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## Effects of Sludge Ash on Short-Term Compressive Strength of Hardened Concrete

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### Abstract

This study describes the short-term compressive strength development of sludge ash in concrete. Digested and dewatered sludge from a wastewater treatment plant was fired to 700°C to produce sludge ash. Using a simple replacement technique of mixture proportioning, 5%, 10%, 15% and 20% cement was replaced with sludge ash. Sludge ash concrete cubes, cast and cured, showed compressive strength development comparable to that of the control specimen (0% sludge ash concrete). It was observed that 10% sludge ash concrete exhibited the fastest initial compressive strength of 25.56 N/mm<sup>2</sup>. For every mix proportion studied, compressive strength increased with curing period. Optimum compressive strength of 31.56 N/mm<sup>2</sup> was achieved at 28 days by the control and closely followed by 10% sludge ash concrete with a compressive strength of 30.56 N/mm<sup>2</sup>. The results indicate that 5% - 20% replacement of cement with sludge ash has a marginal effect on the short-term compressive strength of hardened concrete, therefore, sludge ash concrete can be used as a substitute for normal concrete.

### Keywords

Sludge, Ash, Compressive Strength, Hardened Concrete, and Short - Term

### 1. Introduction

Sludge is generated as a bye product of wastewater treatment. It is produced in bulk quantities and it contains putrescible substances, pathogens, and biomass, which decompose further. However, sludge properties may vary with the type of wastewater and the type of treatment given to wastewater. Because of the peculiar inherent properties of sludge, immediate disposal is required. Many sludge disposal alternatives such as land application, ocean disposal, landfills, and lagooning have adverse environmental impacts (Tay, 1987).

Concrete is a commonly used construction material made by combining mainly cement, water and aggregates. Partial or full replacement of cement in concrete with another suitable material will provide a means of reducing the cost of construction materials. In Nigeria, for example, due to the recent increase in the pump price of fuel, cement now costs ₦1000 per ton, coarse aggregates such as gravel or granite cost about ₦ 350 per ton or ₦ 750 per ton respectively, while fine aggregates such as fine sand cost about ₦ 160 per ton. Consequently, the need for substitute materials in concrete works cannot be overemphasized, as it will provide the construction industry with alternative and cheaper means of using concrete for various projects.

Several researchers have investigated the use of substitute materials for building and construction materials. Olateju (1991) reported the use of pozzolonic fillers such as rice husk ash and brick wastes to stabilize laterites for walling, flooring, block making and other structural components of housing. Malhotra (1997) reported the use of highly reactive metakadin and industrial bye-products such as fly ash, blast-furnace slag and silica fume in partial replacement of cement in concrete.

Compressive strength is a predominant characteristic of concrete, which gives a clue of the quality of hardened concrete. Variation in the compressive strength of concrete occur as a result of many different factors such as strength characteristics of cement, the water-cement ratio, changes in grading of materials, air-voids content of the compacted concrete, curing, temperature, and testing errors (Murdock et al., 1991). However, if these factors are kept constant, varying only the amount of the filler material and hydration period, the strength development characteristics can be obtained from such experiment. The purpose of this study is to determine the effects of sludge ash generated as a bye product of a water hyacinth -based treatment system, on the short - term compressive strength of hardened Portland cement concrete.

## 2. Methods of Study

### 2.1 Collection and Processing of Sludge

Sewer pipes convey wastewater at the University of Ibadan to a water hyacinth covered treatment plant where the hyacinths remove pollutants. This process leads to the production of water hyacinth biomass and sludge as bye products (Fig. 1). Sludge samples from the treatment plants were collected weekly. The collected samples of sludge were air-dried for two weeks. The sludge was then fired in a furnace to a temperature of 700°C in order to remove organic matter and for complete oxidation.

The resulting sludge ash was chemically analyzed according to A.O.A.C (1984) procedures and then pulverized using a milling machine. Those passing through a 150- $\mu$ m-sieve were used to prepare test concrete cubes.

