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Influence of Incinerated and Non-Incinerated waste paper on Properties of Cement Mortar

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Abstract: The cement industry is one of the most polluting industries globally, due to the high amount of CO_2 emissions generated during production. Improving the sustainability of cement production is thus vital. Waste paper is also a big problem for many societies, especially in developed countries, where the use of board and paper increases almost every day. This work examines the possibility of using incinerated waste paper ash (IWPA) and non-incinerated waste paper (NIWP) as a partial replacement for cement (by weight) in mortar mixtures. For non-incinerated waste paper, the tested replacement levels were 1%, 1.5%, 2.5% and 3.5%, while for incinerated waste paper, the replacement levels were 2.5%, 5%, 7.5%, and 10%. An additional mix without any replacement was also cast for comparison purposes. The fresh and hardened properties of mortar were assessed using flow rate, compressive strength, direct tensile strength, water absorption, and dry density tests, and two test ages (7 and 28 days) were considered for the compressive and tensile strength tests, though water absorption and density tests were undertaken at 28 days only. The results showed that the presence of waste paper (incinerated or non-incinerated) reduced the flow rate of fresh mortar as compared with the reference mix. It was also found that, for the NIWP mixtures, 1% replacement of cement was the most efficient percentage; this increased the compressive strength by 16% and the direct tensile strength by 19% at 28 days of age. For the IWPA mixes, the results showed that the best replacement ratio was 5%, where the compressive strength and direct tensile strength were improved by 10% and 11% at 28 days, respectively. These 1% NIWP and 5% IWPA mixtures gave similar water absorption of 7% to the reference mix.

Keywords: Waste paper; cement replacement; cement mortar; sustainability.

1. Introduction

Current rapid industrial and technological progress combined with the global increase in population has imposed an urgent need for more urban building, which in turn has increased the need for cement all over the world. Cement is one of the oldest and most important construction materials, and annually, the cement industry produces millions of tons of CO_2 emissions [1], accounting for about 7% of air pollution all over the world [2]. The cement industry is thus a major polluter [3]. It is thus very important to make the concrete industry more sustainable [4] to allow the production of cement with less air pollution. A number of alternatives are available to achieve this; however, recycling other industrial waste is considered a favourable approach [5]. One such waste product is paper waste [6], which has become one of the major environmental and economic challenge for paper and board making industries [7].

The final stage of paper recycling yields two types of materials: pulp, which is re-used in paper production, and deinked paper sludge, which is the part of paper that cannot be recovered during recycling, a paper industry waste that is the by-product of the de-inking [8] and re-pulping of paper, also known as hypo sludge [9], paper mill sludge, and fibre clay [10]. A large quantity of sludge is generated globally at the rate of 300 Kg for each ton of recycled paper. This occurs mainly in developed countries, and causes a great deal of trouble for such countries [11]. The main organic components in the waste paper sludge are cellulose fibres of various lengths, wood, lignin and to certain organic binders, and the main inorganic components are kaolinite (clay), calcium carbonate, talc, titanium oxide, magnesium, calcium chloride and residual chemicals with high water content in the range of 40 to 70%. Overall, this sludge is viscous, sticky, and not easy to dry [12–14].

The use of waste paper in concrete is promising from an economic and health point of view, as it helps to get rid of environmental pollution, reduces the use of raw material by decreasing the use of Portland cement, and uses environmentally friendly materials [15]. Many researchers have thus investigated its use in concrete. Varkey et al [16] investigated the effect of replacing cement with waste paper sludge ash in proportions of 2.5%, 5%, and 7.5% by weight, showing that the 5% replacement gave optimum results at 28 days, with compressive and tensile strength about 7.5% and 3% higher than the control mix, respectively. Shabbir et al [17] performed a study in which, cement was replaced by different proportions of waste paper sludge ash (5%, 10%, 15%, and 20%) to determine the initial and final setting time, compressive strength, tensile strength, and dry density. The results illustrated that the slump value and initial and final setting times were gradually reduced with increases in the percentage of WPSA in the mix. Compressive and tensile strength increased as the WPSA content was increased from 5% to 15%, though increasing the WPSA content above 15% caused the strength to decrease as compared with the reference mix.

Ahmad et al [18] studied the behaviour of 25 MPa compressive strength grade mixes by replacing cement with 5%, 10%, 15%, and 20% waste paper sludge ash. The results showed that increasing the percentage of WPSA caused the workability of the concrete mix to be reduced, the dry density of concrete to be decreased (making the concrete lightweight), and the percentage of water absorption to be increased as compared with reference mix. The 5% replacement of cement with WPSA generated an increase in compressive and splitting tensile strength by 10% and 15% and 5% and 6%, respectively at 7 and 28 days, as compared with the reference mix. Fava et al [19] prepared mixtures of mortar to determine compressive strength in the presence of paper sludge ash (PSA) added in proportions of 5%, 10%, 15% and 20% as a replacement by cement weight. Various water/ binding ratios (0.4, 0.5, and 0.6) were considered. At 28 days, the results showed that the compressive strength of 5% PSA was the same as that for conventional mortar.

An experimental study by Pandya et al [20] to replace cement with hypo sludge (HS) in proportions of 5%, 10% and 15% (by weight) showed that up to the 10% replacement level, the compressive strength of concrete was increased, while beyond the 10% replacement level, the compressive strength was decreased. Kareem [21] investigated the utilisation of office printing as waste paper in concrete mixes with proportions of 0.5%, 0.7%, and 1% by volume investigated to determine the compressive strength and density. The results showed that by increasing the percentage of WPF in concrete to 1%, the slump value was reduced (the highest reduction was about 25%), but that there was only a very small increase in density at 28 days (the highest increase was about 0.8%), though the compressive strength was increased (the highest increases in values were about 30% and 11% at 7 and 28 days, respectively) as compared with the reference mix.

This study aimed to investigate the effects of incinerated and non-incinerated waste paper on the fresh and hardened properties of cement mortar ,including flow rate, compressive strength, direct tensile strength, water absorption, and dry density tests.

2. Experimental work

2.1 Materials

2.1.1 Cement.

Locally produced Ordinary Portland Cement was used in this work. The cement conformed to Iraqi Specification IQS No.5/1984 [22]. Table 1 shows the chemical and physical properties of the cement.

Table 1: Chemical composition and physical properties of cement.

