American Journal of Construction and Building Materials
2020; 4(1): 8-13
http://www.sciencepublishinggroup.com/j/ajcbm
doi: 10.11648/j.ajcbm.20200401.12
ISSN: 2640-0022 (Print); ISSN: 2640-0057 (Online)

Waste Paper Ash as Partial Replacement of Cement in Concrete

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To cite this article:
Bikila Meko Kejela. Waste Paper Ash as Partial Replacement of Cement in Concrete. *American Journal of Construction and Building Materials*. Vol. 4, No. 1, 2020, pp. 8-13. doi: 10.11648/j.ajcbm.20200401.12

Received: July 4, 2019; **Accepted**: January 18, 2020; **Published**: February 14, 2020

Abstract: Concrete is one of the versatile and widely used building materials in the world construction industry. Cement being the main binder in concrete, its production process is both uneconomical and environmental unfriendly. In order to alleviate these problems, the use of alternative materials which have lower cost of production, lower emission of CO_2, and lower energy consumption, were being implemented. Therefore, the aim of this study is to investigate the effects of waste paper ash as cement replacement material in concrete production. Accordingly, chemical compositions of waste paper ash were investigated and cement was replaced by waste paper ash in a range of 0%, 5%, 10%, 15%, and 20%. To examine the suitability of paper ash for concrete production, its' effect on both fresh and hardened properties of C – 25 concrete was studied. From result of this study, it was observed that, the chemical compositions of waste paper ash were not fulfill the requirements of Pozzolanic material. Paper ash has lengthened the setting times of blended cement paste and its normal consistency was increased. The cement paste with replacement up to 10% showed a normal consistency with in standard range. Workability of the concrete was tested immediately after preparing the concrete mix whereas the compressive strength tests were tested after 7, and 28 days of curing. The results indicated that workability of concrete containing waste paper ash decreases as the waste paper ash content increases. There is significant improvement in compressive strength of concrete. Replacement of ordinary Portland cement by waste paper ash up to 10% resulted in a better compressive strength than that of the convectional mix. An enhancement of 5.6% & 1.2% were observed for 5%, & 10% of replacement respectively. But the compressive strength decreases as the waste paper ash replacement increases over 10%. A highest compressive strength of 37.89kN/m^2 was obtained for concrete containing 5% of waste paper ash.

Keywords: Cement, Concrete, Partial Replacement, Properties of Concrete, Waste Paper Ash

1. Introduction

Concrete is one of the most versatile and widely used building materials in the world construction industry. It is a composition of aggregates, a Portland or blended cement, water, and contains other cementitious materials and/or chemical admixtures. It contains some amount of entrapped air and purposely entrained air obtained by use of an admixture or air-entraining cement [1].

The annual production of concrete is rapidly increasing. This is because many developing countries are experiencing rapid urbanization and population growth, making the demand for housing and infrastructure development greater than ever before.

Cement being the main binder in concrete, its production process is both uneconomical and environmental unfriendly. The production of 1 tonne of Portland cement requires 1.5 tonnes of raw material. According to Malhotra, (1988); and Swamy, (1998) the production process of Portland cement is highly energy intensive, consuming 4–7 MJ of fossil fuel energy per kg, [16, 17] and releases approximately 1 tonne of carbon dioxide for manufacture of each tonne of Portland cement.

As a result, a requirement for economical and more environmental-friendly leads the way to search for supplementary cementing materials in concrete that can be used as replacement of the normal Portland cement. This can be done by two methods. The first method is using another binding material instead of cement which is not possible right now for unavailability of such a binding materials and the second method is partial replacement of cement by appropriate material. The second method is quite simple because of lots of references are available as well as enough suitable materials are also available.

The replacement of cement in concrete by various wastes creates a tremendous saving of energy, costs and also leads to important environmental benefits. As a result, the use of different cement replacing materials has become a common practice in the construction industry.

Supplementary cementitious materials (SCMs) are being utilized as partial replacement of cement. In 2016, Savita D., et al., reviewed the cement replacement materials in concrete and concluded various materials as cement replacing materials. These materials are ceramic waste, paper pulp, Ground granulated blast furnace slag, Silica fume, Hypo sludge, Fly ash, Paper sludge, Waste glass powder, Waste paper sludge ash [2].

