SUSTAINABILITY PERFORMANCE OF PLANTAIN LEAF ASH AND THE COMPRESSIVE STRENGTH OF CONCRETE

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ABSTRACT: Agricultural activities include planting, crop production, harvesting etc, after which the plants sheds off its leaves. This is as a result of change in season or expiration of the plant. The leaves at this point become wastes that make the farm unattractive and needs to be disposed. In disposing these wastes, most time is by open burning which causes environmental pollution and as well global warming. In reducing the release of gaseous substances from burning to the atmosphere, these wastes can be converted to supplementary materials (pozzolans) that are eco-friendly and useful to man, example Plantain Leaf Ash (PLA). These are products of agricultural wastes gotten from burning plantain leaves. The use of PLA will reduce environmental pollution, global warming and high cost of cementitious materials and it is readily available. The increase in human population has consequently led to need for increase in provision of infrastructures like buildings, roads, etc which has technically impacted on the construction industry leading to increase in use of concrete. The overall cost of concrete production depends on the availability and cost of its constituent’s materials and cement remains the most expensive of them. Consequent upon this is the trend towards sourcing for locally available and eco-friendly materials (PLA) that can replace cement in concrete production either partially or total. Materials used in this research include; Ordinary Portland cement, River Sand, Crushed Coarse Aggregates, PLA and Water. This paper showcased the usability of PLA as partial replacement of cement in concrete production. The PLA used was gotten from burning plantain leaves in an incinerator. The ashes passing sieve size 600um were used for this work. There was no further processing of the PLA like grinding. This is to keep the manufacturing process simple. Tests like particle size distribution, specific gravity, etc were performed on the aggregates and concrete grade of 25N/mm² was used. With data gotten from the aggregate tests, design mix of 1:2:3 with w/c of 0.59 was computed and used to cast the concrete samples. Four different sample mixes were made which include; 0% (control sample), 5%, 10%, 15% partial cement replacements with the PLA. They were casted for the 7 days, 14, 21, 28, 56 and 75 days compressive strength. A total of 72 concrete cubes were cast using cube mould of 150mm x 150mm x 150mm. Three samples each of the mixes were crushed at the required age and the average data value computed and properly recorded. The investigation showed that the four concrete mixes attained the required strength as it ages. The normal concrete (mix 1) gained strength faster initially but the PLA concrete samples gained appreciable strength from the 7 to the 28 days age. A Mathematical model was developed to predict the compressive strength of concrete at varying crushing age and PLA/cement percentage replacement. The model sufficiently predicted the experimental data with an average correlation coefficient of 0.98. The result gave a strength that is very much comparable and sustainable at these percentage replacements. Using these PLA replacements in concrete, there would be significant impact on the structures construction cost and the concrete strength comfortably attained. Though the fineness of the PLA does not match that of cement as result of the production process, yet it gave a strength that is very much commendable at these percentage replacements thus it is recommended for use in concrete production.

Key words: Concrete, Pozzolans, Compressive strength, Eco-friendly, Global warming.

1. INTRODUCTION

Concrete is a material widely used in construction of both low and high rise buildings as well as for special purposes. The tremendous increase in building and civil engineering works necessitated by need for provision of shelter and infrastructures for increasing population has consequently led to the corresponding increase in the use of concrete. The conventional concreting materials have always been; cement, sand, coarse aggregate and their prices are continuously on the increase. The search for replacement of the conventional materials with locally sourced materials is on the increase. These local materials may be wastes from agricultural products. Concrete is a compound of granular inert materials held together by the action of cement (binder) and water (Neville, 2010). The inert materials which include fine and coarse aggregates show variation in abundance from...
place to place. Cement is widely noted to be the most expensive constituent of concrete and its high cost has been due to both the limited raw materials and the sophisticated industrial process undergone during manufacturing (Sumaila and Job, 1999), factors in its availability. Consequent upon this, the cost of construction is very high leading to researches on the possible use of locally available materials to either partially or fully replace the cement which is the conventional binder.