Oxide or compound	**Content, %**	**Limit of Iraqi specification No.5/1984**
CaO	62.03	----
SiO_2	20.63	----
Al_2O_3	5.68	----
Fe_2O_3	3.42	----
MgO	3.68	< 5%
SO_3	2.47	< 2.5%
Free lime	1.67	----
L.O.I.	1.46	< 4 %
L.S.F.	0.9	0.66-1.02
Insoluble residue	0.5	< 1.5 %
C_3S	38.84	----
C_2S	29.85	----
C_3A	9.25	----
C_4AF	10.42	----
Physical properties	**Test results**	**Limit of Iraqi specification No.5/1984**
Fineness Blaine method (m^2/kg)	290	> 230
Initial setting (min)	1:55	> 45
Final setting (hrs)	3:05	< 10
Compressive Strength (MPa)		
3- day	22.3	> 15
7- day	32.3	> 23

2.1.2 Fine Aggregate.
Natural sand with properties conforming to Iraqi Specification IQS No.45/1984 [23] was used as a fine aggregate. Table 2 shows the grading, physical, and chemical properties of the fine aggregate, which were within grading zone II of the applicable specifications.

2.1.3 Waste Paper.
Paperboard, which is usually used as packaging for various goods, was used in this study. Samples were taken from markets, where they are considered waste paper. These packages were cut into small pieces and washed with tap water to remove any debris and dust, before being soaked in water container for 24 hours. Thereafter, the paper sludge was dried at 30 ºC for 48 hours, and then ground using electrical grinder until they took on fibre-like shapes as shown in Figure 1. At this stage, the waste paper is called non-incinerated waste paper (NIWP) and it was used as a partial replacement for cement in proportions of 1%, 1.5%, 2.5%, and 3.5%. The controlled thermal activation of waste paper sludge occurs at a temperature range of 500 to 800 ºC and the soaking time of 2 hours resulted in different mineralogical composition changes as the minerals sought to form a stable form of composed ash [24]. A part of sample was the burned in a controlled oven at 700 ºC for 2 hours to produce incinerated waste paper ash (IWPA), as shown in Figure 2. The IWPA was ground and passed through a 0.15 mm sieve opening before being used as a cement replacement in the percentages of 2.5%, 5%, 7.5%, and 10%.

Table 2: The grading, physical and chemical properties of fine aggregates.

Sieve size, mm	**Passing, %**	**Limit of Iraqi specification No.45/1984 Grading Zone II**
4.75	100	95-100
2.36	100	75-100
1.18	66.5	55-90
0.6	38	35-59
0.3	30	8-30
0.15	1	0-10
Physical and chemical properties	**Test results**	**Limit of Iraqi specification No.45/1984**
Specific Gravity (S.G)	2.4	----
Absorption, %	1.6	----
Fineness Materials	1.94	----
Clay	2.3	< 5%
Sulphate Salt Content (SO_3), %	0.12	< 0.5 %
Bulk Density (g/cm^3)	2.37	----

Figure 1: Waste paper before incineration (fibres).

Figure 2: Waste paper after incineration (ash).

The chemical composition of incinerated waste paper ash is presented in Table 3. Amit et al [8] stated that the presence of lime (CaO) could be interesting from the viewpoint of using ash as a hydraulic binder, as high CaO content means the material is likely to have cementitious properties. The mineralogical composition of incinerated waste paper ash is mainly Calcite 84.4%, Talc 11.0%, and Quartz 3.2%, as shown in Figure 3.

2.2 Cement mortar mixtures

In this research, nine cement mortar mixtures were cast, including a reference mix without waste paper (REF). Four of the other mixtures contained non-incinerated waste paper (NIWP) at replacement levels of 1%, 1.5%, 2.5%, and 3.5% by weight of cement, while, the remaining four contained incinerated waste paper ash (IWPA) at replacements levels of 2.5%, 5%, 7.5%, and 10% by weight of

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cement. The mixes of cement mortar were prepared with mix proportions of 1:3 (cement: sand) and a 0.5 water/binder ratio. Table 4 shows the mix proportions for each of the nine mixtures.

Table 3: Chemical composition of incinerated waste paper ash (IWPA)

Chemical composition	**Content, %**
CaO	49.46
SiO_2	17.65
$Al2O_3$	11.14
MgO	2.71
$Fe2O_3$	2.32
SO_3	2.08
TiO_2	0.96
K_2O	0.39
P_2O_5	0.74
Others	< 1
L.O.I	11.98

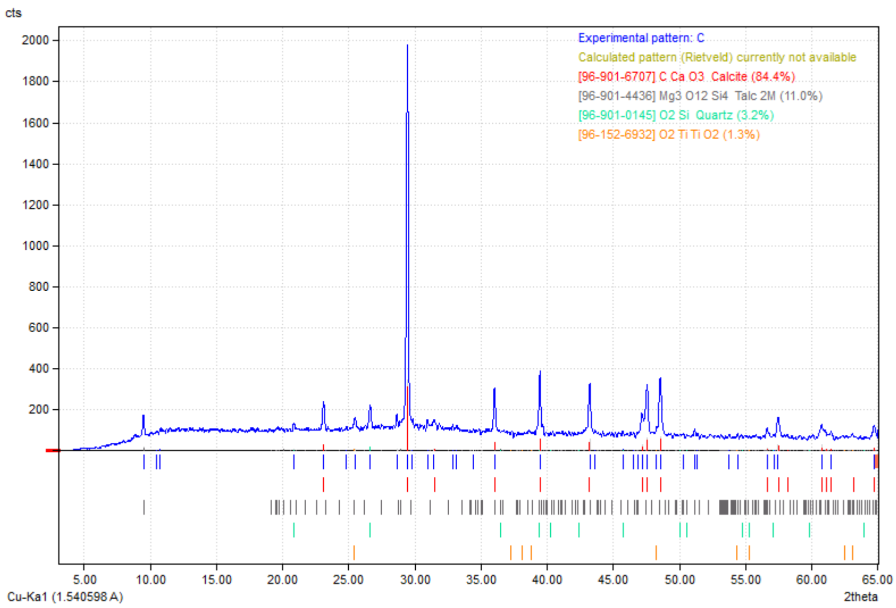

Figure 3: X-Ray diffraction of incinerated waste paper ash.

Table 4: The mix proportions for each mix (12 cubes and 6 briquettes).

