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Ash from timber waste as cement replacement material

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Abstract

Sawdust is a waste product from the timber industry. Research work carried out on the ash derived from the sawdust has confirmed its pozzolanic properties with a pozzolanic index value of 75.9%. This material compares favourably with fly ash and wastes from the oil palm industry. The only difference noticed is in the low content of Al_2O_3 (4.09%) and Fe_2O_3 (2.26%). Concrete mixes have been proportioned to have various percentages of cement replacement with sawdust ash (SDA) ranging from 0% to 30% by mass. Performance of the ash–portland cement mixture has been evaluated with respect to setting time, workability and compressive strength. From the results obtained, 10% replacement of cement with SDA shows good performance giving the desired workability and strength. © 2002 Published by Elsevier Science Ltd.

Keywords: Cement material; Timber waste; Ash

1. Introduction

Sawdust is an industrial waste in the timber industry and causes a nuisance both to the health and environment when not properly disposed. The present utilisation of sawdust is as fuel, and a very small quantity as filler or aggregate material in concrete. The use of sawdust ash (SDA) as partial replacement of cement is new and this has twofold effect, i.e., reducing or total elimination of the material as a waste and reducing the quantity/cost of cement used for concrete works. In the latter the material acts as a pozzolana.

Extensive research has shown that pozzolanas can produce concrete having almost the same behaviour as normal concrete at ages beyond 28 days [2,3]. Pozzolana-concretes also show better resistance to sulphate attack, reduce permeability and improve water tightness [4–6,9].

2. Experimental programme

The experimental programme was planned to study the properties of the ash and evaluate performance of sawdust ash/ordinary portland cement (SDA/OPC) concrete with respect to workability, setting time and compressive strength. "Ashaka" cement designed to have strength of 20 MPa at 28 days was used for this study. SDA of various proportions (0%, 5%, 10%, 15%, 20%, 25%, 30%) was also used with the concrete as replacement of cement.

3. Materials

The sawdust used for this study was collected from some timber milling points in Bauchi. At these milling points, the dominant timber species are Abura, Afara (Black and White), Obeche, Mahogany and Iroko.

SDA used for this study was obtained by the open burning method using a drum. This method was adopted because at the time of conducting this research, the industrial design programme kiln was under construction. The ash was ground to very fine powder using pestle and mortar (in the absence of a ball mill) and made to pass through 212 μm sieve.

The physical and chemical properties of the SDA were determined in the laboratory of National Steel Council, Kaduna and the results of analyses are shown in Tables 1 and 2, respectively. The XRD analysis conducted on the SDA confirmed the presence of silicates and carbonates as dominant constituents of SDA, with accessory materials present in traces.

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Table 1
Physical properties of SDA

Parameter	
Moisture content, % by mass	0.37
Specific gravity	2.29
Loose bulk density (kg/m^3)	830
Loss on ignition (L0I)	4.67
pH	10.10

Table 2
Chemical analysis of SDA

Oxide	Percentage by mass
Al_2O_3	4.09
Fe_2O_3	2.26
SiO_2	67.20
CaO	9.98
MgO	5.80
MnO	0.01
Na_2O	0.08
K_2O	0.11
P_2O_5	0.48
SO_2	0.45

The fine aggregate used was clean river sand, free from deleterious matters. The coarse aggregate was a normal weight aggregate with a maximum size of 19 mm and was obtained from a local supplier. Both the fine and coarse aggregates conform to the British Standard Specifications. The cement used for this study was "Ashaka" cement, which conforms to BS 1881 [11].

4. Mix proportions

The mix used in this work had a total cement content of 373 kg/m^3, fine aggregate content of 812 kg/m^3, coarse aggregate content of 1856 kg/m^3 and a water content of 211 kg/m^3. Cement replacement levels were 5%, 10%, 15%, 20%, 25%, and 30% by mass of ash. The concrete was tested in the fresh and hardened conditions.

Tests on the SDA/OPC pastes were carried out to ascertain the setting time, and soundness of the mixes. The results are shown in Table 3. Table 4 shows the workability of SDA/OPC cement mixes.

The hardened concrete was tested for compressive strength. For this purpose, a total of 84 cube specimens, 150 mm in size, were cast and cured in water for periods of up to 28 days. Three specimens were crushed at the end of each period and the average recorded as compressive strength. Results are shown in Table 5.

