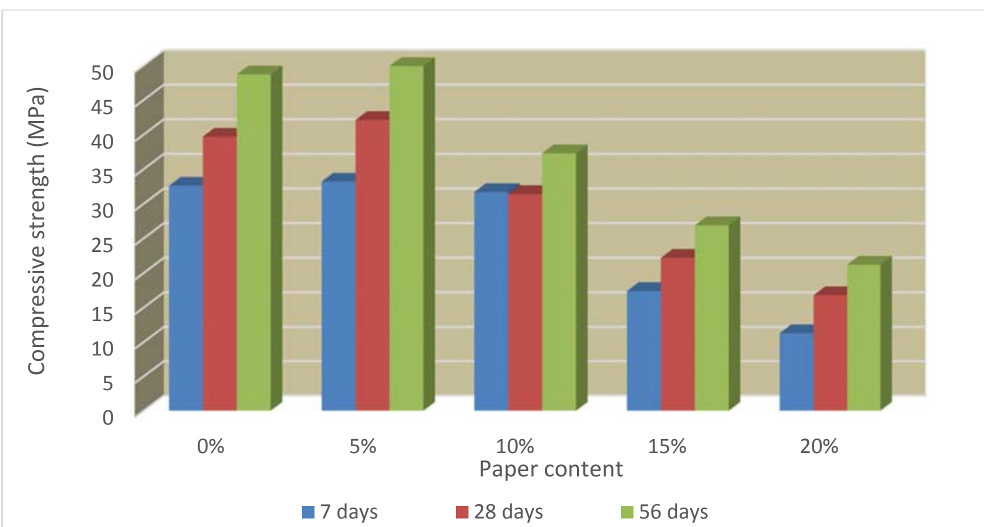

Figure-7. Results of compressive strength of concrete.

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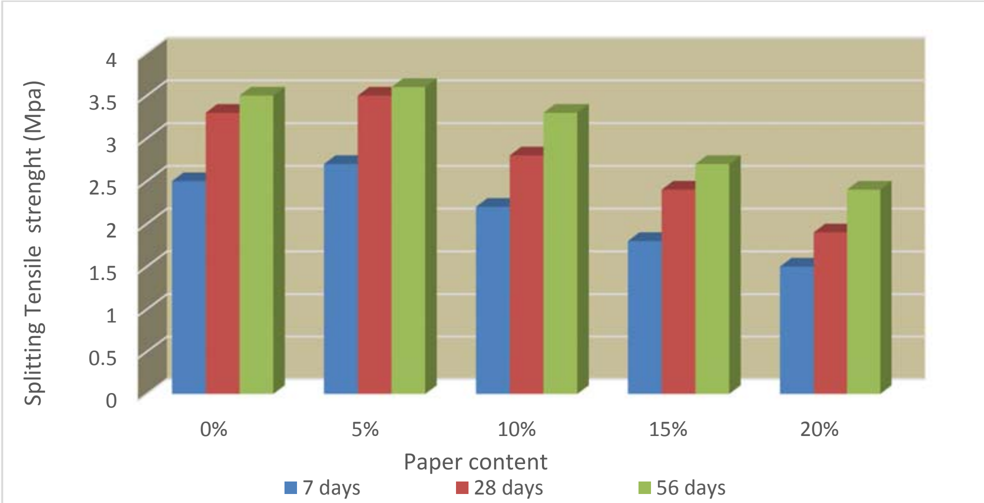

Figure-8. Results of splitting tensile strength of concrete.