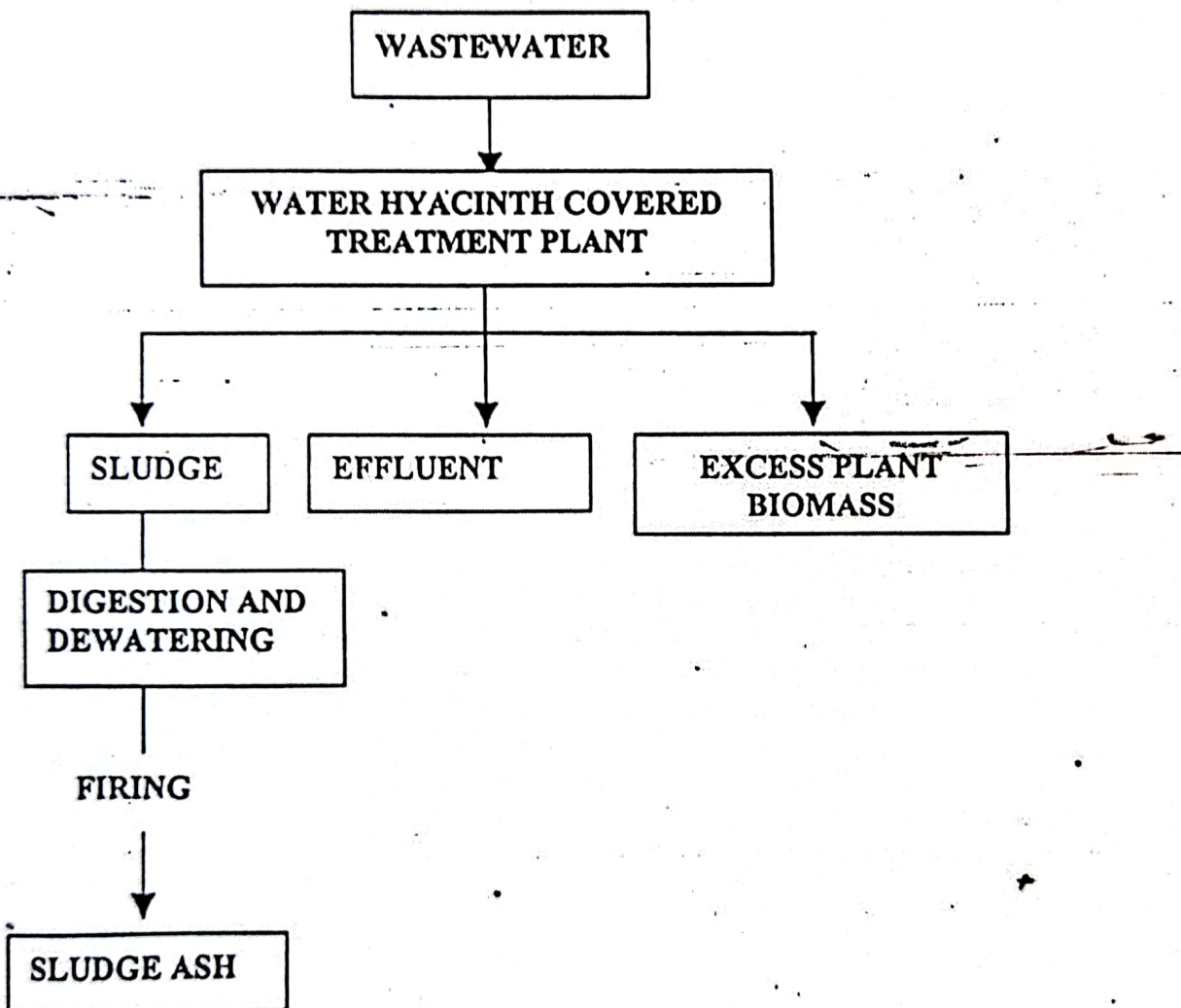


Fig. 1. Flow Chart Showing the Production of Sludge Ash

## 2.2 Mixing and Batching of Concrete

Crushed granite of sizes which range from 5-20mm was used as coarse aggregates while river quartzite sand that is of grading zone 3 (BS 882, 1992) was used as fine aggregate. Portland cement produced by West African Portland Cement Company,

Sagamu, was used as a binder and public water supply was utilized in the preparation of concrete cubes. Batching of materials was done by weight. A nominal mix proportion of 1:2:4 (cement: sand: granite) with water/cement ratio of 0.65 value obtained from trial mixes was used as a control. All other mixes were batched with 5%, 10%, 15% and 20% by weight of sludge ash to replace cement. For each mix, slump test was performed on fresh concrete as described in BS1881 (1983) part 101. Test specimens of concrete cubes were cast in 150 x 150 x 150 mm<sup>3</sup> moulds in accordance with BS1881 (1983) Part108. The cubes were removed from the moulds after adequate setting is allowed for 24 hours and they were cured according to the requirements of BS 1881 (1983) part111. Compressive strength of duplicate samples of a given mix at different curing ages of 7, 14, 21 and 28 days were carried out according to BS 1881 (1970).