Table 3
Consistency and setting time of SDA–cement pastes

Ash (%)	W/C	Soundness (mm)	Initial setting time (min)	Final setting time (min)
0	0.32	0.70	116	241
5	0.32	0.75	118	247
10	0.34	1.00	128	267
13	0.35	1.15	135	283
20	0.37	1.25	160	298
25	0.39	1.30	170	318
30	0.42	1.45	190	337

Table 4
Workability of concrete with SDA

Ash (%)	Slump (mm)	Compacting factor
0	80	0.95
5	75	0.94
10	60	0.93
15	58	0.93
20	54	0.92
25	46	0.92
30	40	0.92

Table 5
Compressive strength for concrete mixes with SDA

Ash (%)	Compressive strength (MPa)			
	3 days	7 days	14 days	28 days
0	16.4	17.63	21.74	23.12
5	12.89	13.91	19.65	21.6
10	12.13	13.11	16	18.14
15	8.27	8.98	12	15.74
20	7.29	7.96	9.47	11.52
25	4.49	5.96	8.54	9.25
30	4.32	5.29	6.54	8.76

5. Analysis of results and discussion

Tables 1 and 2 show the physical and chemical characteristics of the SDA. The average moisture content of bulk ash is 0.37%. The total percentage of $S_iO_2 + Al_2O_3 + Fe_2O_3$ is 73.55%, which is greater than the minimum (70%) specified in ASTM C-618 [1]. XRD analysis showed that SDA is mainly composed of silicates and carbonates, with traces of other elements. The SO_2 percentage in the ash is below 5% and the maximum loss on ignition is less than 6%. This shows proper conditions of burning under which ash was produced. Preliminary tests carried out on the SDA/OPC mixture to determine the pozzolanic activity as per British Standard Specifications gave a pozzolanic activity index of 75.9%.

Table 6
Chemical and physical characteristics of SDA and different mineral admixtures

Composition	Type of Ash				
	SDA	Soto de Ribera fly ash [3]	Mairama fly ash [3]	Bagasse ash [7]	Oil-palm waste ash [8]
SiO_2	67.20	50.04	53.85	73.0	34.3
Al_2O_3	4.09	31.20	33.12	6.7	24.6
Fe_2O_3	2.26	7.15	4.62	6.3	14.9
Total $SiO_2 + Al_2O_3 + Fe_2O_3$	73.55	88.35	91.59	86.0	73.8
CaO	9.98	2.84	5.92	2.8	37.8
MgO	5.80	1.76	1.50	3.2	21.1
SO_2	0.04	0.52	0.72	–	–
Na_2O	0.08	–	–	1.1	2.3
Mn_2O	0.01	–	–	0.26	0.3
K_2O	18.75	–	–	2.4	–
P_2O_5	0.048	–	–	2.09	–
C	–	–	–	–	–
pH	10.1	–	–	–	9.50
H_2O	–	–	–	–	–
MC	0.37	–	0.29	–	0.59
Specific gravity	2.29	0.08	2.24	–	1.84
Bulk unit weight (kg/mm^2)	0.83	2.06	–	–	–
L0l	4.67	–	1.33	0.9	18.22
Specific surface area	–	2.52	–	–	–

Comparison of the physical and chemical characteristics of SDA with other pozzolanic ashes is shown in Table 6. Marina et al. [2] used fly ash from two thermal stations in Northern Spain; Soto de Ribera and Meirama, respectively. The chemical analyses of various types of fly ash compared favourably with that of SDA except for the low content of Al_2O_3 (4.09%) and Fe_2O_3 (2.26%). In contrast, the oil palm waste has very high percentage of CaO (37.8%), compared to the low values for SDA and other fly ash.

Fig. 1 shows that the value of normal consistency of the pastes increased as the proportion of SDA in the paste is increased. This means that with the addition of more and more SDA, an increased amount of water is required to obtain the desired consistency. This is in conformity with the normal behaviour of the pozzolanas reported by Ahmad and Shaikh [12].

The soundness (delayed expansion) of the samples (Fig. 2) shows a gradual increase as the proportion of SDA in the mix is increased. A range of values from 0.70 to 1.45 mm is recorded and this is within the limits specified by the British Standard Specifications [10].

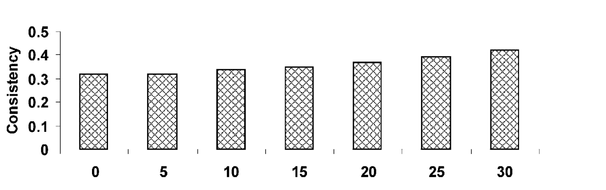

Fig. 1. Consistency of SDA/OPC paste.