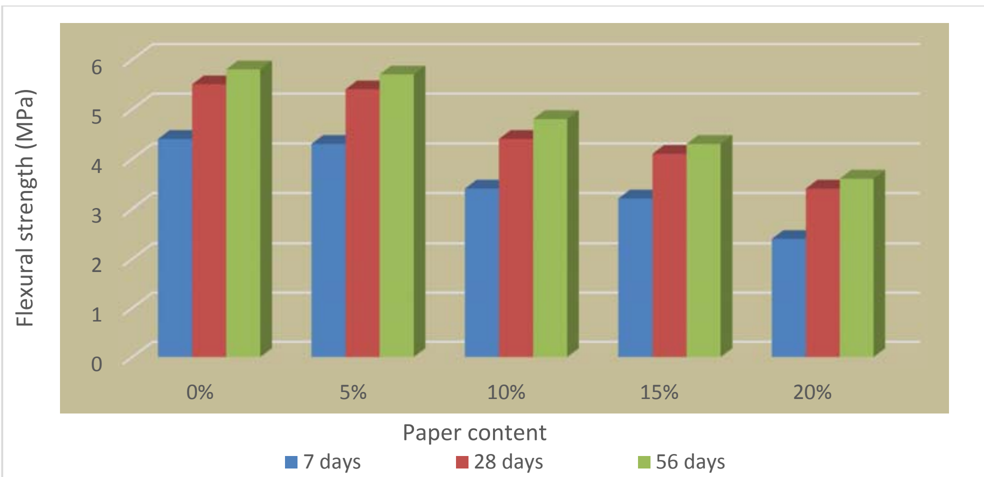

Figure-9. Results of flexural strength of concrete.

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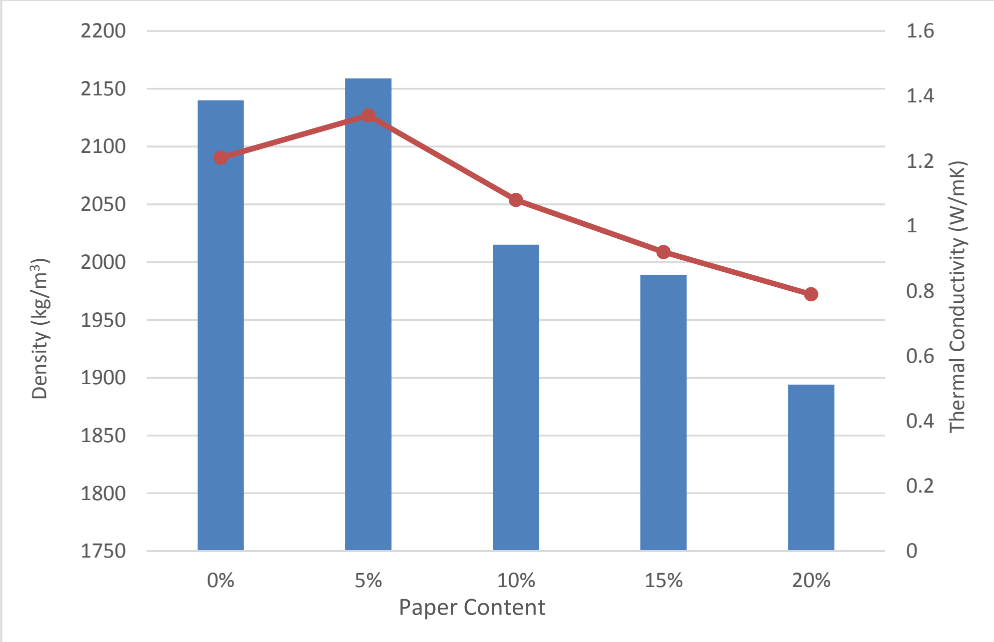

Figure-10. Variation in air dry density with thermal conductivity.