### 3. Results and Discussion

The chemical properties of sludge ash presented in Table 1 indicate that it is inert in nature and it does not contain sulphate and chloride compounds that would adversely affect the hydration of cement. The largest chemical constituent found in sludge ash is sulphur with a weight of 125 g/kg while the lowest constituent is lead, which weighted 1.0 g/kg. The pH value was found to be 7.32, showing that it is alkaline in nature. Table 2 shows the grading of sludge ash with a very large percentage passing 150-µm-sieve thereby making the sludge ash suitable for the experiment. The slump test result is shown in Table 3. The 0% sludge ash concrete was found to have a slump of 80 mm, 5% sludge ash concrete gave 100 mm slump, 10% sludge ash concrete gave 150 mm slump, 15% sludge ash concrete gave 100 mm slump while 20% sludge ash concrete had 130 mm slump. The results show that all slumps were within the medium and high degree of workability recommended by Neville (1995) and it tends to improve with a higher percentage of sludge ash in concrete.

Table 1. Properties of Sludge Ash

| Properties                       | Composition |
|----------------------------------|-------------|
| <b>Chemical Composition</b>      |             |
| Sulphur                          | 125.0 g/kg  |
| Calcium                          | 100.0 g/kg  |
| Aluminum                         | 77.0 g/kg   |
| Copper                           | 41.6 g/kg   |
| Iron                             | 38.0 g/kg   |
| Zinc                             | 37.6 g/kg   |
| Silicon                          | 12.5 g/kg   |
| Magnesium                        | 8.3 g/kg    |
| Sodium                           | 7.0 g/kg    |
| Potassium                        | 5.56 g/kg   |
| Manganese                        | 3.6 g/kg    |
| Nickel                           | 2.9 g/kg    |
| Lead                             | 1.0 g/kg    |
| Average Specific Gravity at 20°C | 1.90 g/kg   |
| Average pH Value                 | 7.32 g/kg   |

Table 2. Grading of Ordinary Portland Cement Concrete and Sludge Ash

| Sieve Size ( $\mu\text{m}$ ) | Percentage passing       |            |
|------------------------------|--------------------------|------------|
|                              | Ordinary Portland Cement | Sludge Ash |
| 212                          | 96.00                    | 100.00     |
| 150                          | 92.50                    | 96.20      |
| 75                           | 85.60                    | 90.20      |

Table.3. Slump Characteristics of Sludge Ash Concrete

| Percentage of Sludge Ash | Water/Cement Ratio | Slump (mm) |
|--------------------------|--------------------|------------|
| 0                        | 0.65               | 80         |
| 5                        | 0.65               | 100        |
| 10                       | 0.65               | 105        |
| 15                       | 0.65               | 100        |
| 20                       | 0.65               | 130        |

The compressive strength of sludge ash concrete varies with the amount of sludge ash in a mix as well as curing period, while unit density is marginally affected by the percentage of sludge ash as shown in Table 4. A typical plot of compressive strength of sludge ash concrete versus curing period for different mixes is given in Fig. 2. There is a general increase in compressive strength with curing period from age of 7 days to the age of 28 days. The result shows a decrease in strength as the percentage of sludge ash increases from 0% sludge ash to 5% sludge ash and an increase in compressive strength from 5% sludge ash concrete to 10% sludge ash content for all ages. From 10% sludge ash concrete up to 20% sludge ash concrete, there is a gradual decrease in compressive strength. Figure 3 shows the relationship between the compressive strength of different sludge ash concrete at various ages with respect to 0% sludge ash concrete (which serves as a control). It indicates that for 5%, 10%, 15%, and 20% sludge ash concrete, 28<sup>th</sup> day compressive strength of the control decreased by 17%, 3%, 9%, and 12% respectively. However, 10% sludge ash concrete exhibited an early inter particle bonding with cement resulting in a faster initial strength development (25.56 N/mm<sup>2</sup>) than the control (22.78 N/mm<sup>2</sup>). Also, the compressive strength of 10% sludge ash concrete at 7 days is approximately 83% of 28 – day strength.