Mix type	Mix designation	Replacement ratios, %	Cement, g	Sand, g	Waste paper, g	Water, g
Reference mix	REF	0	1500	4500	0	750
Non-incinerated waste paper	1 NIWP	1	1485	4500	15	750
	1.5 NIWP	1.5	1477.5	4500	22.5	750
	2.5 NIWP	2.5	1462.5	4500	37.5	750
	3.5 NIWP	3.5	1447.5	4500	52.5	750
Incinerated waste paper	2.5 IWPA	2.5	1462.5	4500	37.5	750
	5 IWPA	5	1425	4500	75	750
	7.5 IWPA	7.5	1387.5	4500	112.5	750
	10 IWPA	10	1350	4500	150	750

2.3 Mixing Procedure

The following mixing procedure was used:

1. The dry materials (cement and sand) were mixed at a speed rate of 140 rpm for one minute.
2. The mixer was then stopped and water added; then the mixer was operated at a low-speed of 140 rpm for one minute.
3. While the mixer was working, the incinerated or non-incinerated waste paper (as appropriate) was added gradually, with all ingredients mixed for a further one minute. The total mixing time was thus 3 minutes, excluding stoppages.

2.4 Casting and Curing

After mixing, the cement mortar was cast into standard moulds for compressive and direct tensile strength tests that were lubricated with a thin layer of oil. The specimens for compressive strength and direct tensile tests were damped according to ASTM C109 [25] and AASHTO T132 [26], respectively. After 24 hours from casting, the specimens were lifted from the moulds and immersed in tap water containers at room temperature until the testing.

2.5 Tests

2.5.1 Fresh Tests.

2.5.1.1 Flow Test.

The flow rates of fresh mortar were assessed immediately after mixing using the flow table, according to ASTM C1437 [27].

2.5.2 Hardened Tests.

2.5.2.1 Compressive Strength Test.

The 50 mm cubes were utilised for measuring the compressive strength of the hardened mortar. Two testing ages were adopted, 7 and 28 days.

2.5.2.2 Direct Tensile Strength Test.

Briquette-shape specimens were used for measuring the direct tensile strength. Two testing ages were assessed, 7 and 28 days.

2.5.2.3 Dry Density and Water Absorption Test.

In this study, dry density and water absorption tests were conducted at 28 days after curing, following ASTM C642 [28]. For this test, cement mortar was cast in 50×50×50 mm cubes. The specimens were placed in the oven at 100 to 110 ºC for 24 hours, then cooled. Thereafter, the specimens were returned to the oven again, before again being cooled and weighed. The procedure was continued until the mass difference between any successive values was less than 0.5%; the mass at that point was recorded as the dry mass. After that, the specimens were immersed in water and weighed every 24 hours until the mass difference between any successive values was again less than 0.5%; that mass was recorded as the wet mass. The specimens were then placed in boiling water for 5 hours, then cooled for at least 14 hours and weighed in air (A), before being suspended and weighed in water. The water absorption and density were calculated using the following equations:

$$\text{Water Absorption} = \frac{W-D}{D} * 100 \quad (1)$$

$$\text{Dry Density} = \frac{D}{A-H} *1000 \quad (2)$$

where D: Dry sample weight, W: Wet sample weight, A: Wet sample weight in air after boiling, H: Wet sample weight suspended in water after boiling, 1000: Density of water.

3. Results and Discussion

3.1 Fresh Cement Mortar Results

3.1.1 Flow Results.

The flow results for all cement mortar mixtures are represented in Figures 4 and 5. In general, the presence of NIWP and IWPA decreased the flow rates in comparison to the reference mix. For NIWP, the reduction percentages were 12%, 24%, 17%, and 14% for 1%, 1.5%, 2.5%, and 3.5% NIWP proportions, respectively. According to Kareem [21], as the paper fibres have a higher water absorption capability of up to 198% of their weight, this gives a stiff dense consistency to concrete. The same study revealed that a further increase in waste paper fibres led to agglomeration and resulted in a non-workable concrete. The results also show that the flow rates decreased with the increase of NIWP up to 1.5%, and then tended to increase beyond 1.5 %, though the flow values remained lower than that of the reference mixture.

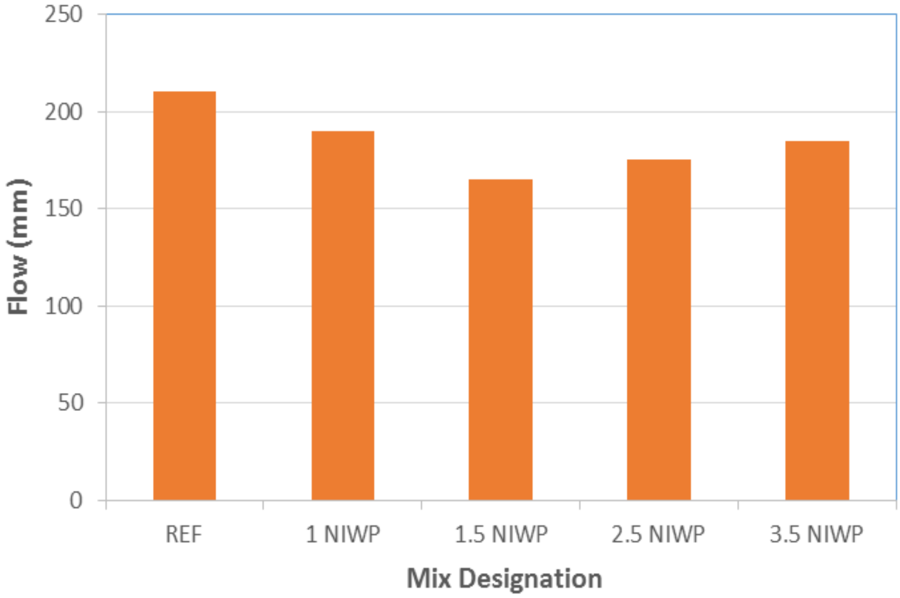

Figure 4: Flow results for non-incinerated waste paper mixtures.

For IWPA, the flow reduction percentages were 14%,19%, 22% and 29% for replacement ratios 2.5%, 5%, 7.5%, and 10% respectively. This reduction in flow rates agrees with the work of Ahmad et al [18], who concluded that increasing waste paper ash content could decrease slump, as waste paper ash particles absorbed higher levels of water as compared with cement, and consequently decreased the slump of fresh concrete. Bai et al [29] also attributed the reduction in slump to the high water demand of waste paper ash, which allows the waste paper ash to absorb water more rapidly and effectively than Ordinary Portland Cement.