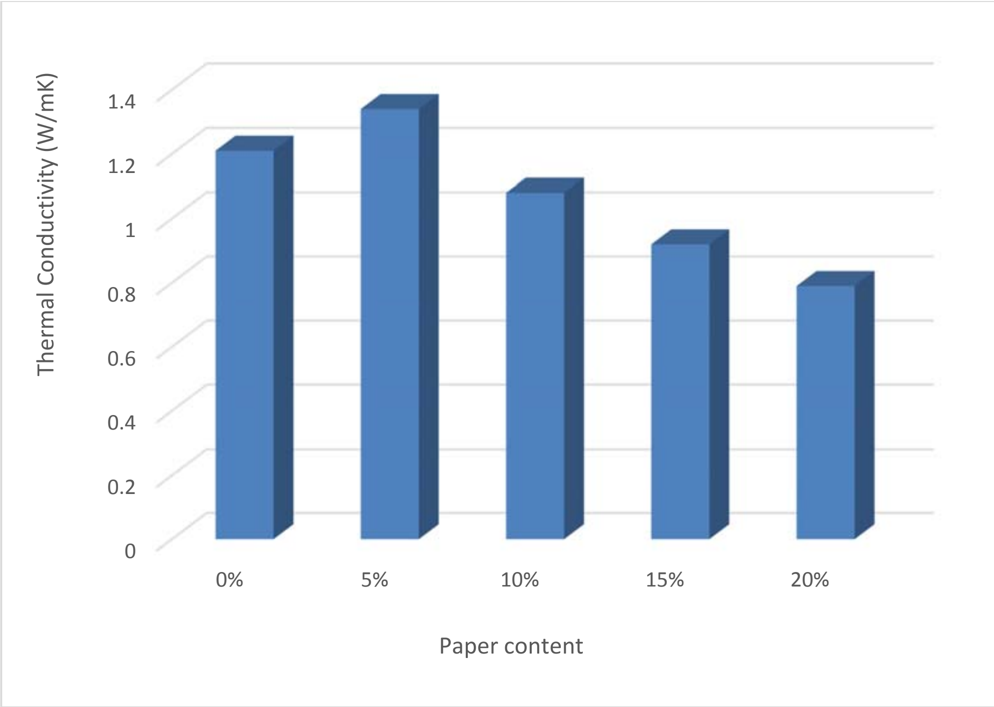

Figure-11. Results of thermal conductivity of concrete.

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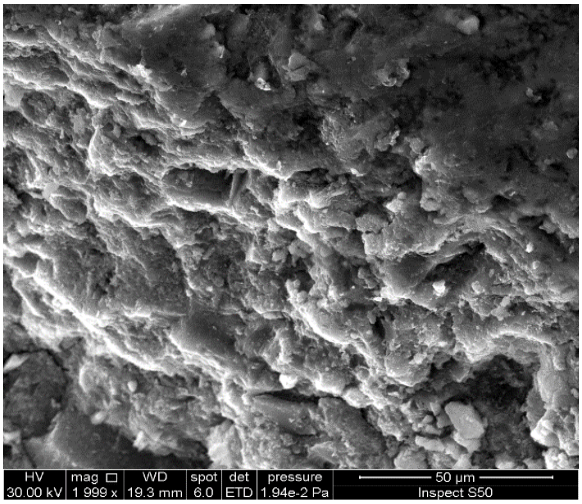

Figure-12. SEM micrograph of the specimen with 0% re-pulped paper.

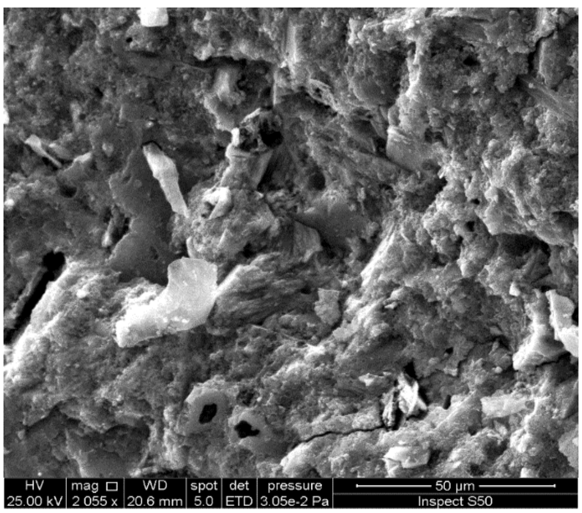

Figure-13. SEM micrograph of the specimen with 5% re-pulped paper.