According to Ali et al, (2013), more than 450 million tons of paper is produced worldwide per annual and it is expected that the demand for paper will reach 500 million tons per annual by the end of 2020 [10]. And also Asmare, (2015) in his study predicted that the demand of paper to be imported to Ethiopia by the year 2015/16 was 157,956.7 tons of paper and paper board. This demand of paper was increasing from year to year because of education expansion policies and overall economic development of the country [9].

As it was described by Oriyomi M. O., el at, Paper is an example of valuable materials that can be recycled [3]. Disposable paper available in abundance throughout the world is composed mainly of short, natural, cellulose fibers and is already used in many local raw materials. Waste paper arises from several sources such as newspapers, office and printing papers etc. The chemical composition of paper ash mainly contains SiO_2 (60%), CaO (14%), Al_2O_3 (2.06%), and Fe_2O_3 (0.92%) which are the main essential compounds needed for cement hydration for strength development (Sumit, A. B., et al, 2013).

Due to this pozollanic property, waste paper ash has a possibility to be used as partial replacement of cement in concrete production. So, this study was targeted at investigating the properties of concrete produced by using waste paper ash in order to ascertain their suitability to be used as a cement replacing material in concrete.

2. Materials and Methods

The main materials used for this study were Portland cement (OPC), Fine aggregate, Coarse aggregate, waste paper (office copy paper), and Potable water.

2.1. Materials

2.1.1. Cement

The cement used in this study was Dangote Ordinary Portland Cement (OPC) of grade 42.5, which is obtained commercially. This cement complies with the requirements of Ethiopian Standards, ES C. D5 201.

2.1.2. Sand

The river sand, passing through 4.75 mm sieve was used as a fine aggregate. The sand is free from clay, silt and organic impurities. In order to investigate the properties of sand, different tests were carried out. These tests include gradation and fineness modules, specific gravity and absorption capacity, moisture content, silt content and unit weight. The silt content was found to be 4.54%, which is below the 5% limit of Ethiopian standard [7]. Fineness modulus is found to be 2.8, which is in the range of ASTM C33 standard 2.3 to 3.1 [5]. The physical properties of sand are compiled in table 1.

Table 1. *Properties of sand.*

No.	Test description		Test result
1	Silt content		4.54%
2	Moisture content		1.6%
3	Unit weight (Compacted):		1437.3kg/m^3
4	Absorption capacity		2.04%
		Bulk	2.65
5	Specific gravity:	Bulk (SSD)	2.70
		Apparent	2.80
6	Fines Modules		2.8

2.1.3. Coarse Aggregates

Coarse aggregates used in this research were crushed granite, supplied from a local quarry, with maximum size of 20 mm. In a similar routine like the fine aggregate, the coarse aggregate was tested for its physical requirements such as gradation, fineness modulus, specific gravity, bulk density and presented in the following table 2.

Table 2. *Properties of coarse aggregate.*

No.	Test description		Test result
1	Maximum size		20mm
2	Moisture content		1%
	Unit weight compacted		1591.35kg/m^3
4	Absorption capacity		1%
		Bulk	2.77
5	Specific gravity:	Bulk (SSD)	2.80
		Apparent	2.86

2.1.4. Waste Paper Ash

Waste paper was collected from different office and burned using incinerator at a temperature of 850°C to avoid formation of crystalline ash which is less reactive to lime. Burned powder was then sieved using sieve size of 7.4µm. According to A. M. Neville there is no simple relation between strength and cement particle size [8]. So, particle size distribution analysis was neglected.

2.2. Mix Design and Sample Production

ACI method of mix design [4] was used in designing the mixes based on collected data. The mix was prepared for C-25 Concrete with Design Strength (target mean strength) of 33.5MPa. The mixing proportion was found to be 1:2.35:3. After determining the relative amount of materials to be used for the specimens, waste paper ash is thoroughly blended with cement at 5%, 10%, 15%, and 20%. Then the aggregates and sands are added and mixed in dry for one minute. Later water was added and, all the materials were mixed for another two minutes. Finally, the prepared specimens was submerged in curing tanker and cured for an age of 7days, and 28days at room temperature according to ASTM C192 Standard [6].