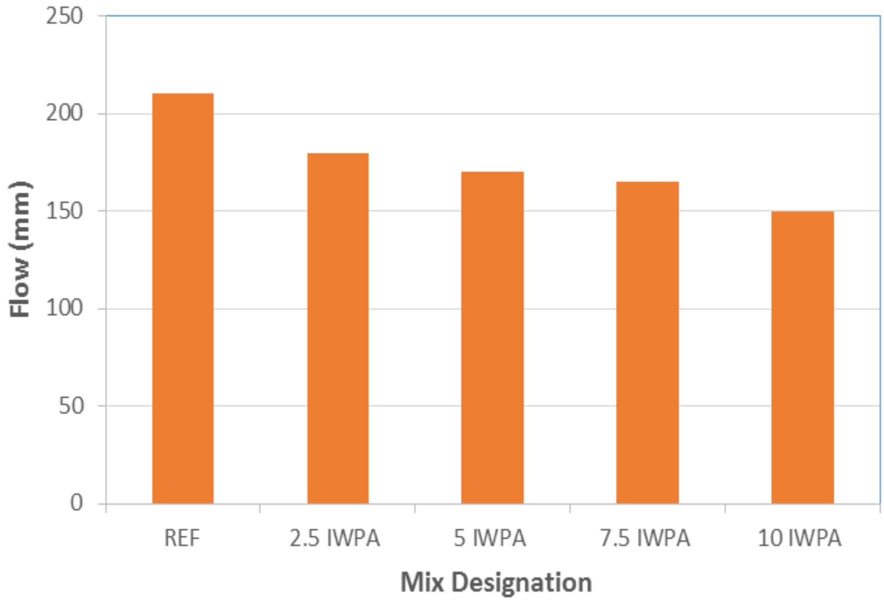

Figure 5: Flow results of incinerated waste paper mixtures.

In addition, the IWPA mixes were more coherent, as shown in Figure 6, than the NIWP mixes, as shown in Figure 7. This behaviour may be attributed to the fineness of IWPA compared with waste paper prior to incineration, which takes the form of tangled fibres.

Figure 6: Flow shape of mortar mixture with 10% incinerated waste paper ash.

Figure 7: Flow shape of mortar mixture with 3.5% non-incinerated waste paper ash.

3.2 Hardened Cement Mortar Results

3.2.1 Compressive Strength Results.

The compressive strength results of the mortar mixes at 7 and 28 days are presented in Figures 8 and 9. For NIWP mixes, the results indicated that replacing cement with 1% non-incinerated waste paper increased the compressive strength by 13% and 16% at 7 and 28 days of age, respectively, as compared with the reference mix. This enhancement can be attributed to the role of waste paper fibres in decreasing voids and increasing bonding ability, which improves the compressive strength [21].

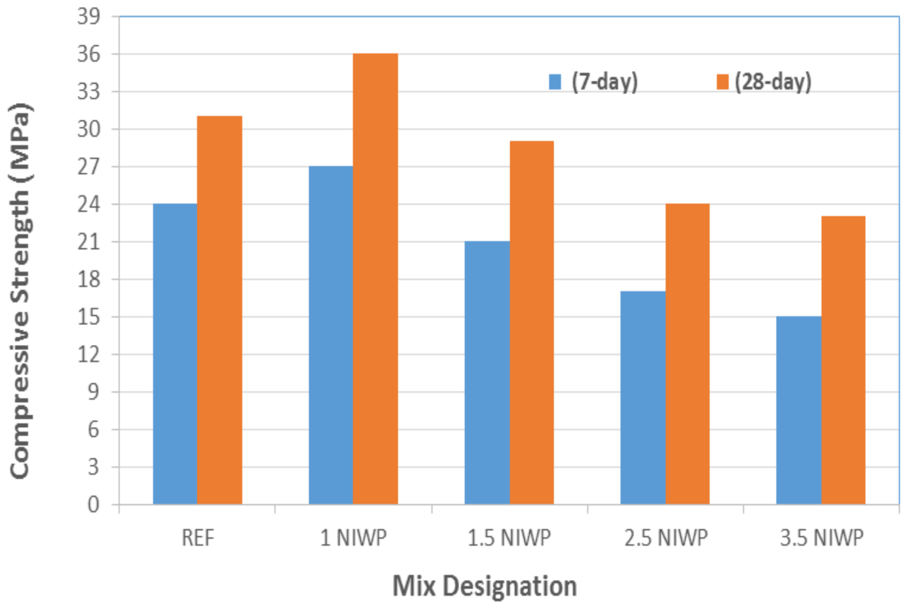

Figure 8: Compressive strength results for non-incinerated waste paper mixtures at 7 and 28 days.

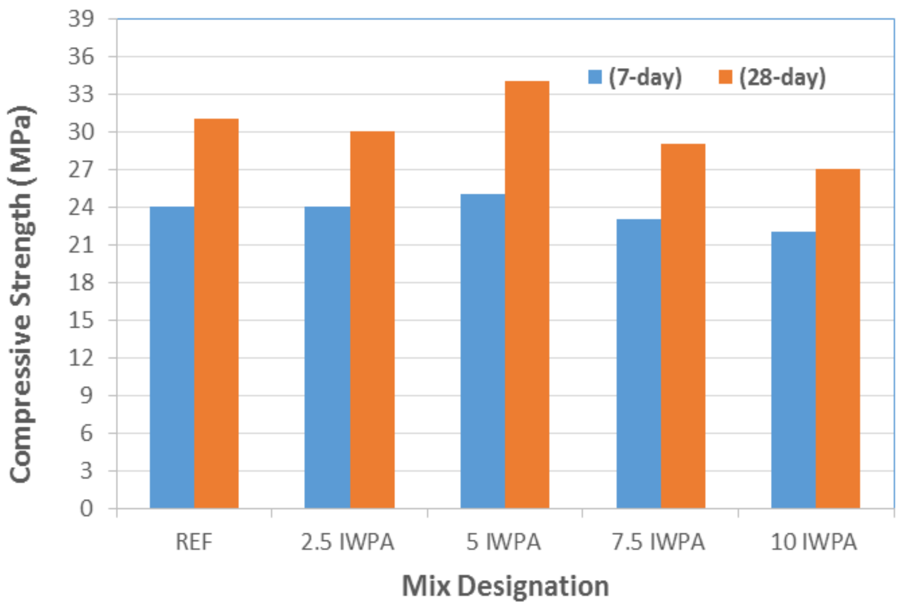

Figure 9: Compressive strength results of incinerated waste paper ash mixtures at 7 and 28 days.

In contrast, replacement levels higher than 1% percent (1.5%, 2.5% and 3.5%) decreased the compressive strength by 13%, 29% and 38% and 6%, 23% and 26% at 7 and 28 days, respectively in comparison to the conventional mortar. Kareem [21] stated that when the waste paper fibre content exceeded a specific level (1% of concrete volume), the mortar became less workable, and the volume of trapped air is increased, leading to more voids and reducing the compressive strength. Similar results were also found by Parveen et al [30].