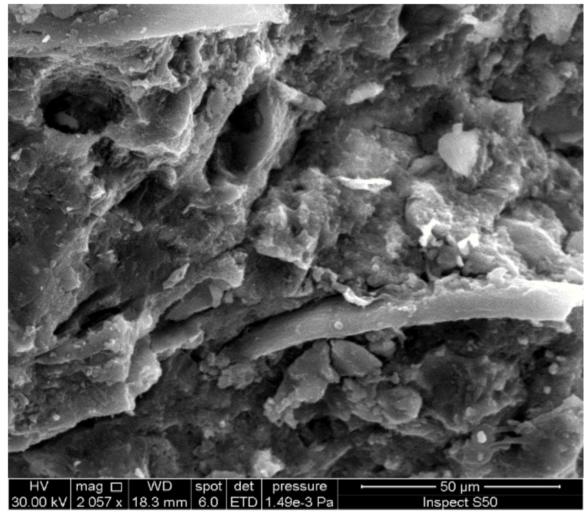

Figure-14. SEM micrograph of the specimen with 10% re-p ulped paper.

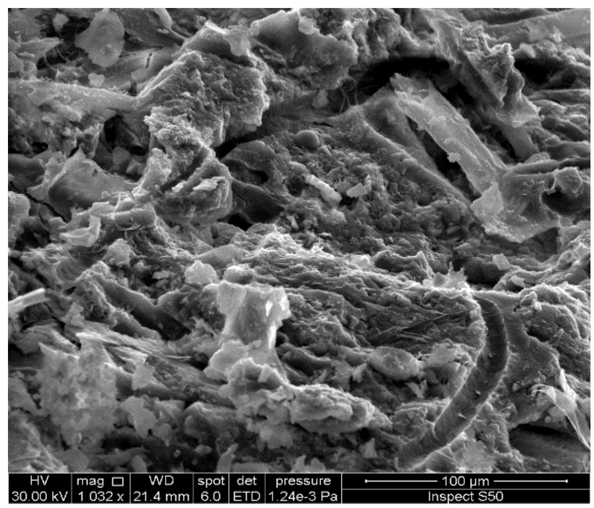

Figure-15. SEM micrograph of the specimen, with 15% re-pulped paper.

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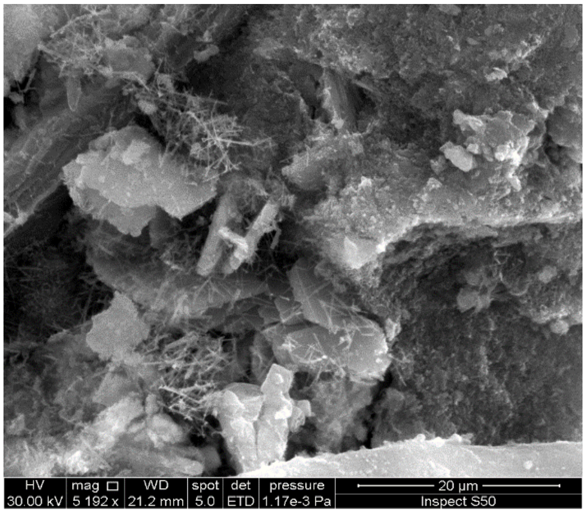

Figure-16. SEM micrograph, of the specimen with 20% re-pulped, paper.

CONCLUSIONS

Based on the test results in this work, the following conclusions can be drawn:

a) The low bulk density, of papercrete demonstrates the waste paper could be important material as alternative sustainable resources to produce lightweight concrete.

b) It has been, confirmed that adding waste paper has a distinct antagonistic impact on the slump and fresh density. For which, request higher water or higher chemical admixture dosages to keep the slump values as for as the possible.

c) Adding waste paper to concrete mix prompted increment in water absorption and decrease in dry density for all mixes used aside from the mixture with 5% of paper pulp. The results of dry, density demonstrate that, lightweight concrete could be created by adding, waste paper.

d) Adding waste paper to concrete mix led to increase in water absorption and decrease in dry density for all mixes used except the mixture with 5% of paper pulp. The results of dry density indicate that lightweight concrete could be produced by adding waste paper.

e) Compressive strength, splitting tensile strength and flexural strength for mixes decrease with increasing of amount of wastepaper. While the mixture with (5%) indicate strength nearly equal to that of reference mix.

f) Addition of paper pulp leads to reduced thermal conductivity, this reduction is improvement with increasing the addition of paper pulp.

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