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Partial replacement of cement by plant solid waste ash in concrete Production

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Abstract: *Chemical analysis of saw dust ash (SDA), maize cob ash (MCA), and sugarcane bagasse ash (SCBA) was performed to verify their pozzolanic activity for use in concrete manufacture. The sum of SiO_2, Al_2O_3 and Fe_2O_3 was 75.39%, 77.64%, and 80.23% for SDA, MCA, and SCBA respectively, indicating pozzolanic activity. Cement replacement was done at 0%, 5%, 10%, 15%, 20%, 25%, and 30% by weight of cement. Workability decreased as cement replacement increases, but increased as cement replacement increases for SCBA. Absorption and compressive strength of 150mmx150mmx150mm cubes cured for 7, 14 and 28 days increased as cement replacement increases up to an optimum then decreased as a consequence of decreased formation of cementitious matrix. Optimum compressive strength was 26.30, 27.71, and 49.58 Nmm^{-2} for SDA, MCA, and SCBA respectively at 10% SDA and MCA, and 25% SCBA. The results have shown that the use of blended concrete can reduce environmental degradation attributed to disposal of plant wastes and raw materials mining for cement manufacture, and pollution from cement manufacturing process.*

Keywords: *Absorption, Compressive Strength, Concrete, Pozzolanic Cement, Workability*

I. Introduction

Cement is one of the most important concrete making materials in the building and construction industry. However, high cost of cement and other construction materials, over exploitation of the natural resources, and environmental concerns have necessitated the search for alternative materials for the building and construction industry. The search for alternative cement replacement has led to the discovery of industrial by-products and agricultural wastes with pozzolanic abilities capable of being used as cementitious materials in the manufacture of concrete. Substantive energy and cost savings can be made when these by-products and wastes are used as cement replacement [1, 2]. Environmental degradation due to mining and dumping of large quantities of waste materials would be reduced. Some of agricultural waste materials under research include Saw dust ash (SDA), maize cob ash (MCA) and sugarcane bagasse ash (SCBA).Saw dust ash (SDA) as a potential cement replacement binder has been studied by several researchers for several years. Marthong, Raheem and Sulaiman, Obilade and Nahak and Dash [3,4,5,6] reported that the compaction factor and the compressive strength decreased with increased cement replacement. The optimum SDA cement replacement was 10%.

Olafusi and Olutoge [7] determined the compressive strength of cubes of size 150 mm x150 mm x150 mm made from corn cob ash (CCA) or maize cob ash (MCA) as partial replacement for cement in concrete and found out that it will be sufficient for plain concrete works and non-load bearing structures since it will enhance waste to wealth initiative. However, if high strength concrete is desired, then it will take longer curing period to achieve the designed strength. Consequently, the use of superplasticizers will be required to enhance workability. Price et al. [8] reported that replacing a portion of ordinary portland cement (OPC) with up to 10 % CCA or MCA increased the compressive strength, enhanced insulation performance and workability time.

Ganesan et al. [9] studied sugarcane bagasse ash (SCBA) and reported that the addition of SCBA as cement replacement provides additional improvements in strength and permeability. Since SCBA is finer than OPC, its presence in OPC leads to an increase in water uptake with subsequent increase in both initial and final setting times with accelerated hardening [9]. In addition, the pozzolanic activity of SCBA depends significantly on its particle size and fineness [10,11]. Compressive strength of the composite concrete increased as the amount of cement replacement increases up to an optimum of 20% cement replacement [9,11,12,13].

Recycling materials that otherwise would be treated as waste can create endless sustainable construction opportunities [8]. The main objectives of this study are to determine the pozzolanic activity of these plant ashes, their respective compressive strengths, and the optimum cement replacement that gives maximum strength concrete that can enable such blended concretes to used in construction works to reduce environmental degradation associated with mining materials for cement manufacture.

II. Materials and Methods

2.1 Plant ashes

Saw dust was obtained from a Joinery Workshop at Gikomba Market, Nairobi. Dry maize cobs were obtained from a farmer in Kamulu, Machakos. The saw dust and maize cobs were burnt separately in an open metallic drum to produce the saw dust ash (SDA) and maize cob ash (MCA). They were then ground using pestle and mortar. The sugarcane bagasse ash (SCBA) was obtained from Mumias Sugar Mill in Mumias, Kenya. The ashes were then sieved through a British standard (BS) 75µm sieve to remove impurities and larger particles.

