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PULVERISED SEWAGE SLUDGE ASH PARTIAL REPLACEMENT OF CEMENT IN CONCRETE

##### BY

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###### ABSTRACT

The potential of the ash produced from the incineration of sewage sludge, as partial replacement of cement in concrete has generated research interest in recent times as a result of the increase in its production due to rapid urbanization and the problem of getting functionally adequate landfill sites for its disposal. Physical properties if sewage sludge from one of the two waste treatment plants located at the University of Ibadan were investigated. The properties evaluated were specific gravity, colour, particle size distribution and pH. The colour of the sewage sludge changed from greenish-brown when fresh to brownish-orange after incineration when the organic materials had been burnt off. The specific gravity was 1.9 while the pH was 7.32. The particle size grading of the pulverized sewage sludge was similar to that of cement, which it was meant to partially replace. The properties if fresh and hardened concrete, in which cement was partially replaced with 0, 5, 10, 15 and 20% of pulverised sewage sludge ash by weight, were determined. There was an improvement in workability with increasing sludge ash content. The best performance of sludge ash concrete was attained with 10% sludge ash content. Concrete with up to 20% replacement of cement with pulverized sewage sludge ash produced concrete with properties above grade 20 concrete.

**Keywords:** Sewage sludge, cement, concrete

##### 1.0 INTRODUCTION

Sewage sludge ash is a by-product of wastewater treatment. The rapid increases in population and sewered areas in most urban cities have led to a corresponding increase in sewage sludge production, which is becoming increasingly difficult to dispose of. The traditional methods of sludge disposal such as open dumping, land filling, marine disposal and agriculture uses have adverse environmental impacts. Tay and Show (1997) reported that in

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highly urbanized cities, disposal of sewage sludge by land filling may not be feasible due to land scarcity and stricter environmental regulations. They concluded that incineration would offer an efficient method of converting bulky sludge to practically inert and sterile ash. The high temperature required for incineration, according to Swithenback *et al* 1999 decomposes the hazardous and toxic organic compounds in the sludge. Anderson (1999) observed that through incineration, it has been possible to reduce 75m3 of semi-liquid sewage sludge to 1m3 of incinerated sludge ash. However, the ash produced from the incineration process must be subsequently disposed of.

The problems associated with sludge disposal would be considerably reduced if sludge in its dewatered or incinerated form can be put to productive uses. Pinarli (2000) suggested that the construction industry could offer a number of potential applications for waste materials such as sludge and sludge ash, in order to turn them to useful resources. Tay and Show (1997) are part of the several workers that have investigated the use of sewage sludge and sewage sludge ash in the construction industry, as material for concrete works. Some areas of potential application include; the use of sludge ash as material for brick, as an alternative to natural aggregate, as a covering material for landfill, for filling underground voids, in ceramic tile production, in the production of flower vases and ornamented accessories, as base material for roads, as filler for Portland cement concrete and also for restoring degraded soils. Chan (2009) explained that the sludge ash studied by him contained materials such as calcium, alumina and iron oxide that could be used as raw materials for cement production.

Anderson (1999) reported that bricks containing 6% sewage sludge ash possessed lower water absorption, higher strength and lower bulk density values than standard products. The major drawback was in the increased level of water required during the production due to the absorbent nature of sewage sludge ash. He further observed that the addition of sewage sludge ash led to a significant reduction in drying shrinkage of some experimental bricks produced. Tseng *et al* (2002) observed that workability and compressive strength of sewage sludge ash mortar dramatically decreased with increasing replacement of fine aggregate. This was attributed to water adsorption capacity and poor mechanical properties of sewage sludge ash cement mortars. The result of an experiment by Tay *et al* (2001) to determine the suitability of round and angular aggregates, made from a mixture of sludge and dredged marine clay, for use as coarse aggregate in concrete showed that compressive strengths in the range of 31.0 to 39.0 N/mn2 could be achieved. Round aggregates of 100% sludge and crushed aggregates of sludge with 20% clay have strengths that were superior to 38N/mn2 for conventional aggregates. Khanbilvardi and Afshari (1995) however, concluded that it could be possible to replace up to 30% by weight of fine aggregate by weight of fine

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aggregate by sludge ash in a concrete mix for normal practice. Partial replacement of cement by finely ground sewage sludge ash at ratio less than 20% were found by Tseng *et al* (2002) to give similar performance as fly ash in concrete.