Table 4. Compressive Strength and Unit Density of Hardened Sludge Ash Concrete

| %Sludge Ash | Average Weight (Kg) | Volume $\times 10^{-3}$ (m <sup>3</sup> ) | Effective Area $\times 10^{-2}$ (mm <sup>2</sup> ) | Average Crushing Load (KN) | Unit Density (Kg/m <sup>3</sup> ) | Compressive strength (N/mm <sup>2</sup> ) |       |       |       |
|-------------|---------------------|-------------------------------------------|----------------------------------------------------|----------------------------|-----------------------------------|-------------------------------------------|-------|-------|-------|
|             |                     |                                           |                                                    |                            |                                   | 7                                         | 14    | 21    | 28    |
|             |                     |                                           |                                                    |                            |                                   | Day                                       |       |       |       |
| 0           | 8.460               | 3.375                                     | 2.25                                               | 512.5                      | 2507                              | 22.78                                     | 28.22 | 30.22 | 31.56 |
|             | 8.515               |                                           |                                                    | 635.0                      | 2523                              |                                           |       |       |       |
|             | 8.553               |                                           |                                                    | 680.0                      | 2534                              |                                           |       |       |       |
|             | 8.663               |                                           |                                                    | 710.0                      | 2567                              |                                           |       |       |       |
| 5           | 8.188               | 3.375                                     | 2.25                                               | 380.5                      | 2426                              | 16.91                                     | 20.56 | 22.89 | 26.22 |
|             | 7.797               |                                           |                                                    | 462.5                      | 2310                              |                                           |       |       |       |
|             | 8.655               |                                           |                                                    | 515.0                      | 2564                              |                                           |       |       |       |
|             | 8.763               |                                           |                                                    | 590.0                      | 2596                              |                                           |       |       |       |
| 10          | 8.375               | 3.375                                     | 2.25                                               | 575.0                      | 2481                              | 25.56                                     | 26.44 | 27.33 | 30.56 |
|             | 8.484               |                                           |                                                    | 595.0                      | 2514                              |                                           |       |       |       |
|             | 8.460               |                                           |                                                    | 615.0                      | 2507                              |                                           |       |       |       |
|             | 8.470               |                                           |                                                    | 687.5                      | 2510                              |                                           |       |       |       |
| 15          | 8.471               | 3.375                                     | 2.25                                               | 430.0                      | 2510                              | 19.11                                     | 25.00 | 26.67 | 28.67 |
|             | 8.485               |                                           |                                                    | 562.5                      | 2514                              |                                           |       |       |       |
|             | 8.564               |                                           |                                                    | 600.0                      | 2537                              |                                           |       |       |       |
|             | 8.323               |                                           |                                                    | 645.0                      | 2466                              |                                           |       |       |       |
| 20          | 8.285               | 3.375                                     | 2.25                                               | 397.5                      | 2455                              | 17.67                                     | 18.78 | 26.00 | 27.67 |
|             | 8.405               |                                           |                                                    | 422.5                      | 2490                              |                                           |       |       |       |
|             | 8.425               |                                           |                                                    | 585.0                      | 2496                              |                                           |       |       |       |
|             | 8.423               |                                           |                                                    | 622.5                      | 2496                              |                                           |       |       |       |