2.2 Materials

Coarse aggregates were obtained from a hard stone quarry in Kayole, Nairobi, River sand was used as fine aggregates, and were obtained from a river in Mwala, Machakos, and ordinary Portland cement (OPC) was bought from a hardware store in Nairobi.

2.3 Chemical composition of the plant ashes

The chemical composition of the ashes was determined in the Technical University of Kenya Chemistry Department Laboratory, and in accordance with ASTM C 311 (Standard Test Methods for sampling and testing fly ash or natural pozzolans for use in Portland cement concrete) [14], and evaluated in accordance with ASTM C618 (Standard specifications for coal fly ash and raw or calcined natural pozzolan for use in concrete) [15].

2.4 Fresh Concrete

A mix proportion of 1:2:4 was used to manufacture concrete in accordance with BS 1881-109, 1983 (Method for making test beams from fresh concrete) [16] at a water cement (w/c) ratio of 0.5. Replacement of OPC by the plant ashes was done at 0%, 5%, 10%, 15%, 20%, 25%, and 30% by weight of cement. Slump test was done in accordance with BS 1881-102, 1983: Method for determination of slump. Compaction factor (CF) was done in accordance with BS 1881-103, 1993: Method for determination of compacting factor [17].

2.5 Casting and curing of concrete test cubes

Concrete test cubes were casted in 150 mm x 150 mm x 150 mm cube steel moulds in accordance with BS 1881-108, 1983: Method for making test cubes from fresh concrete [18], and were cured for 7, 14 and 28 days, and in accordance with BS 1881-111, 1983: Method of normal curing of test specimens (20 °C method) [19].

2.6 Hardened Concrete

Water absorption test was carried out on hardened concrete after 28 days cure in accordance with BS 1881-122, 2011: Method for determination of water absorption [20]. Compressive strength tests were carried out at 7, 14, and 28 days, and in accordance with BS 1881-116, 1983: Method for determination of compressive strength of concrete cubes [21].

III. Results and discussion

3.1 Chemical Composition of the plant ashes

TABLE 1 shows the chemical composition of the plant ashes (SDA, MCA and SCBA). The results indicate that all have pozzolanic ability since, in terms of their chemical composition, the sum of SiO_2, Al_2O_3 and Fe_2O_3 were 75.39%, 77.64%, and 80.23% for SDA, MCA, and SCBA respectively. The American Society for Testing of Materials (ASTM) has defined pozzolana on the basis of chemical composition as a substance whose sum of SiO_2, Fe_2O_3 and Al_2O_3 should be at least 70.0% for good binding properties (ASTM C618, 2003). However, the SCBA exhibited high pozzolanic strength as compared with SDA and MCA.

Table 1: Chemical Composition of Plant ashes (SDA, MCA, and SCBA)

Oxide	Percentage Content (%)		
	SDA	MCA	SCBA
SiO_2	65.22	66.8	69.82
Al_2O_3	5.96	6.64	6.05
Fe_2O_3	4.21	3.2	4.35
CaO	4.50	11.21	1.63
MgO	5.60	4.31	0.95
SO_3	0.46	1.55	1.84
MnO	0.01	0.02	0.01
Na_2O	0.12	0.25	1.10
K_2O	0.15	6.41	4.96
P_2O_5	1.56	1.80	1.26
LOI	4.41	6.21	10.32

3.2 Workability

TABLE 2 shows Slump test and Compaction factor (CF) results for SDA, MCA, and SCBA at 0%, 5%, 10%, 15%, 20%, 25%, and 30% cement replacement. The results indicate that the slump and compaction factor for SDA and MCA decreases with increase in cement replacement. This could be due to decreased formation of the cementitious matrix attributed to insufficient water for workability and hydration. However, slump and compaction factor for SCBA increased with increase in cement replacement. This could be due to high surface area of SCBA that required less water for wetting the cement particles as more cement is being replaced.