3. Results and Discussion

3.1. Chemical Compositions of Waste Paper Ash

The chemical compositions of materials are very crucial in determining their suitability as Supplementary cementitious materials (SCMs). So, the chemical composition of waste paper ash was studied in Geological survey of Ethiopia and compiled in Table 3 based on the finding of laboratory investigation.

Table 3. *Chemical composition of waste paper ash.*

Chemical Composition (%)	Waste paper Ash
SiO_2	29.20
Al_2O_3	2.65
CaO	50.88
Fe_2O_3	1.74
MgO	0.86
Na_2O	0.30
K_2O	<0.01
MnO	<0.01
P_2O_5	0.67
TiO_2	<0.01
H_2O	0.62
LOI	12.52
SO_3	0.51

From these results, the chemical compositions which are $SiO_2 + Al_2O_3 + Fe_2O_3 = 33.59\%$ is less than 70%. According to ASTM C- 618 specification, the waste paper ash did not fulfill the requirements of Pozzolanic material.

According to this finding the principal constituents present in Waste Paper Ash are lime (CaO) and silica (SiO_2). The chemical activity of admixtures in cement is dependent essentially on their lime, silica and alumina contents which are the main essential compounds needed for cement hydration for strength development.

The silica content of paper ash was higher than that of OPC. This gives an indication that the paper ash would produce satisfactory results in terms of strength. However, the alumina content was very low (2.65%). Alumina makes little direct contribution to the strength of Portland cement. Iron oxide content (1.74) which is also low has no effect on cement but acts as flux to aid cement and gives the grey color. The other minor constituents like TiO_2, MnO_2 and P_2O_3 were less than 1% and have no effect on strength and properties of cement products.

A number of published literatures have reported chemical composition of paper pulp. In 2006, Sumit, et al, (2013) has studied elemental analysis of waste paper pulp and Paper pulp mainly contains Si (60%) and Ca (14%) [11]. But in this study paper ash mainly contains Si (29.20%) and Ca (50.88%) which is different from previous studies.

The loss on ignition (LOI) value for the paper ash was found to be 12.52% which was slightly higher than that specified by the standard (10%). The loss on ignition shows the extent of carbonation and hydration of free lime and free magnesia due to the exposure of cement to the atmosphere. The maximum loss on ignition (at 1000°C) permitted by BS EN 197-1: 2000 is 5 percent [14] and by ASTM C 150-07 is 3 percent except for Type I cement (2.5 per cent) [15]; 4 per cent is acceptable for cements in the tropics.

3.2. Setting Times of the Blended Paste

The setting times of the blended paste containing waste paper ash are given in Table 4. The set time was determined from an average of three sets of samples for each type of blended cement pastes.

Table 4. *Setting time of blended cement pastes.*

No	% of replacement	Initial setting Time (Min.)	Final setting Time (Min.)
1	0%	176	301.2
2	5%WPA	208	339.6
3	10%WPA	220	354
4	15%WPA	225	360
5	20%WPA	250	390

It was observed that the common effect of the paper ash has lengthened the setting times of blended cement paste. This due to the reaction which is responsible for the setting of cement is the reaction of C_3A with both water and gypsum ($CaSO_4.2H_2O$) but the amount of C_3A found in paper ash is lower, when compared with that of OPC. So this lower amount of C_3A retarded setting time of blended cement paste.

The Ethiopian standard limits the initial setting time of cement not to be less than 45 minutes and the final setting time not to exceed 10hrs. The results for the setting time indicated that addition of waste paper ash retarded the setting; however, this retardation was within limits as specified by the Ethiopian standard.

3.3. Consistency of Blended Cement Paste

A certain minimum quantity of water is required to be mixed with cement, so as to complete chemical reaction between water and cement. Less water than this quantity would not complete chemical reaction thus resulting in reduction of strength and more water would increase water cement ratio and reduce its strength. So, correct proportion of water to cement is required to be known to achieve proper strength while using cement in structure. In order to get proper amount of water normal consistency test of blended cement pastes was carried out. The normal consistency of blended pastes containing waste paper ashes are shown in figure 1.