For IWPA, results showed that replacing 2.5% of cement with IWPA gave comparable values to the control mixture at 7 and 28 days of curing. These results were in agreement with the literature

[16]. At the replacement level of 5%, enhancements in compressive strength of 4% and 10% at 7 and 28 days, respectively. were recorded, matching the findings observed by Ahmad et al [18] and Varkey et al [16]. The cementitious activity of the IWPA can explain this improvement [19,31,32].

In contrast, the compressive strength values were reduced at replacement levels of 7.5% and 10%. The reduction rates were 4% and 7% (for 7.5% replacement) and 8% and 13% (for 10% replacement) at 7 and 28 days, respectively. These results agree with those of Varkey et al [16], Ahmad et al [18], and Fava et al [19] works. Sarma et al [33] attributed this decrease in compressive strength to the low silica content in waste paper sludge. The large specific surface of waste paper ash, together with the distribution of many fine particles, results in an increase in the amount of absorbed water, which affects the process of cement hydration and prevents the production of products to fill the voids within the mixture [24].

3.2.2 Direct Tensile Strength.

The results of direct tensile strength for NIWP and IWPA at 7 and 28 days are shown in Figures 10 and 11, respectively. For NIWP, as with the compressive strength results, replacing cement with 1% NIWP led to the direct tensile strength of the cement mortar being increased. In comparison to the control sample, the enhancements were 15% and 19% at 7 and 28 days, respectively. This increase in tensile strength may be due to the major effect of fibres, which is increasing the bond between concrete components and controlling matrix cracking [34]. The presence of fibres can work in two ways: first, by space-filling especially at large quantities when well-arranged to arrest any microcracks, and second, by stopping crack expansion by “bridging” small cracks, which results in an increase in bonding across the two sides of a crack, and thus increases the direct tensile strength [35].

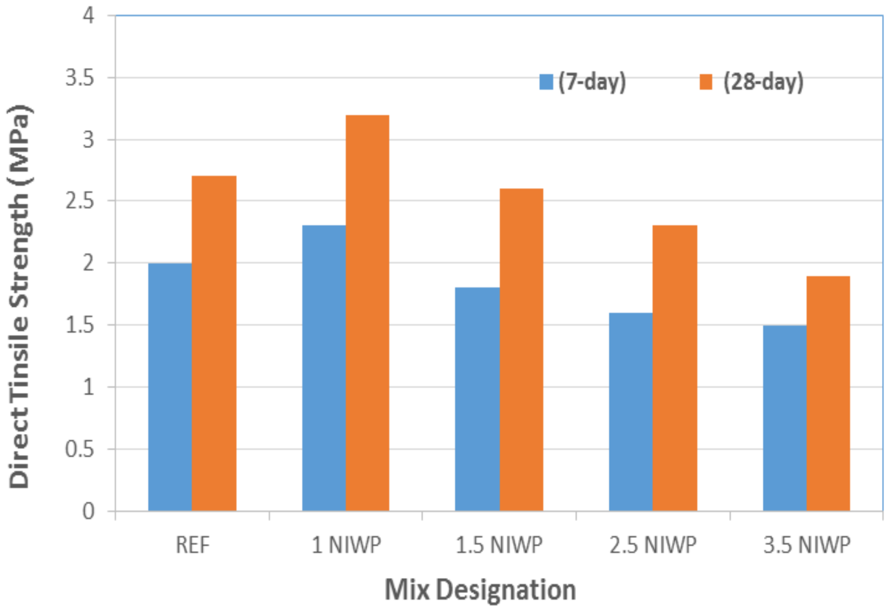

Figure 10: Direct tensile strength results of non-incinerated waste paper mixtures at 7 and 28 days.

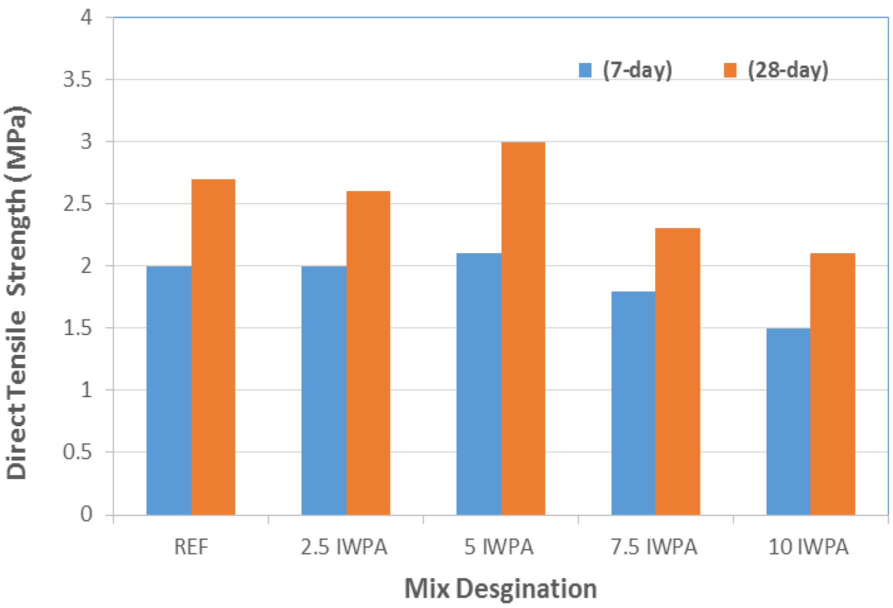

Figure 11: Direct tensile strength results of incinerated waste paper ash mixtures at 7 and 28 days.

Increasing the replacement ratio of cement with NIWP in proportions of 1.5%, 2.5%, and 3.5% resulted in decreases in the direct tensile strength by 10%, 20%, and 25% and 4%, 15%, and 30% at 7 and 28 days, respectively, compared with reference mixture. These results coincide with the findings of Gorgis et al [36], who observed that the splitting tensile strength decreased as the amount of waste paper increased. They attributed this behaviour to the poor binding characteristics of calcium-silicate-hydrate (C-S-H) gel on cellulosic fibre and to the resulting loss of cohesion. Moreover, the addition of waste paper fibres in the mix stabilises the volume of the sample and any expansion that interferes with fibre interfaces can result in weakness of the concrete.

For IWPA, the 2.5% replacement ratio of cement gave comparable results to the reference mix at 7 and 28 days. These results coincide with those of Varkey et al [16]. Furthermore, a significant enhancement at a substitution ratio of 5% IWPA was noted at 7 and 28 days; the enhancement percentages were 5% at 7 days and 11% at 28 days. Similar behaviour was reported in previous works [16,18], as the tensile strength of mortar is affected by the density of the intermediate zone between the aggregate and the binder material (here, cement and waste paper ash). Thus, as the number of voids decreases in this zone, the tensile strength increases. The presence of any fine substance acts as a filler and ab active substance can result in obliteration of these voids in the intermediate zone and increase bonding, resulting in an increase in density, which in turn increases the tensile strength.