Table 2: Slump and Compaction Factor (CF) of fresh blended concrete

Ash Type	Parameter	Cement Replacement (%)						
		0	5	10	15	20	25	30
SDA	Slump	62.5	60.2	58.6	56.8	50.3	45.0	32.3
	C.F	0.97	0.92	0.91	0.90	0.88	0.86	0.84
MCA	Slump	71.2	68.3	65.2	63.1	59.2	55.0	46.0
	C.F	0.94	0.93	0.91	0.88	0.85	0.84	0.82
SCBA	Slump	70.2	172	195	213	220	229	233
	C.F	0.95	0.96	0.96	0.97	0.97	0.98	0.98

3.3 Water absorption

TABLE 3 shows water absorption test results for 150 mm x 150 mm x 150 mm blended concrete cubes after 28 days curing period for all the three plant ashes. The results indicate that absorption increases as cement replacement increases for all the ash concretes. However, the rate of increase was lower for SCBA concrete. This could be due to formation of less pervious cementitious matrix caused by increased workability and hydration. In addition, absorption decreases for all blended concrete after 25% cement replacement (Fig. 1).

Table 3: Water absorption for 150mmx150mmx150mm blended concrete test cubes after 28 days cure.

Ash Type	Parameter	Cement Replacement (%)						
		0	5	10	15	20	25	30
SDA	Dry Wt. (gm)	8265	8357	8230	8118	7995	7950	7900
	Wet Wt. (gm)	8355	8452	8341	8239	8129	8108	8066
	Water Absorbed (gm)	90.0	95.0	111.0	121.0	134.0	158.0	166.0
	Absorption (%)	1.09	1.14	1.35	1.49	1.68	1.99	2.10
MCA	Dry Wt. (gm)	8260	8351	8225	8112	7990	7942	7897
	Wet Wt. (gm)	8352	8449	8338	8236	8125	8100	8071
	Water Absorbed (gm)	92.0	98.0	113.0	124.0	135.0	158.0	174.0
	Absorption (%)	1.11	1.17	1.37	1.53	1.69	1.99	2.20
SCBA	Dry Wt. (gm)	8260	8337	8231	8100	7986	7941	7900
	Wet Wt. (gm)	8343	8425	8343	8227	8126	8089	8051
	Water Absorbed (gm)	83.0	88.0	112.0	127.0	140.0	148.0	151.0
	Absorption (%)	1.00	1.06	1.36	1.57	1.75	1.86	1.91

3.4 Compressive Strength

TABLE 4 shows the compressive strength of concrete cubes measuring 150 mm x 150 mm x 150 mm after 7, 14, and 28 days curing period. The compressive strength increased as cement replacement increases up to an optimum at 10% for SDA and MCA, and 25 % for SCBA. This could be due to decreased formation of the cementitious matrix attributed to insufficient water for workability and hydration. At 28-day curing period, the compressive strength increased to an optimum of 26.30 Nmm^{-2}, 27.71 Nmm^{-2}, and 49.58 Nmm^{-2} for SDA, MCA, and SCBA respectively at 10% cement substitution for SDA and MCA, and 25% cement substitution for SCBA (Fig. 2). This followed the trend of the pozzolanic activity of the ashes. In addition, the compressive strength of 10% SDA and MCA concrete is about the same as 0% cement replacement at 28-day curing period. The results also indicate that the composite concretes can attain the same order of strength as conventional concrete at longer curing periods.

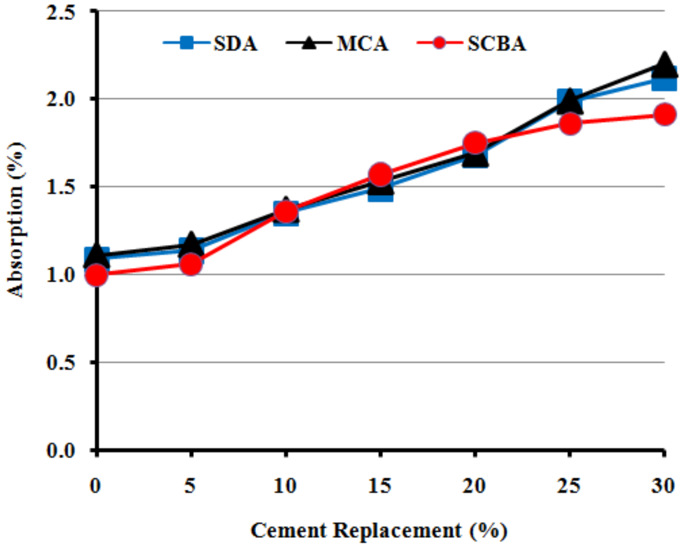

Fig. 1: Water absorption for 150mmx150mmx150mm blended concrete test cubes after 28 days cure.