The use of alternative materials in construction favours not only the correct composition but also provide technically feasible solutions to technical analysis. The use of these materials is intended to obtain quality, properties and satisfactory characteristics. Over the past recent years, concrete has moved from its conventional nature to a customised material consisting of new constituents to meet the specific needs of the construction industry. The ever growing use of concrete in special construction works and often closely spaced reinforcing bars have made it very important to produce concrete that ensures proper filling ability, good structural performance and adequate durability and sustainability (Shah et al, 2014). Many countries have large supply of these local materials for example agricultural by-products which they can harness as pozzolans and abundance availability. Some researchers have investigated some agricultural by-products like rice husk ash, bamboo leaf ash, sugar cane straw ash, corn cob ash, groundnut shell ash etc as partial replacements of cement in concrete and found out their potentialities as good pozzolans and good prospects in concrete quality (Malhotra and Mehta, 2004; Dwivedia et al, 2006; Cordeiro et al, 2009; Nimityongskul and Daladar, 1995; Hernandez et al, 1998; Minddendorf et al, 2003).

Among the various construction wastes are the pozzolanic materials which are characterised by possessing reactive activity when in contact with moisture form compounds of cement (Marceau et al, 2002). The pozzollanic material used here is the Plantain Leaf Ash (PLA), a local additive and agricultural by-product from plantain. The processes involved in disposing some agricultural wastes are usually by open burning or by putting into landfill. These are harmful for our environment as it can lead to air or land pollution, global warming or climate change (Girisha et al, 2012). These agricultural wastes can be used to enhance the strength of concrete as well bringing down the cost of concrete production by reducing the quantity of cement used hence the main aim of this experimentation to show the sustainability of PLA on the compressive strength of concrete.

2. POZOLLANS

Pozzollans are siliceous and aluminous materials which in itself possess little or no cementitious value but which will in finely divided form in the presence of moisture, reacts chemically with calcium hydroxide at ordinary temperature to from compounds possessing cementitious properties. These pozzollans can be obtained from natural occurring minerals, industrial and agricultural by-products. Calcium hydroxide \([\text{Ca(OH)}_2]\) is among the products of cement hydration which influences the deterioration of cement composites. When a pozzolan is mixed with Portland cement it reacts with the lime to produce additional calcium-silicate-hydrate \((\text{C-S-H})\), which is the main cementing compound. Hence the pozzolan reduces the quantity of lime and increases the quantity of C-S-H. This action enhances the cement quality if a pozzolan material is mixed in suitable quantity with Portland cement (Padney et al., 2003, Ettu et al., 2013).

The assessment of the pozzolanic activity of cement replacement materials is increasingly important because of the need for more sustainable cementitious products. The increasing interests in using pozzollanas are because of:

1. It reduces environmental pollution by helping in climate mitigation.
2. It reduces the cost of construction when used with cement.
3. It reduces the carbondioxide emitted to the air/environment.
4. It improves the physical properties of the resulting concrete thereby achieving sustainability
5. It will definitely create empowerment to the locals that works in the farms.
6. It will increase agricultural farming as well.

3. MATERIALS AND METHODS

1. Ordinary Portland Cement of IBETO brand obtained from the market.
2. Fine Aggregate from Nyama River in Enugu State Nigeria.
   Its specific gravity is 2.67 and finess modulus of 2.250.
3. Crushed Coarse Aggregate from Ishiagu Abakiliki, Ebonyi State Nigeria with maximum aggregate size of 10mm well graded and has specific gravity of 2.8.
4. Plantain Leaf Ash. Plantain leaves (old and dry leaves) were gotten from Nsukka district of Enugu State Nigeria. It was further sun-dried for about 12 hours to make sure it’s properly dried. The leaves were subjected to burning and calcined into ash in a make-up container at temperature below 650°C. After it was allowed to cool for 24 hours and the ash collected. The ash was then sieved using the 600um sieve size and the ashes that passed through this sieve size were used for this research and those retained on the sieve were discarded. No further grinding or special treatment was applied to improve the ash quality and to enhance its pozzolanicity as this research wants to utilise simple processes that can be easily applied by local community dwellers. A simple form of pozzollonicity test was carried out by chemical titration with a solution of Ca(OH)2.