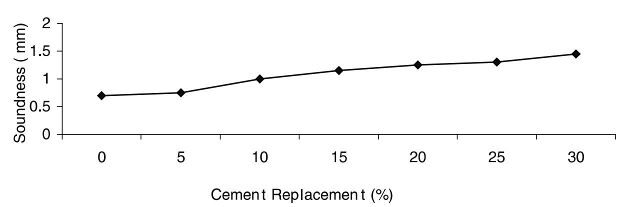

Fig. 2. Soundness of SDA/OPC paste.

The setting time of SDA/OPC paste is important for practical applications of the material. This was determined using the Vicat method [11] and shown in Fig. 3. This showed that SDA/OPC paste conforms to specifications for setting times for similar materials. Also, the workability of the concrete decreases as the percentage addition of SDA increases. A decrease in slump from 80 to 40 mm was recorded (Table 4).

Figs. 4 and 5 show the values of compressive strength of SDA/OPC concrete mixes with different ash contents and with different periods of water curing. Fig. 4 shows the effect of curing on compressive strength. An in-

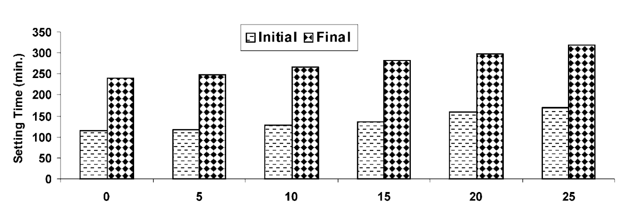

Fig. 3. Setting time of SDA/OPC paste.

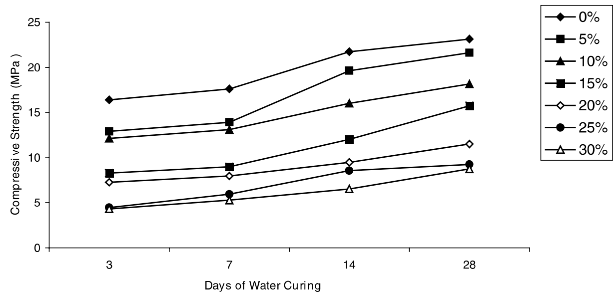

Fig. 4. Compressive strength of SDA/OPC concrete.

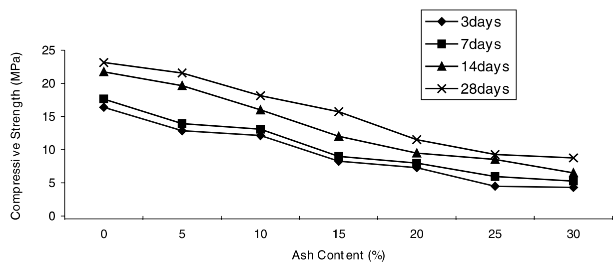

Fig. 5. Compressive strength of SDA/OPC concrete.

creasing trend in the strength of the OPC/SDA concrete as the period of curing increases is indicated. Fig. 5 on the other hand, shows that the compressive strength decreases as the percentage of ash in the mix is increased. A closer look reveals an interesting behaviour of the SDA/OPC concrete. As the age curing increases, the difference in strength between the control mix (0% ash) and the mixes with various percentage replacements tends to get smaller. The strengths at 5%, 10%, and 15% replacement are about 93%, 78% and 68%, of the control mix, respectively. This process of strength development is expected to continue with curing time until completion of hydration of the cement–ash mixture.

6. Conclusions

The possibilities of using SDA as pozzolana have been explored. SDA used had 73.55% by mass of $SiO_2 + A1_2O_3 + Fe_2O_3$, and a pH of 10.1; the pozzolanic activity index was 75.9%. The XRD analysis indicated that the ash contained predominantly silicates (67.20%). The normal consistency of the paste increased as the proportions of SDA in the paste increased, while the soundness test showed a possible risk of expansion if its CaO content is above 5%. SDA in this work had a CaO content of 9.98%, but the soundness test showed that expansion did not amount to 10 mm, the maximum limit specified.

The 28-day compressive strengths of the SDA/OPC concretes at 5%, 10% and 15% of levels of replacement of cement are about 93%, 78% and 68% of the control mix, respectively. These results obtained for SDA/OPC concrete appear encouraging in the future use of SDA in concrete works.

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