Table 4: Compressive Strength (Nmm^{-2}) for 150mmx150mmx150mm blended concrete test cubes after 7, 14, and 28 days curing period.

Ash Type	Curing Period (Days)	Cement Replacement (%)						
		0	5	10	15	20	25	30
SDA	7	16.71	15.57	18.01	14.53	13.21	13.02	12.84
	14	22.65	18.91	21.88	15.01	14.95	14.76	14.53
	28	26.28	22.20	26.30	22.50	18.25	18.01	17.82
MCA	7	16.00	14.93	17.80	15.56	14.90	14.68	13.03
	14	22.57	19.78	23.02	23.00	22.81	20.54	15.23
	28	27.80	22.56	27.71	23.51	20.40	18.37	17.13
SCBA	7	30.04	25.42	34.00	35.93	36.01	36.21	35.25
	14	35.56	30.86	36.35	38.63	39.72	40.27	39.20
	28	48.90	42.50	44.50	46.45	47.23	49.58	48.65

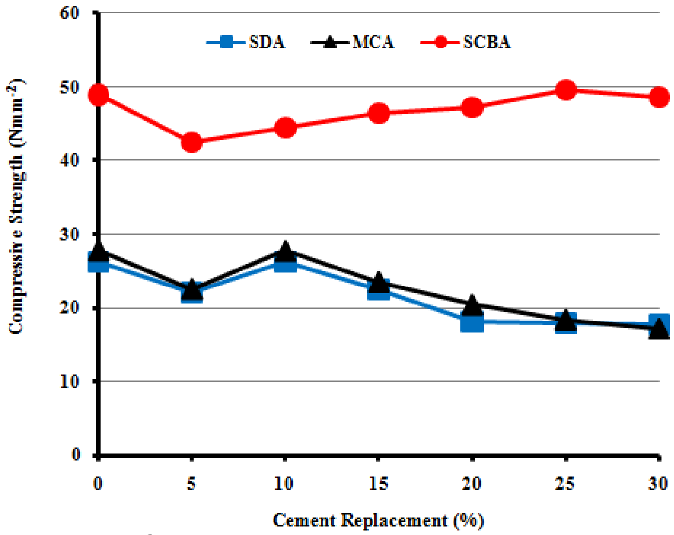

Fig. 2: Compressive Strength (Nmm^{-2}) for 150mmx150mmx150mm blended concrete test cubes after 28 days curing period.

IV. Conclusions

The following conclusions may be made from this study:

1. The SDA, MCA and SCBA have pozzolanic ability since, in terms of their chemical composition, the sum of SiO_2, Al_2O_3 and Fe_2O_3 were 75.39%, 77.64%, and 80.23% respectively. However, the SCBA shows high pozzolanic strength as compared with SDA and MCA.
2. Workability for SDA and MCA decreased with increase in cement replacement but increased as cement replacement increases for SCBA. This could be due to high surface area of SCBA that requires less water for wetting the cement particles as more cement is being replaced.
3. The compressive strength increased as cement replacement increases up to an optimum at 10% cement replacement for SDA and MCA, and 25 % cement replacement for SCBA. This could be due to decreased formation of the cementitious matrix attributed to insufficient water for workability and hydration. At 28-day curing period, the compressive strength increased to an optimum of 26.30 Nmm^{-2}, 27.71 Nmm^{-2}, and 49.58Nmm^{-2} for SDA, MCA, and SCBA respectively at 10% cement substitution for SDA and MCA, and 25% cement substitution for SCBA.
4. The compressive strength of 10% SDA and MCA concrete was about the same as that of 0% cement replacement at 28-day curing period. This indicates that blended concretes can attain the same order of strength as conventional concrete at longer curing periods.
5. The results have demonstrated that the use of plant ashes such as SDA, MCA, and SCBA as cement replacement should be encouraged for use in concrete to reduce environmental degradation associated with mining of cement manufacturing materials. This would also reduce construction budget associated with the high cost of cement since blended concrete of higher strength can be made with longer curing periods.

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