Effects of the Incorporation of Sawdust Waste Incineration Fly Ash in Cement Pastes and Mortars

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Abstract

This paper presents the result of a study on the use of sawdust waste incineration fly ash (SWIFA) as supplementary cementing materials. Tests on the setting times and strength development of cement paste and mortar with up to 30 percent SWIFA were carried out. Results of the setting times and compressive strengths show that with increasing amounts of SWIFA, the setting times of the paste were extended and the compressive strengths decreased. Pozzolanic activity index of the material was also confirmed to be approximately 76 percent and that the material performed better in a nitric acid solution environment than in sulphuric acid solution.

Keywords: sawdust ash; portland cement; pozzolana; compressive strength; durability

Introduction

The use of waste in concrete manufacture may serve as one of the solutions to the present problems encountered in waste management. Large quantities of the conventional materials are used in the construction industry and the cost of such conventional materials and other adverse environmental effects have necessitated the search for adequate alternatives.

Some industrial wastes have been used for a number of years as cement and concrete components such as fly ash (Bilodeau and Malhotra 1998; Bouzoubaa et al 1999), silica fume (Khedr and Abou-Zeid 1994), Slag (Olorunsogo and Wainwright 1998), and a host number of others (Kim and Soh 2002; Remond et al 2001 a,b; Wang et al 2001). Performances of these materials have been improved using other supplementary cementing materials (Ding Zhu 2002) or supper plasticizers (Page and Spiratos 2000).

There are other new materials such as agricultural wastes (Elinwa and Awari 2001), that could be used but their performance characteristics need be adequately ascertained to satisfy the specifications determined by its applications. It is also important that the use of wastes in concrete should not affect the durability of the concrete.

This study is on using sawdust waste incineration fly ash (SWIFA) to produce cement pastes and concrete mortars. Simple preliminary tests have been conducted and its performance in an acidic environment evaluated.

Materials

Sawdust is a waste from the timber industry. The sawdust waste used for this study was collected from the timber milling points in Bauchi. Bauchi is the State capital of Bauchi state in Nigeria. The dominant species at these milling points have been classified in an earlier works (Elinwa and Mahmood 2001). Burning of sawdust into ash was by open burning using a drum. After cooling, the SWIFA was grinded using pestle and mortar before sieving using sieve size 212µm. Table 1 shows the sieve analysis results while Figure 1 shows that the material falls within zone 2 of the grading curve.

Characterization of the material by physical and chemical analyses have been published earlier (Elinwa and Mahmood 2001). Tables 2 and 3 show the physical and chemical characteristics of the SWIFA material. The result of the X-ray analysis confirms that silica is dominant (Figure 2).

The sand used for the study was river sand with a bulk density of 2.55 and a specific gravity of 1533kg/m³. The sand was free from deleterious material. The sieve analysis of the sand is shown in Table 4 and Figure 3 shows that the grading of the sand is within zone 2 (BS 1881 1970).

The coarse aggregate was a normal weight aggregate with a maximum size of 20mm. It was obtained from a local supplier in Bauchi and has an average specific gravity of 2.50 and a bulk density of 1364 kg/m³. The aggregate crushing value of the aggregate was 12.82. This was tested according to BS 1881 (1970).

Test on Cement Paste

The pozzolanic activity index (PAI) of SWIFA with Portland cement was determined as per ASTM C618 - 78. A total of six specimens were cast and cured for 28
days. Three specimens were cast as the control (i.e. containing zero percent SWIFA), and the remaining three cast with 35 percent SWIFA as cement replacements. Table 5 shows details of the mix composition and the achieved strengths. The value of the PAI is 75.90 percent. This is greater than the 70.00 percent minimum specified by the code.

Tests on Mortars
To study the influence of SWIFA on the short - term and middle - term properties of mortars, certain performance characteristics of mortars containing increasing levels of SWIFA were studied.

The consistency, setting times and soundness of SWIFA mortar mix were studied using seven mixes as shown in Table 6 and according to BS 4550: Part 3 (1978) and BS 12 (1978).