5. Good water supply free from organic impurities.

The tests performed on these materials include; particle size distribution for the aggregates, specific gravity, slump/workability test, compressive strength etc. Design parameters gotten from aggregates tests were used in the mix design that gave a ratio of 1:2:3 and w/c of 0.59 used. Mixing was done manually on a smooth concrete pavement and homogeneity of the mix was ensured. The workability of the fresh concrete was measured by slump according to the percentage replacement.

Four different concrete sample mixes were made which include; 0% (control sample), 5%, 10%, 15% partial cement replacements with the PLA and were casted for the 7 days, 14, 21, 28, 56 and 75 days compressive strength. A total of 72 concrete cubes were cast using cube mould of 150mm x 150mm x 150mm. After 24 hrs of casting the concrete, it was de-moulded and immersed in the curing tank. Three concrete cubes for each percentage replacement of OPC with PLA and the control were crushed to obtain their compressive strengths at 7, 14, 21, 28, 56, and 75 days of curing. Average values of concrete compressive strengths and densities for the various curing ages and percentages of OPC replacement with PLA were obtained and presented in tables and graphs.

4. POZZOLLANICITY TEST

A pozzolanic material is capable of binding calcium hydroxide in the presence of water. This chemical measurement represents a way of evaluating pozzolanic materials. This is by directly measuring the amount of calcium hydroxide a pozzolan consumes over time.

The plantain leaf ash (PLA) has specific gravity of 1.80, and fineness modulus of 1.35. A simple form of pozzolanicity test was carried out for the PLA. The test was done by mixing a given mass of the ash with a given volume of Calcium hydroxide solution [Ca(OH)2] of known concentration and titrating samples of the mixture against hydrochloric acid solution of known concentration at time intervals of 30, 60, 90, and 120 minutes using phenolphthalein as indicator at normal temperature. The titre value reduced with time, confirming the ash as a pozzolan that fixed more of the calcium hydroxide thereby reducing the alkalinity of the mixture.

5. OBSERVATION AND DISCUSSION OF RESULT

The relationship between the slump and the percentage PLA replacement is shown in Table 1 and Fig.1. The water absorption of cement is more than that of PLA and consequently, increase in the percentage replacement with cement, increases the amount of free water available for mixing and hence workability increases.

Table 1: Slump result

| % PL Ash | 0% | 5% | 10% | 15% |
|----------|----|----|-----|-----|
| Slump (mm) | 38 | 40 | 42 | 44 |

Fig.1. Slump with the various PLA percentages.
Table 2: Pozzollanicity test data

| Time (mins) | Titre Values (mol/dm$^3$) |
|------------|---------------------------|
| 30         | 0.240                     |
| 60         | 0.224                     |
| 90         | 0.113                     |
| 120        | 0.102                     |

Fig. 2: Graph showing reduction of alkalinity of the mixture with time.