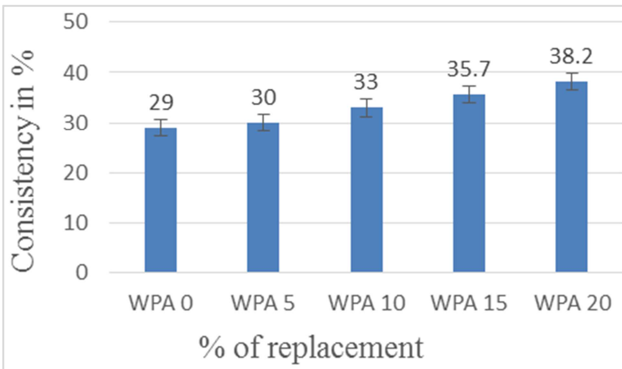

Figure 1. *Consistency of Blended cements Paste.*

The control paste or the paste without waste paper ash had normal consistency of 29%. All of the pastes containing waste paper ash showed normal consistency higher than the control paste. The usual range of water to cement ratio for normal consistency is between 26% and 33% [11]. The pastes with replacement up to 10% showed a consistency with in this range, however, after 10% replacement the results showed higher values of consistency.

3.4. Workability of Concrete

In order to determine the workability of the fresh concrete the slump test was conducted according to ASTM C 143. Slump test is conducted on fresh concrete for all percentage of waste paper ash replacement. The slump values of all the mixtures are presented in Figure 2 below.

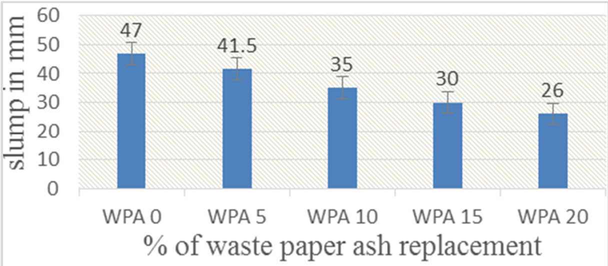

Figure 2. *Workability of concrete.*

These results indicate that, the slump decreased with the increase in waste paper ash content. This effect can be attributed to the fact that paper ash has high water absorption capacity as compared to cement and thus the content of water in the mix is reduced, hence less workable concrete is produced. The second reason is due to its' lower density of paper ash giving it a higher porosity resulting in higher water demand. Even though the slump value is decreased as percentage of waste paper ash is increased, until the amount of percentage is became 20% the slump value is within the specified limit, which is 30-50. The highest slump was seen for the control concrete mix.

The effect of replacing Portland cement with paper pulp on the workability of concrete has been done by a number of preceding researchers and concluded that the workability was decreased when a higher amount of paper ash content was included. As Sumit, et al, (2013) reported in his work, the slump increased up to 5% replacement of cement, above 5% the slump decreased as the paper pulp content in the concrete mixtures was increased [11].

3.5. Compressive Strength of Concrete

Compressive strength test was conducted on hardened concrete using a compression testing machine of 2000 KN capacity. Three cubes (150mm X 150mm X 150mm) were casted for each percentage replacements of cement by waste paper ash and cured for 7days & 28 days. After the successful curing of concrete, all specimens are tested in compression testing machine by applying compressive load. Figure 3 and table 5 shows the measured compressive strengths of concrete cubes with various content of paper ash at age of 7th and 28th days.

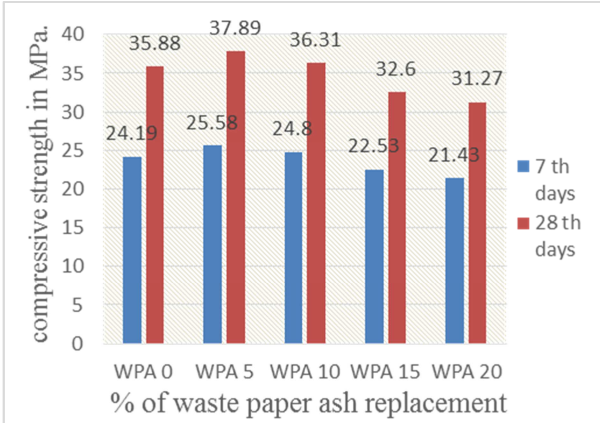

Figure 3. *7th and 28th day compressive strength.*

Based on these experimental results the strength properties of concrete are increasing as percentage of paper ash increases up to 10%, later the strength is decreasing when compared with the control specimen.