Consistency of Pozzolanic Mix
The normal consistency of pastes of SWIFA/PC was determined as per ASTM C 143-78. SWIFA of 0, 5, 10, 15, 20, 25 and 30 percents was used to replace cement and a total of 21 samples were prepared. An average of 3 samples was taken as the final value. The results are shown in Table 7.

![Fig.1. Particle size distribution of SWIFA](image1)

![Fig.2. X- Ray Diffraction Analysis of SWIFA](image2)
Table 4. Particle Size Distribution– Fine Aggregate

| BS Sieve Size | Wt. Retained | Cum. Retained | Wt. Passing | % Passing |
|---------------|--------------|---------------|-------------|-----------|
| 2.36mm        | 54           | 54            | 946         | 94.60     |
| 2.00mm        | 32           | 86            | 914         | 91.40     |
| 1.18mm        | 208          | 294           | 706         | 70.60     |
| 600μm         | 393          | 687           | 313         | 31.30     |
| 425μm         | 170          | 857           | 143         | 14.30     |
| 300μm         | 72           | 929           | 71          | 7.10      |
| 212μm         | 42           | 971           | 29          | 2.90      |
| 150μm         | 17           | 988           | 12          | 1.20      |
| 63μm          | 8            | 996           | 4           | 0.40      |
| Receiver      | 4            | 1000          | 0           | 0.00      |

Specific Gravity 2.55
Bulk Density 1.533kg/m³

Fig.3. Particle size distribution of sand.

Table 5. Pozzolanic Activity Index:

| Test Specimen | 28Days Strength (MPa) | Ave. Strength (MPa) |
|---------------|-----------------------|---------------------|
| 00-SDA – 1    | 20.05                 |                     |
| 00-SDA - 2    | 20.60                 | 20.37               |
| 00-SDA – 3    | 20.45                 |                     |
| 35-SDA – 1    | 15.18                 |                     |
| 35-SDA - 2    | 15.63                 | 15.46               |
| 35-SDA – 3    | 15.56                 |                     |

P.A.I = 15.43/20.37 = 75.9%

Table 6. Summary of Mixes

| Mix No | W/B | Mix Ratio               |
|--------|-----|-------------------------|
| CPM-0/1| 0.28| (1.0 +0.0) : 2 : 4       |
| CPM-0/2| 0.28| (0.95 +0.05) : 2         |
| CPM-0/3| 0.28| (0.85 + 0.2) : 2         |
| CPM-10/1| 0.28| (0.75 +0.25) : 2         |
| CPM-10/2| 0.28| (0.70 + 0.3) : 2         |

CPM is Consistency Pozzolanic Mix

Table 7. Consistency of Pozzolanic Mix:

| Mix   | Normal Consistency (%) |
|-------|------------------------|
| CPM-0 | 32                     |
| CPM-5 | 32                     |
| CPM-10| 34                     |
| CPM-15| 35                     |
| CPM-20| 37                     |
| CPM-25| 39                     |
| CPM-30| 42                     |
Setting Time and Soundness of the Pozzolanic Mix

Setting times and soundness tests were performed in accordance with BS 12 (1978). The test results are presented in Tables 8 and 9 respectively for setting times and soundness.

### Table 8. Setting Times of Pozzolanic Mix:

| Mix   | Initial Setting Time (min) | Retard. (min) | Final Setting Time (min) | Retard. (min.) |
|-------|----------------------------|---------------|--------------------------|----------------|
| CPM-0 | 116                        | 0             | 241                      | 0              |
| CPM-5 | 118                        | 2             | 247                      | 6              |
| CPM-10| 128                        | 12            | 267                      | 26             |
| CPM-15| 135                        | 19            | 283                      | 42             |
| CPM-20| 160                        | 44            | 298                      | 57             |
| CPM-25| 170                        | 54            | 318                      | 77             |
| CPM-30| 190                        | 74            | 337                      | 96             |

### Table 9. Soundness of Pozzolanic Mix:

| Mix   | Soundness (mm) |
|-------|----------------|
| CPM-0 | 0.70           |
| CPM-5 | 0.75           |
| CPM-10| 1.00           |
| CPM-15| 1.15           |
| CPM-20| 1.25           |
| CPM-25| 1.30           |
| CPM-30| 1.45           |