Table 3: Loads of the different mix according to age

| Age (days) | 7  | 14 | 21 | 28 | 56 | 75 |
|------------|----|----|----|----|----|----|
| % PL Ash;  |    |    |    |    |    |    |
| 0%         | 463.50 | 480.00 | 637.10 | 795.18 | 815.25 | 830.32 |
| 5%         | 318.25 | 316.50 | 429.30 | 484.90 | 556.50 | 746.60 |
| 10%        | 294.18 | 383.90 | 404.20 | 476.44 | 538.45 | 625.61 |
| 15%        | 294.00 | 374.37 | 430.90 | 476.80 | 533.93 | 593.86 |

Table 4: Concrete strengths of the different mix as it ages.

| Age (days) | 7  | 14  | 21  | 28  | 56  | 75  |
|------------|----|-----|-----|-----|-----|-----|
| % PL Ash;  |    |     |     |     |     |     |
| 0%         | 20.50 | 21.3 | 28.34 | 35.20 | 36.10 | 36.78 |
| 5%         | 14.14 | 14.06 | 18.84 | 21.50 | 24.60 | 33.18 |
| 10%        | 13.30 | 17.17 | 18.19 | 21.30 | 24.02 | 27.62 |
| 15%        | 13.0 | 16.60 | 19.01 | 21.16 | 23.73 | 26.17 |
The Plantain leaf Ash (PLA) was burned in a make-up container. Ash passing sieve 600um was used. The Plantain Leaf Ash (PLA) used was much coarser than Ordinary Portland Cement by physical observation and feeling as there was no further grinding to finer particles. The pozzolanicity test confirmed PLA as a pozzolan since it fixed some quantities of lime over time, thereby reducing the alkalinity of the mixture as reflected in the smaller titre value over time as in Table 2 and Fig.2.

The crushing load and compressive strengths of the control concrete and PLA replacements concrete are shown in tables 3 and 4 respectively. The results showed that the compressive strength values of the control concrete increased steadily as the concrete ages. At 7 to 75 days age, the concrete compressive strength increased from 20.50N/mm² to 36.78N/mm², though the concrete strength has gradual increase after 28 days. The PLA replacement concrete compressive strength consistently decreases with increase in percentage replacement. The compressive strength values are much lower than the control values for all PLA percentage replacements. The results show that the strength of the control concrete (0% PLA) increased steeply with age until about 28 days after which the strength increases much more slowly such that the strength at 75 days is not much greater than the strength at 56 days as in Fig.3.

The investigation showed that the four concrete mixes attained the required strength of 25N/mm² as it ages in Fig.3. The normal concrete (mix 1) gained strength faster initially but the PLA concrete samples gained appreciable strength from the 7 to the 28 days age. The initial low strength gain of PLA concrete can be attributed to the low rate of pozzolanic reaction at those ages. The silica from pozzolans reacts with lime produced as by-product of hydration of OPC to form additional calcium-silicate-hydrate (C-S-H) that increases the binder efficiency and the corresponding strength values at later days of curing.

The variation in strength with age for the PLA concrete is different from that of the control as it continues to attain much higher strength as the concrete age increases. The PLA concrete compressive strength picks up more slowly up to 21 days, after which it begins to increase rapidly at 75 days.

![Graph of Compressive Strength of the Concrete Mixes.](image)

**Fig.3: Graph of Compressive Strength of the Concrete Mixes.**

### 6. MATHEMATICAL MODEL FOR COMPRESSIVE STRENGTH OF CEMENT-PLA PERCENTAGE REPLACEMENT

The mathematical model for predicting the compressive strength of concrete from cement-PLA percentage replacement as it ages is presented here. The general mathematical equation for the compressive strength of the concrete is given as:

\[
F = 18.54 \log (1.82\theta) e^{-0.024\lambda} 
\]

Where:

- \( F \) = Average Compressive Strength (N/mm²)
- \( \theta \) = Crushing age (days)
- \( \lambda \) = % replacement

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5
The individual mathematical equations according to the concrete ages are:

\[ F_7 = 18.54 e^{-0.02855\lambda} \]  
\[ F_{14} = 18.56 e^{-0.01096\lambda} \]  
\[ F_{21} = 24.94 e^{-0.03466\lambda} \]  
\[ F_{28} = 30.43 e^{-0.03072\lambda} \]  
\[ F_{56} = 32.33 e^{-0.02565\lambda} \]  
\[ F_{75} = 36.71 e^{-0.02409\lambda} \]

The values of the compressive strength of concrete using the model equations (2) to (7) are presented in Table 5 and its graphical representation in Fig. 5. The laboratory and model results according to their ages are shown in Table 6.