However, for replacement ratios of 7.5% and 10%, decreases in the direct tensile strength was recorded, 10% and 25% and 15% and 22% at 7 and 28 days, respectively. This reduction in tensile strength was in agreement with Varkey et al [16] and Ahmad et al [18], and it may be due to the decrease in bonding strength between cement mortar components, which creates intermediate voids within the mortar and leads to a reduction in the tensile strength of mortar mixes.

3.2.3 Water Absorption.
The results of water absorption for reference, non-incinerated, and incinerated waste paper mixes at 28 days are illustrated in Figures 12 and 13. For NIWP, the results showed that these mixtures had higher water absorption than the control mix with the exception of the 1% replacement level, which exhibited a similar absorption ratio to that of the reference sample. Otherwise, the higher the

replacement level, the higher the water absorption. The maximum increment was recorded at the 3.5% replacement ratio, which was 10% higher than the reference specimen. This increase in water absorption can be attributed to the large amount of voids created in the presence of a high amount of fibres, which consequently leads to increased water absorption [37].

For IWPA mixtures, the results indicated that, up to 5% substitution, the water absorption did not increase. However, beyond 5% (for the 7.5% and 10% proportions), the water absorption of the mortar mixtures increased with the increase in replacement level. For the 10% replacement mix, the water absorption was 57%, compared to only 7% for the reference mixture. These findings coincide with previous studies [18,19]. Frias et al [24] concluded that, under optimal circumstances, the use of waste paper ash results in a parabolic increase in water demand in the mix for normal consistency. The increase in total specific surface area of waste paper ash, together with fine size particles, complicates the fluidity of the mix; thus, higher quantities of water are needed with this addition to wet the cement surface thoroughly.

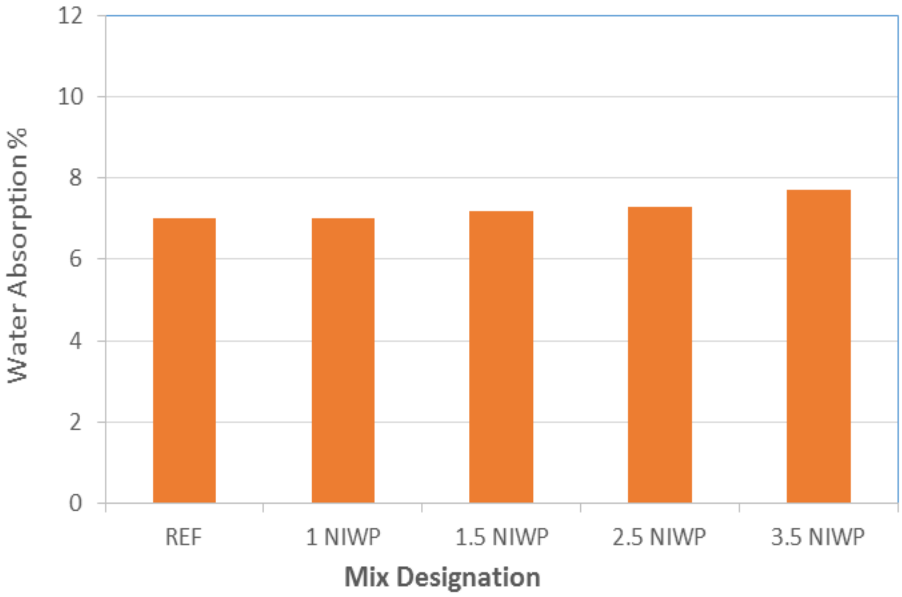

Figure 12: Water absorption results for non-incinerated waste paper mixtures at 28 days.

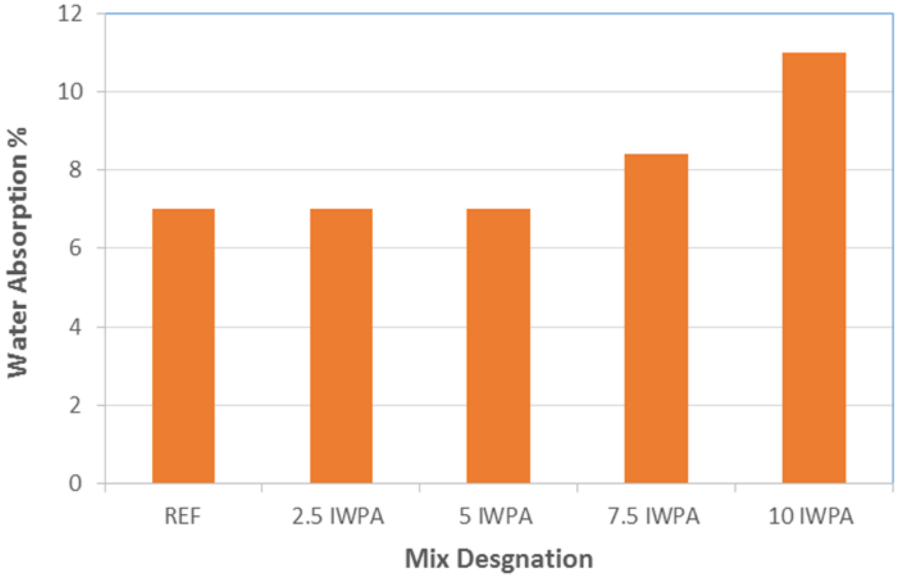

Figure 13: Water absorption results of incinerated waste paper ash mixtures at 28 days.

3.2.4 Dry Density.

The results of dry density testing for all mixtures at 28 days are shown in Figures 14 and 15. For NIWP, the results demonstrated that the 1% replacement led to an increase in the density of about 1.5% compared to the control sample. This increment can be attributed to the fibre properties that offer the ability to absorb water during mixing and retain it in the sample, increasing the density of the sample [37]. However, replacement levels above 1% led to decreases in the density by 0.3%, 1.3%, and 3% for replacement ratios 1.5%, 2.5%, and 3.5% respectively in comparison to the reference mixture. This may be due to the fact that increasing the number of cellulose fibres yields additional voids in the sample, reducing the overall density [33,38]. Yun et al [39] concluded that the decrease in density of paper concrete with high waste paper content can be simply attributed to the lower density of waste paper, which reduces the total density of the samples, however.