Portland cement concrete has been a major construction material. However, the periodic scarcity and high and continuously increasing cost of its number one constituent materials, which is cement, has made it imperative to search for alternative materials which can serve as partial or total replacement for cement in concrete. Significant saving in cost of construction can be achieved by replacing some proportion of cement with pulverized sewage sludge ash (PSSA), since cement is a major cost centre. The space required for the disposal of dewatered sludge would be significantly reduced if sludge were put to productive use. Environmental pollution resulting from sewage disposal would also be reduced. This paper report the results from an investigation carried out to determine the properties of sewage ash and its suitability as partial replacement for cement in concrete.

##### 2.0 MATERIAL AND METHODS

The digested and dewatered sewage sludge used in this investigation was obtained from one of the two sewage treatment plants serving the University of Ibadan, Nigeria. The sludge samples were collected on seven successive days as a check on the variability of sludge produced at the plant as suggested by Tay (1987). The collected samples of sludge were subsequently air-dried for two weeks for moisture reduction before incineration at 7000C in a muffle furnace for six hours. The ash resulting from the incineration was pulverized using a milling machine and only those portions passing through the 150  m sieve were used in the experiment.

Physical and chemical properties of the sludge were determine. The physical properties evaluated included colour, specific gravity and particle size grading. Chemical composition of the ash was analysed using the atomic absorption spectrophotometer. The elements investigated included Lead, Nickel, Magnesium, Zinc, Iron, Copper, Silicon, Sodium, Aluminium, Sulphur, Calcium and Potassium. The pH of the ash was also determined.

Concrete cubes of 150mm X 150mm dimension were cast in accordance with BS 1881: part108 (1983), using a nominal mix proportion of 1:2:4 (cement:sand:granite), with a water/cement ratio of 0.56 as suggested by Dahunsi (2000) from trial mixes produced manually, using shovels and trowel in a mixing pan. Cement content of mixes was subsequently replaced by 5, 10, 15 and 20% of sewage sludge ash by weight. From each batch of mix produced, samples were taken and workability of fresh concrete measured by slump, was determined in accordance

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with BS 1881 part 101 (1983). The concrete cubes were then cured by complete immersion in water for specific number of days (7, 14, 21 and 28 days) as recommended by BS 1881 part 111 (1983). The cubes were tested for compressive strength using the universal testing machine. For each mix and curing age, three replicates were made and tested. The average of the three test results was taken and recorded for every mix, curing age and percentage replacement of cement.

##### 3.0 RESULTS

Samples of sewage sludge collected from the treatment plant is seven successive days were observed to have similar physical appearance. The sludge that was greenish-brown in colour, at the time of collection and having presence of organic materials, changed to brown-orange after incineration with all the organic materials burnt off. The pH, specific gravity and chemical composition of the sewage sludge ash are shown in Table 1. The specific gravity was found to be 1.9 while the pH was 7.32. The values were lower than 2.81 obtained as specific gravity of sewagw sludge ash by Tay (1987). The specific gravity for ordinary Portland Cement as reported by Neville (1995) was 3.14 while its pH as obtained by Tay (1987) was 9.0. The implication of the lower value of the specific weight of sewage sludge compared with Portland Cement is that, for the same mass of cement that it replaced, the sludge ash would occupy more volume. This could alter the mix ratio of constituent materials if the batching was by volume. Sulphur, which constituted 125.0g/kg of ash was the largest constituent while lead was the least at 1.0g/kg. The total sum of the addition of the quantity of Silicon, Alumunium and Iron was less than 70%, hence the material would have weak pozzolanic properties. The particle size grading of ordinary Portland cement and sewage sludge ash are shown in Table 2. The particles grading of the pulverized sewage sludge ash was similar to that of ordinary Portland cement. Pulverised sewage sludge ash was however slightly finer with 96.20 percent passing through the 150m sieve, compared to 92.50 percent for ordinary Portland cement.