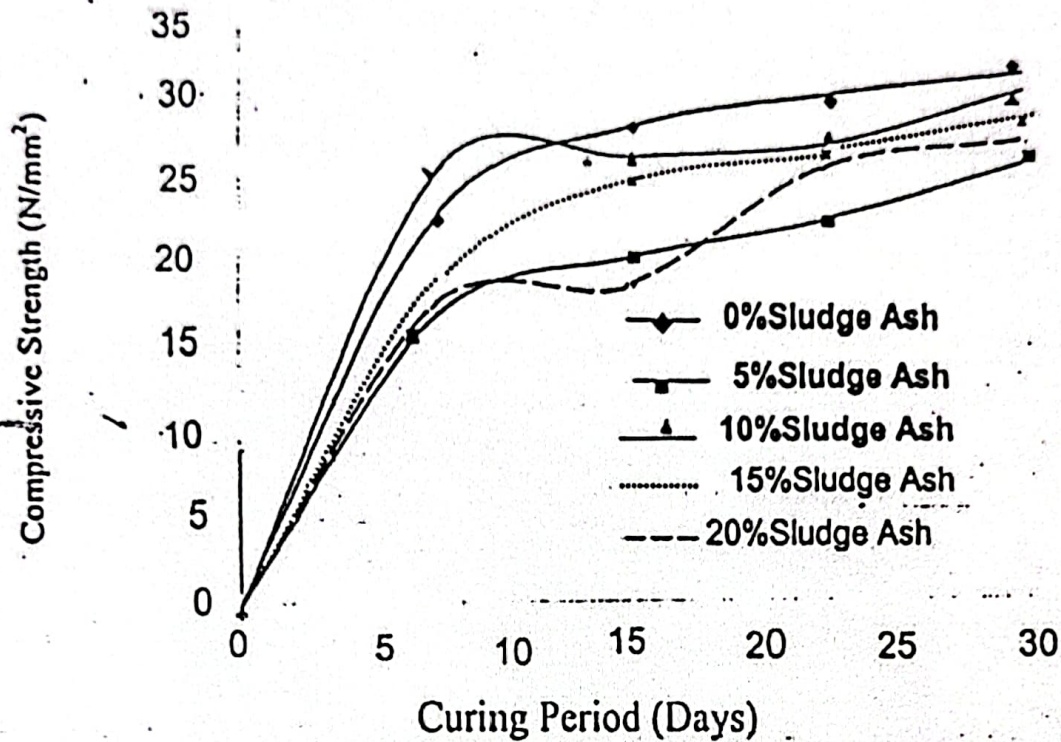


Fig. 2 Compressive strength- curing period relationship

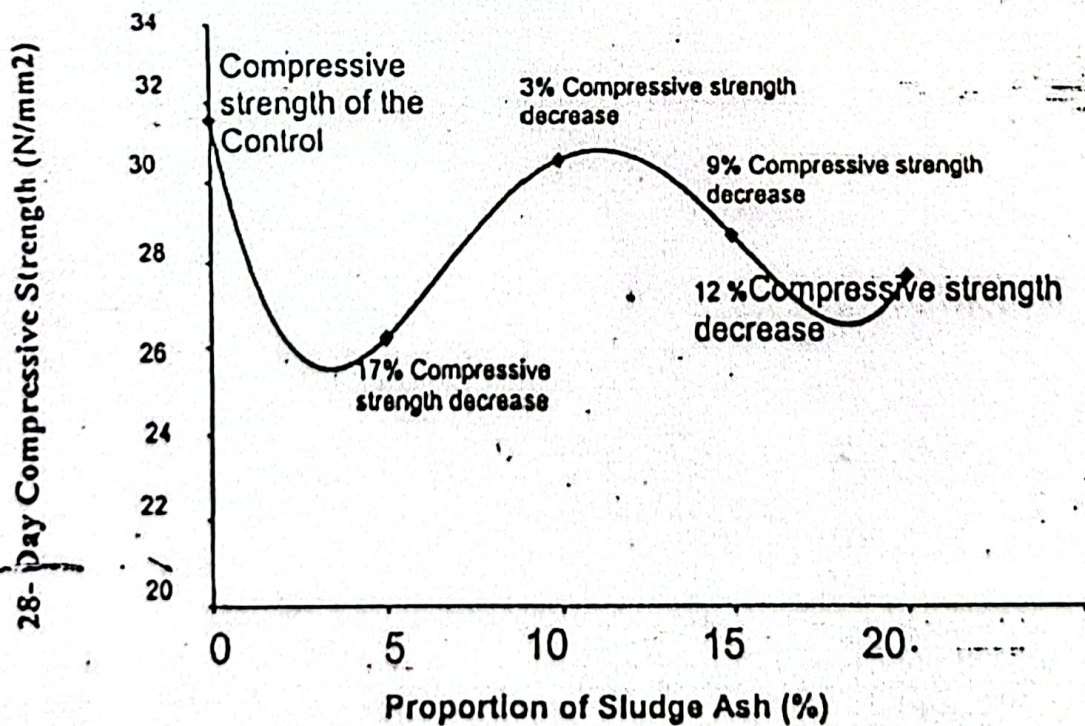


Fig. 3. 28- Day Compressive Strength of Sludge Ash Concretes

## 4. Conclusion

The dosage of sludge ash and curing period are obviously important parameters influencing compressive strength of sludge ash concrete. Generally, as the percentage of sludge ash increases from 0% to 20%, the 28<sup>th</sup> day compressive strength decreases. 10% sludge ash concrete has the fastest initial strength development at 7 days (1.12% higher than normal concrete) and optimum compressive strength of 30.56 N/mm<sup>2</sup> (97% of the control) at 28 days. It is evident therefore that sludge ash has pozzolanic properties and maximum chemical reaction between sludge ash and cement was obtained at 10% sludge ash concrete. However, all the compressive strength values obtained from the tests are well above the requirement of 20N/mm<sup>2</sup> for normal strength concrete (CP110, 1972), hence, 5% - 20% sludge ash concrete can be used as a substitute for normal strength concrete.

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