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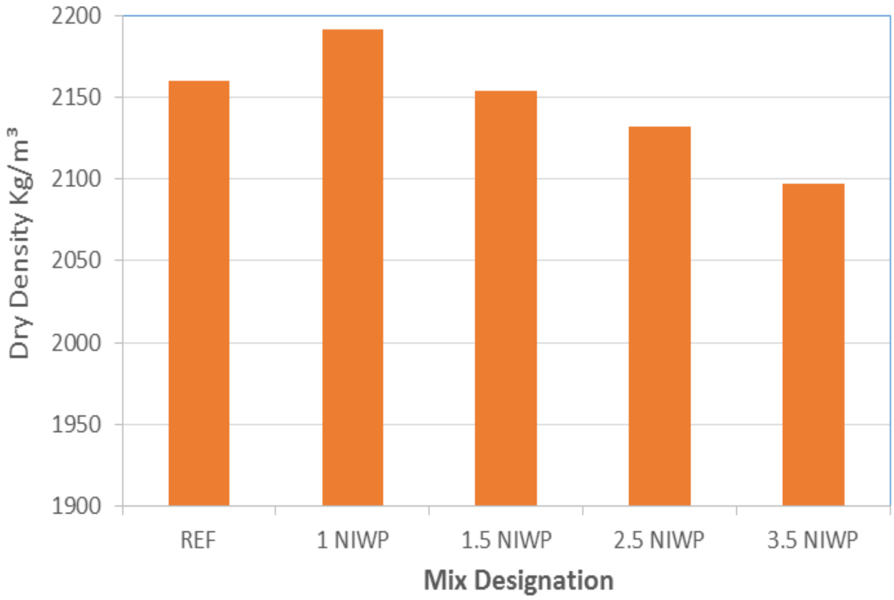

Figure 14: Dry density results of non- incinerated waste paper mixtures at 28 days.

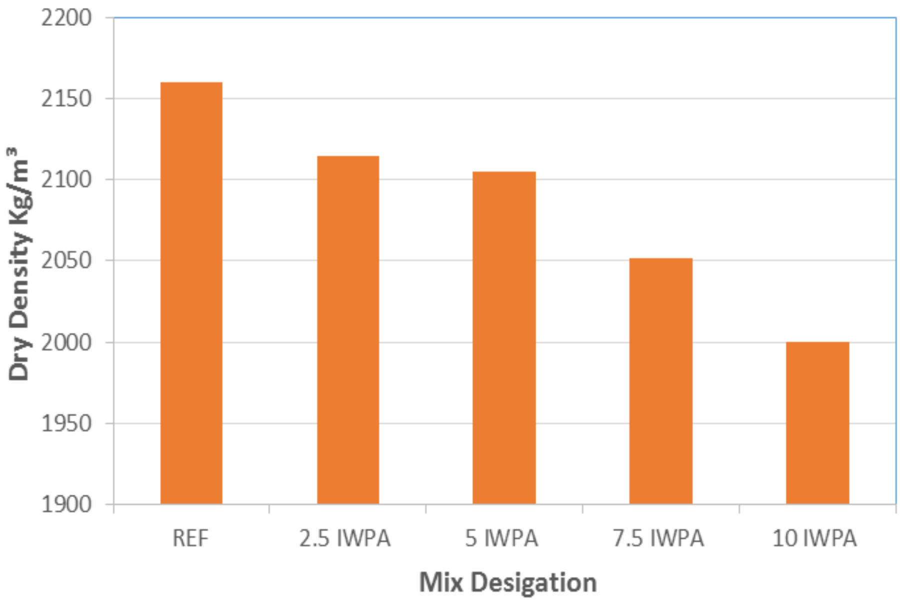

Figure 15: Dry density results of incinerated waste paper ash mixtures at 28 days.

For IWPA, the results showed that the higher the IWPA percentage in the mix, the lower the density of the hardened mortar. The reduction rates were 2%, 2.5%, 5%, and 7% for replacement percentages 2.5%, 5%, 7.5%, and 10% respectively as compared to the conventional mixture. These results coincide with those of Ahmad et al [18], who found that increase of waste paper ash replacement caused dry density to be decreased. This reduction in dry density may be due to the lower specific gravity of waste paper ash, which is 2.6 as compared to the 3.15 for cement; thus, waste paper ash concrete is lightweight in nature. Shabbir et al [17] concluded that the addition of waste paper ash decreased the density, resulting in lightweight concrete.

4. Conclusions

1. Replacement of cement by waste paper has a negative impact on the flow of fresh mortar. The flow rate of cement mortar decreases with the increase of replacement ratios of both incinerated and non-incinerated waste paper as compared with the reference mix.
2. A 1% replacement of cement by non-incinerated waste paper can enhance the compressive strength by 13% and 16% at 7 and 28 days curing, respectively, as compared with the reference mix. This percentage replacement also improves the direct tensile strength by 15% and 19% at 7 and 28 days, respectively. Increased replacement, above 1%, of cement by non-incinerated waste paper results in decreases in compressive and direct tensile strength of cement mortar, however.
3. Replacement of cement by 5% incinerated waste paper increases the compressive strength by 4% and 10% and the direct tensile strength by 5% and 11% at 7 and 28 days curing, respectively, as compared to the control mix. Above 5% replacement, the compressive and direct tensile strength of hardened mortar tends to decrease, however.
4. The substitution of cement with 1% non-incinerated waste paper or 5% incinerated waste paper shows a similar water absorption value (7%) to that of the reference mixture. In general, the percentage of water absorption increases with the increase in replacement ratios of cement with waste paper as compared with conventional mortar.
5. The dry density of cement mortar decreases with the increase of replacement level of cement by both incinerated and non-incinerated waste paper, except for the 1% replacement of cement with non-incinerated waste paper, which increases the dry density by 1.5% as compared with the reference sample.
6. Considering the hardened tests undertaken in this study, the best replacement levels of cement with NIWP and IWPA were 1% and 5%, respectively.