The result of the slump test presented in Table 3 indicates an improvement in workability with increasing percentage of sludge ash, up to 10% replacement of cement. A reduction in workability was however, noticed in mixes with 15% replacement of

Cement with sludge. The sludge ash behaves as a \_lasticizing agent in the concrete mixes. This was in agreement with the findings of Tay (1987). However, this trend was contrary to the findings of Tseng *et al* (2002), which showed a reduction in workability with increasing sludge ash content in cement mortars. Okpala showed a

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reduction in workability with increasing sludge ash content in cement mortars. Okpala (1986, 1987) obtained results that were similar to Tseng et al (2002) when pulverized fuel ash and rice husk ash were used in partial replacement of cement.

The addition of sewage sludge ash did not lead to major differences in the density of the concrete cubes. The density at 28 days ranged from 2466 to 2596 kg/m3 with the highest density obtained in cubes with 5% replacement of cement while those with 15% replacement had lowest density value.

The strength development characteristics of the test samples are indicated in Figure 1. Compressive strength increased with age in all the samples. The ratio of the 28 day strength to 7 day strength is given in Table 4. It ranged from 1.15 to 1.57 with the highest percentage strength gain obtained in cubes with 20% replacement. Samples with sludge ash showed higher strength gain than the controls without sludge ash. The only exception was found in samples with 10% sludge ash, having strength gain of 1.15.

The compressive strength of cubes with 10% of sludge ash exhibited higher strength than those with other percentages of sludge ash at all curing ages. At 7 days, cubes with 10% sludge ash by weight of cement gave higher strength value than that of the control. This was reversed at other curing ages of 14, 21 and 28 days when the controls had higher strength values. The 28 day strength of the control was 31.56 N/mm2 while for 5% sludge ash it was 26.22 N/mm2. The compressive strength was 30.56, 28.67 and 27.67 N/mm2 for 10, 15 and 20% sludge ash respectively. All the test conditions exhibited higher strength than required for grade 20 concrete, hence could be used for normal concrete work including reinforced concrete as recommended by BS & 110 (1997).

##### CONCLUSIONS

The properties of fresh and hardened concrete with specified proportion of sewage sludge ash as partial replacement of cement by weight in concrete were investigated. The following conclusions could be drawn from the experimental work carried out.

* + 1. The specific gravity of the sewage sludge ash was 1.9 while its pH was 7.32.
    2. Workability of PSSA concrete paste, increased with increasing sewage sludge ash content.
    3. Optimum performance of PSSA concrete was at 10% replacement of cement by sludge ash.
    4. Cement was replaced with up to 20% by weight of PSSA to produce concrete with acceptable properties.
    5. Since long-term studies were not carried out and the weathering characteristics and durability of sewage sludge ash concrete were not determined. PSSA concrete should only be applied to non- critical structural members, such as flooring, temporary structures, culverts and slabs on grade until a database of performance characteristics can be established from long-term studies on physical structures under normal and severe service conditions.
    6. Further research efforts need to be directed at the properties of sludge from various sources in order to determine their suitability for use as partial replacement for cement in concrete

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Table 1: PH, Specific Gravity and Chemical Composition of Sewage Sludge Ash.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Specific  Gravity | PH | Chemical Composition (g/Kg) | | | | | | | | | | | | |
|  |  | S | Ca | Al | Si | Cu | Fe | Zn | Mg | Na | K | Mn | Ni | Pb |
| 1.9 | 7.32 | 125 | 125 | 77 | 58.20 | 41.60 | 38 | 37.60 | 8.30 | 7 | 5.56 | 3.60 | 2.9 | 1 |

Table 2: Particle Size Grading of Ordinary Portland Cement and Pulverised Sewage Sludge Ash.

|  |  |  |
| --- | --- | --- |
| Sieve Size | Percentage Passing (%) |  |
|  | Ordinary Portland Cement | Pulverised Sludge Ash |
| 212 m | 96.00 | 100.00 |
| 150 m | 92.50 | 96.20 |
| 75 m | 85.60 | 90.20 |
|  |  |  |

Table 3: Slump of Pulverised Sewage Ash Concrete

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Percentage of  Sludge Ash | 0 | 5 | 10 | 15 | 20 |
| Slump (mm) | 80 | 100 | 105 | 100 | 130 |

Table 4: Strength Ratio of 28 to 7 Day Compressive Strength.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Percentage of  Sludge Ash | 0 | 5 | 10 | 15 | 20 |
| Strength Ratio | 1.39 | 1.54 | 1.15 | 1.50 | 1.57 |