Compressive Strength Test:

To study the effects of the incorporation of sawdust waste incineration fly ash on compressive strength of cement mortar, a mix of 1:3 (cement: sand) was used. The mix had a cement content of 456kg/m², fine aggregate of 1366kg/m² and a water-binder ratio of 0.60. Seventy two mortar cubes of 50mm were cast and cured for 3, 7, 28 and 60 days. Cement content was replaced by SWIFA using replacement levels of 0, 5, 10, 15, 20 and 30 percent. Three cubes were crushed at the end of each curing regime and the average crushing strength recorded. The results are shown in Table 10.

### Table 10. Mortar Compressive Strength

| Cement : SWIFA | Compressive Strength (MPa) |
|----------------|-----------------------------|
|                | 3 days | 7 days | 28 days | 60 days |
| 100 : 00       | 14.04  | 15.66  | 21.08   | 22.44   |
| 95 : 05        | 8.20   | 10.17  | 15.04   | 18.00   |
| 90 : 10        | 10.49  | 11.83  | 17.63   | 21.45   |
| 85 : 15        | 9.13   | 10.23  | 14.54   | 15.78   |
| 80 : 20        | 7.40   | 8.63   | 11.09   | 13.99   |
| 70 : 30        | 3.70   | 4.93   | 7.40    | 8.02    |

Durability Test:

To study the effect of the incorporation of sawdust waste incineration fly ash on the durability of cement mortar, the same mix used for the compressive strength test was used for the experiment. Forty specimens were cast and cured for 28 days before immersing in 20 percent concentrated solutions of hydrochloric acid (H₂SO₄) and nitric acid (HNO₃); twenty for each concentration. They were immersed for a period of 5 (five) weeks and readings were taken at intervals of one week. The results are as shown in Table 11.

### Table 11. Durability Test

| Mix         | Medium  | Weight (kg) |
|-------------|---------|-------------|
|             | Week    |             |
| Control     | 0       | 1           | 2           | 3           | 4           | 5           |
| 10%SWIFA    | Nitric  | 100         | 90.90       | 89.20       | 82.10       | 78.90       | 76.20       |
|             | Acid    | 100         | 95.80       | 96.30       | 89.20       | 79.80       | 76.50       |
| Control     | Sulphur | 100         | 72.10       | 49.60       | 39.00       | 23.80       | 18.60       |
| 10%SWIFA    | Acid    | 100         | 64.40       | 48.50       | 34.90       | 21.30       | 12.40       |
Water Absorption Test

The water absorption test was carried out by casting 10 (ten) mortar cubes of dimensions 50mm and cured for 28 days. Five (5) of the mortar cubes were cast as the control and the remaining five using 15 percent of sawdust ash to replace cement. At the end of 28 days the specimens were removed and kept dry for 3 (three) days before immersing them completely in water for 24 hours and measurements taken by weighing and finding the difference in weight. The results are shown in Table 12.

Discussion of Results

Consistency of SWIFA Content Paste

Normal consistency of the pastes increased as the proportions of SWIFA in the paste is increased (Fig.4). This means that with the addition of more and more SWIFA, an increased amount of water is required to obtain the desired consistency.

Soundness of SWIFA Cement Paste

Figure 5 shows the effect of adding SWIFA on the soundness. The soundness of the sample, which is, delayed expansion showed a gradual increase as the proportion of SWIFA is increased. A range of values from 0.70 to 1.45mm is recorded and this is within the limits specified by the British Standard Specifications (BS 12 1978).

Setting Times of SWIFA Cement Paste

The setting time of SWIFA cement paste is important for practical applications of the material. This was determined in accordance to BS 1881(1970) and shown in Fig.6. This shows there is retardation due to the effects of SWIFA. SWIFA is a latent hydraulic material and when it is incorporated with Portland cement its reaction has to be initiated by calcium hydroxide released from the portland cement hydration. Therefore, it defers the hydration of blended cement, and prolongs the setting time of cement. This observation was also made by Wang et al (2001) working with amorphous silica residues as supplementary cementing materials.