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5. Reference

[1] Nasr M S, Hussain T H and Najim W N 2018 Properties of cement mortar containing biomass bottom ash and sanitary ceramic wastes as a partial replacement of cement *Int. J. Civ. Eng. Technol.* **9** 153–65

[2] Nasr M S, Hasan Z A and Abed M K 2019 Mechanical Properties of Cement Mortar Made with Black Tea Waste Ash as a Partial Replacement of Cement *Eng. Technol. J.* **37**, **Part C** 45–9

[3] Harrison J and FCPA B S B E 2003 New cements based on the addition of reactive magnesia to Portland cement with or without added pozzolan *Proc., CIA Conference: Concrete in the Third Millenium, CIA: Brisbane, Australia*

[4] Hasan Z A, Abed M K and Nasr M S 2019 Studying the Mechanical Properties of Mortar Containing Different Waste Materials as a Partial Replacement for Aggregate *Int. Rev. Civ. Eng.* **10** 155–61

[5] Jevtic D, Zakic D and Savic A 2012 Achieving sustainability of concrete by recycling of solid waste materials *Mech. Test. Diagnosis* **2** 22

[6] Nayel I H, Burhan S K and Nasr M S 2018 Characterisation of prepared rice husk ash and its effects on strength development in recycled aggregate concrete *IOP Conference Series:*

Materials Science and Engineering vol 433 (IOP Publishing) p 12009

[7] Teja K S, Pradesh A, Kumar K U, Pradesh A, Sarath P V and Pradesh A 2017 Hypo sludge as a partial replacement *Int. J. Civ. Eng. Technol.* **8** 1645–51

[8] Kumar S, Amit S and Islam M R 2016 Application of paper sludge ash in construction industry – A review *Proceedings of the 3rd International Conference on Civil Engineering for Sustainable Development* pp 978–84

[9] Pitroda J, Zala L B and Umrigar F S 2013 Innovative use of paper industry waste (hypo sludge) in design mix concrete *Int. J. Adv. Eng. Technol.* **4** 31–5

[10] Niutanen V and Korhonen J 2002 Management of old landfills by utilizing forest and energy industry waste flows *J. Environ. Manage.* **65** 39–47

[11] Bajpai P 2015 Generation of waste in pulp and paper mills *Management of Pulp and Paper Mill Waste* (Springer) pp 9–17

[12] Nkana J C V, Tack F M G and Verloo M G 1999 Dynamics of nutrients in tropical acid soils amended with paper pulp sludge *Waste Manag. Res.* **17** 198–204

[13] Zhang S, Wang S, Shan X and Mu H 2004 Influences of lignin from paper mill sludge on soil properties and metal accumulation in wheat *Biol. Fertil. soils* **40** 237–42

[14] Rothwell A and Éclair-Heath G 2007 *A new approach to paper mill sludge* (Oxon)

[15] Suleiman M Z, Talib R and Fadila R 2011 The potential usage Paper Fiber Reinforced Foam Concrete (PFRFC) wall paneling system as an ideal building material *Elixir Int. J.* **36** 3302–6

[16] Varkey C, John J P, Neema V N and Joshy N 2016 Study on utilization of waste paper sludge by partial replacement of cement in concrete *Int. Res. J. Eng. Technol.* **3** 589–92

[17] Shabbir F, Ejaz N, Khan D, Ahmad N, Hussain J and Tahir M F 2015 Investigation of using paper industry waste (hypo sludge) in concrete mix *J. Eng. Appl. Sci.* **34** 7–12

[18] Ahmad S, Malik M I, Wani M B and Ahmad R 2013 Study of concrete involving use of waste paper sludge ash as partial replacement of cement *JOSR. J. Eng* **3** 6–15

[19] Fava G, Ruello M L and Corinaldesi V 2010 Paper mill sludge ash as supplementary cementitious material *J. Mater. Civ. Eng.* **23** 772–6

[20] Pandya A, Engineer C and Joshi T 2017 Gainful Utilization of Hypo Sludge in Concrete *Int. J. Civ. Eng. Technol.* **8** 128–34

[21] Kareem S L 2014 *Effect of Using Waste paper on Some Mechanical Properties of Concrete* (Baghdad University)

[22] Iraqi specification NO.5 1984 Portland cement *Cem. Agency Stand. Qual. Control*

[23] Iraqi specification NO.45 1984 Aggregate from natural sources for concrete and building construction *Cem. Agency Stand. Qual. Control*

[24] Frías M, Vegas I, de la Villa R V and Giménez R G 2011 Recycling of waste paper sludge in cements: characterization and behavior of new eco-efficient matrices *Integrated Waste Management-Volume II* (InTech)

[25] ASTM C109/C109M-13e1 2013 *Standard test method for compressive strength of hydraulic cement mortars (Using 2-in. or [50-mm] cube specimens)* (ASTM International)

[26] AASHTO T132–00 2000 *Standard Method of Test for Tensile Strength of Hydraulic Cement Mortars* (Washington: AASHTO Standard Specifications for Transportation Materials and Methods of Sampling and Testing)

[27] ASTM C1437-13 2013 *Standard Test Method for Flow of Hydraulic Cement Mortar* (West Conshohocken, PA: ASTM International)

[28] ASTM C642-13 2013 *Standard Test Method for Density, Absorption, and Voids in Hardened Concrete* (West Conshohocken, PA: ASTM International)

[29] Bai J, Chaipanich A, Kinuthia J M, O'farrell M, Sabir B B, Wild S and Lewis M H 2003 Compressive strength and hydration of wastepaper sludge ash–ground granulated blastfurnace slag blended pastes *Cem. Concr. Res.* **33** 1189–202

[30] Parveen A S 2013 Structural behaviour of fibrous concrete using polypropylene fibres *Int. J. Mod. Eng. Res.* **3** 1279–82

[31] Sharipudin S S, Ridzuan A R M and Mohd Saman H 2012 Performance of foamed concrete with waste paper sludge ash (wpsa) and fine recycled concrete aggregate (frca) contents *Int Sustain Civ Eng J* **1** 19–27

[32] Mavroulidou M, Boulouki G and Unsworth C 2013 Incorporating Waste Paper Sludge Ash as Partial Cement Replacement in Concrete *Proceeding of the 13th International Conference of Environment Science and Technology* pp 5–7

[33] Sarma V V S, Rambabu P V and Anil N C 2016 Durability Studies on Concrete with Hypo Sludge as Partial Replacement of Cement *Int. J. Eng. Res. Appl.* **6** 81–5

[34] ACI Committee 544 Report on Fiber Reinforced Concrete Rep. No. ACI 544.1 R-96 (Reapproved 2009)

[35] Balaguru P N and Shah S P 1992 *Fiber-reinforced cement composites*

[36] Gorgis I N, Zaki H M and Salih S A 2017 Properties of papercrete *ARPN J. Eng. Appl. Sci.* **12** 7400–12

[37] Fadila R, Suleiman M Z and Noordin N M 2008 Paper Fiber Reinforced Foam Concrete Wall Paneling System *2nd International conference on Built Environment In Developing Countries ICBEDC*

[38] Sangrutsamee V, Srichandr P and Poolthong N 2012 Re-pulped waste paper-based composite building materials with low thermal conductivity *J. Asian Archit. Build. Eng.* **11** 147–51

[39] Yun H, Jung H and Choi C 2007 Mechanical properties of papercrete containing waste paper *18th International Conference on Composite Materials*