An improvement of 5.6% & 1.2% were observed for 5% and 10% replacement, when compared with 28-day compressive strength of Control mix which made with ordinary Portland cement. This due to the higher amount of silica found in paper ash than cement. However, the degree of improvement in strength appeared to be highly dependent on the cement replacement level. It observed that the concretes with 15% and 20% waste paper ash had shown reduction of compressive strength.

The effects of paper ash on the compressive strength of concrete did not vary from the findings of previous researchers. A number of published literature [Sumit, et al, 2013 and H. Yun et al, 2007] reported similar observations.

In 2007, H. Yun et al. worked on mechanical properties of papercrete concluded that the average compressive strength which includes 5% paper-cement replacement ratio was 34 MPa [12].

Also Sumit, et al, (2013) in their studies on Utilization of Waste Paper Pulp by Partial Replacement of Cement in Concrete, concluded that, the compressive, splitting tensile and flexural strength increased up to 10% addition of waste paper pulp and further increments in replacement of cement gradually reduces the strengths of concrete [11].

Table 5. *Compressive Strength of Concrete.*

S/N	Mix code	% of replacement	Average Compressive strength in N/mm2			
			7th day	Increment in %	28th day	Increment in %
1	WPA 0	OPC	24.19		35.88	
2	WPA 5	95%OPC+5%WPA	25.58	5.43%	37.89	5.6%
3	WPA 10	90%OPC+10%WPA	24.8	2.52	36.31	1.2%

S/N	Mix code	% of replacement	Average Compressive strength in N/mm2			
			7th day	Increment in %	28th day	Increment in %
4	WPA 15	85%OPC+15%WPA	22.53	- 6.86%	32.60	- 9.14%
5	WPA 20	805%OPC+20%WPA	21.43	- 11.40%	31.27	- 12.84%

3.6. Density of Concrete

The weights and the dimension of the concrete cubes are measured just before testing them for the compressive strength after curing for 7, and 28 days. The samples have similar volume of 0.00338 m^3. Their unit weight was measured and compiled in table 6 below.

Table 6. *Unit weight of concrete.*

S. N	% of replacement	Unit wt. (kg/m^3)	Reduction in (%)
1	OPC	2444.44	
2	95%OPC+5%WPA	2419.95	1%
3	90%OPC+10%WPA	2392.88	1.12%
4	85%OPC+15%WPA	2359.79	1.4%
5	805%OPC+20%WPA	2311.52	2.05

The results of this study revealed that, paper ash reduces the hardened density of concrete as its percentage in the mix increases. The percentage of reduction was increased as amount of paper ash increases. But these densities of the concrete fall within the range of 2200 - 22400kg/m^3, which is considered to be of normal weight concrete [1].

The above findings are not different from the preceding studies. H. Yun et al, (2007) studied the physical properties of the Papercrete and concluded that the density of papercrete was decreased when the replacement ratio of waste paper of papercrete increased [12]. The physical properties of papercrete were also reported by Shivangni Khandelwal et al, (2015). They concluded that, the density of the papercrete has a tendency of decrease as a higher waste paper was included [13].

4. Conclusion

The results of this study reveal, Waste paper ash cannot be as classified as pozzolanic material. As prescribed by ASTM C 618, in order to classify particular material as pozzolanic materials, its chemical composition (SiO_2 + Al_2O_3 + Fe_2O_3) have to be greater than 70% but that of paper ash is less than 70%.

Higher replacement of cement by waste paper ash resulted in higher normal consistency (implying higher water demand for certain workability) and longer setting time. Workability of the concrete containing waste paper ash decreases as the waste paper ash content increases.

Significant enhancement was seen in compressive strength of concrete. Replacement of ordinary Portland cement with up to 10% of waste paper ash results in a better compressive strength than that of the conventional concrete for all curing ages. A highest compressive strength of 37.89kN/m^2 was obtained for concrete containing 5% of waste paper ash. But beyond 10% of replacement, there is a gradual reduction in compressive strength.

The density of the concretes containing waste paper ash has shown a reduction. It was found that a reduction of unit weight up to 2.05% was observed when 20% of the cement was replaced by waste paper ash.

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