Compressive Strength

The compressive strength of the sawdust fly ash mortar cubes decreased as the ash content was increased. This is shown in Figure 7. An explanation to this can be given if the reaction mechanism of sawdust ash is divided into physical and chemical aspects (Ding Zhu 2000). The physical effect is that the ultra - fine particles fill the voids in cement, which makes the microstructure of cement paste denser. The chemical effect is the reaction of SWIFA with the cement hydrates. Ding Zhu (2002) working with metakaolin and slag has stressed that the slag reacted more slowly than the alite and thus strength development of slag was slow and that the strengthening effect of slag to the compressive strength of portland cement will be seen after the concrete was cast for a long time, for example, after 91 days. The same effect is

| Table 12. Absorption Test. | SWIFA (%) | Mix | Water Absorption (%) | Average (%) |
|---------------------------|-----------|-----|----------------------|-------------|
|                           | A – 1     |     | 1.26                 |             |
|                           | A – 2     |     | 1.32                 |             |
|                           | A – 3     |     | 1.28                 |             |
|                           | A – 4     |     | 1.31                 |             |
|                           | A – 5     |     | 1.29                 |             |
|                           | A/S – 1   |     | 0.91                 |             |
|                           | A/S – 2   |     | 0.72                 |             |
|                           | A/S – 3   |     | 0.76                 |             |
|                           | A/S – 4   |     | 0.86                 |             |
|                           | A/S – 5   |     | 0.77                 |             |
inferred for the sawdust ash and strength development is therefore slower to an extent that increases with the proportion of sawdust ash. The maximum strength is obtained at 10 percent cement replacement. Figure 8 shows that as the curing proceeds, the compressive strength increases.

Durability of Sawdust Fly Ash Mortar Cubes

Figure 9 shows that the mortar with SWIFA offered better resistance to deterioration by nitric acids than Portland cement mortar. Figure 10 shows that the effect of the sulphuric acid was very drastic both on the SWIFA mortar and Portland cement mortar. This shows that SWIFA will not perform viably in such environment. A further confirmation on this issue is needed before final conclusion can be drawn.

The rate of deterioration of the mortar cube in the nitric acid can be represented empirically by $y = a - bx - cx^2$, where $y$ is the weight (kg) and $a$, $b$ and $c$ are coefficients. The values of the coefficients are 99.839, 1.7975 and 0.6268 respectively. For such behaviour the correlation factor ($R^2$) is 0.9585. The rate of deterioration of the mortar in sulphuric acid is exponential and can be represented by $y = ae^{-bx}$, where $y$ is the weight (kg) and $a$ and $b$ are the coefficients with the values of 100.75 and 0.3422 respectively. $X$ in the two equations is the percentage sawdust ash.

Water Absorption

The low water absorption exhibited by the mortar cube containing 15 percent SWIFA shows that a more dense microstructure was formed because the ultra-fine particles fill the void in cement and SWIFA can absorb CH to form C-S-H which is a continuum structure.

Conclusion

The conclusions of this study can be summarized as follows:

a. Sawdust waste incineration fly ash can react with CH released by cement clinker hydration to produce secondary C-S-H gel inside the cement paste which improves the microstructure of cement paste matrix.

b. The SWIFA can defer the reaction of cement hydration and prolong the setting time of cement paste. SWIFA has a pozzolanic activity index of approximately 76% and thus can be used as supplementary cementing materials but its reaction is slow.

c. An increased amount of water is needed when using SWIFA in order to produce concrete that has consistent workability.

d. The mortar compressive strength decreases as SWIFA content is increased. For this study 10% SWIFA is recommended.

e. In acid environment, the rate of deterioration of SWIFA mortar cube is adversely affected in sulphuric acid than when in nitric acid and so SWIFA concrete or mortar should not be used in such environment.

f. The rate of deterioration of SWIFA mortar cube in nitric acid environment can be evaluated using the empirical formula $y = a - bx - cx^2$ and in sulphuric acid environment as $y = ae^{-bx}$.
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