### Table 5: Result of Compressive Strength from Model.

| Age (days) | 7   | 14  | 21  | 28  | 56  | 75  |
|------------|-----|-----|-----|-----|-----|-----|
| % PL Ash;  |     |     |     |     |     |     |
| 0%         | 18.54 | 18.56 | 24.94 | 30.43 | 32.33 | 36.71 |
| 5%         | 16.07 | 17.57 | 22.05 | 26.10 | 28.44 | 32.54 |
| 10%        | 13.94 | 16.63 | 19.48 | 22.38 | 25.02 | 28.85 |
| 15%        | 12.08 | 15.75 | 17.23 | 19.19 | 22.00 | 25.60 |

Fig. 4: Compressive Strength Result of the Model
Table 6: showing the laboratory and model strength values.

| % PL Ash | Age (days) | Lab     | Model  |
|----------|-----------|---------|--------|
| 0%       | 7         | 20.50   | 18.54  |
|          | 14        | 21.30   | 18.56  |
|          | 21        | 28.34   | 24.94  |
|          | 28        | 35.20   | 30.43  |
|          | 56        | 36.10   | 32.33  |
|          | 75        | 36.78   | 36.71  |
| 5%       | Lab       | 14.14   | 16.07  |
|          | 14        | 14.06   | 17.57  |
|          | 21        | 18.84   | 22.05  |
|          | 28        | 21.50   | 26.10  |
|          | 56        | 24.60   | 28.44  |
|          | 75        | 33.18   | 32.54  |
| 10%      | Lab       | 13.30   | 13.94  |
|          | 14        | 17.17   | 16.63  |
|          | 21        | 18.19   | 19.48  |
|          | 28        | 21.30   | 22.38  |
|          | 56        | 24.02   | 25.02  |
|          | 75        | 27.62   | 28.85  |
| 15%      | Lab       | 13.00   | 12.08  |
|          | 16        | 16.60   | 15.75  |
|          | 21        | 19.01   | 17.23  |
|          | 28        | 21.16   | 19.19  |
|          | 56        | 23.73   | 22.00  |
|          | 75        | 26.17   | 25.60  |

Table 7: Correlation result of the concrete strength

| Crushing Age (days) | Correlation Coefficient |
|---------------------|-------------------------|
| 7                   | 0.98                    |
| 14                  | 0.97                    |
| 21                  | 0.98                    |
| 28                  | 0.97                    |
| 56                  | 0.98                    |
| 75                  | 0.99                    |
| Average             | 0.98                    |

From the results of the compressive strengths obtained from the model equations, when compared to the laboratory values are near as in table 6. This was clearly observed in Fig.3 and Fig.4 which showed the sustainability of the PLA/Cement concrete for use. The correlation coefficient values of the analysis used to check the relationship between two results were very good as in table 7.

7. CONCLUSION

The strength of PLA concrete increased more than the control concrete as it aged. Therefore in civil engineering works, PLA concrete can be used for high strength requirements at curing ages greater than 28 days where early strength is not a major requirement. The obtained compressive strength from this material can be improved on when the PLA ash is much finer. Ashes gotten by using sieve sizes of 300um, 150um which will give much finer ash materials will give better results. Also processing the agricultural by-product (Plantain Leaves) in a well conditioned process will also give a more improved concrete.

The developed mathematical model sufficiently predicted the experimental data with an average correlation coefficient of 0.98. Using these PLA replacements in concrete would give significant impact on the structures construction cost and the concrete strength comfortably attained. Though the fineness of the PLA does not match that of cement as result of the production process, yet it gave a strength that is very much comparable at these percentage replacements thus it is recommended for use.
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