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EFFECT OF BANANA LEAVE ASH ON THE MICRO, PHYSICAL, AND MECHANICAL PROPERTIES OF CEMENT PASTE AND CONCRETE

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ABSTRACT

Concrete is most widely used construction material due to its good compressive strength and durability. The increasing demand in cement as constituent of concrete has inspired researchers in both developed and developing countries around the world to explore and consider alternative materials as partial replacement of cement both in concrete and in mortar. Banana Leaves Ash (BLA) was used as partial replacement of cement in concrete. Microanalysis inform of Fourier Transform Infrared Spectroscopy (FTIR) and X-Ray Diffraction Analysis (XRD) was carried out on the powdered BLA and

Introduction

BACKGROUND OF THE STUDY

Building materials accounted for two-third of the building production costs (Ayangade, Olusola, Ikpo, Ata, 2012). Therefore a reduction in its costs would definitely decrease the overall costs of the construction project. Ordinary Portland cement is recognized as a major construction material throughout the world. The continued expansion of global economies leads to intensification in construction activities and rising demand in construction materials, propelled by the continued increase in cement consumption, the worldwide production of cement is projected to grow to over 5 billion tons globally by 2030 (An, 2016).

Portland cement has high-energy consumptions and emissions (greenhouse gas and particulates) associated with its manufacture, which is reduced or conserved when amount used in concrete is reduced (Chindaprasirt, Rukson, Sirivivatnanom, 2008). According to Kamau, Ahmed, Hirst, Kangwa (2016), the heavy energy-intensive processes involved in cement production contribute to about 7 % to 10 % of the overall worldwide emissions. While according to Reddy, Ashalatha, Madhuri (2015) it is about 5 % to 8 % of global CO_2 emissions and are economically expensive with potential adverse environmental implications. This environmental problem will most likely be increased due to exponential demand of Portland cement.

The increasing demand in cement and its exponential increase in price, has inspired researchers in both developed and developing countries to explore alternative materials as partial replacement

the lateritic soil and it oxide composition using X-Ray Fluorescence (XRF). The FTIR of the hydrated banana leave ash and cement was also carried out after 28 days of curing. Concrete cubes were produced using various replacement levels of 0, 5, 10, 15 and 20 percent of Ordinary Portland cement (OPC) with BLA. A total of 45 cubes of size 100 x 100 x 100 mm were produced and cured by immersing in water for 7, 14, and 28 days respectively. Properties such as density, aggregate impact value, aggregate crushing value, standard consistency, sieve analysis, specific gravity, soundness, slump test, and compressive strength were determined. The XRD microanalysis test shows the presence of calcite, quartz, Sylvite and Magantite at 56 %, 25 %, 13 % and 6 %. XRF chemical composition results shows BLA of SiO_2 at 27.37 %, Al_2O_3 of 2.21 % and Fe_2O_3 of 1.41 %. This compounds it is pozzolanic. BLA was acting as a retarder as it delays the initial and final setting time of OPC Grade 42.5 at 15 and 20%. All other preliminary test met the requirement. The target grade of 15 N/mm^2 was achieved at replacement of up to 5 % for the compressive strength.

Keywords: Banana Leave Ash, Fourier Transform Infrared Spectroscopy (FTIR), Ray Diffraction Analysis (XRD), X-Ray Fluorescence (XRF), Compressive strength

of cement. Researchers all over the world such as Bajrang, Vijay and Pramod (2020); Musthafa *et al.* (2019); Afolayan, Oriola, Sani (2018); Olutaiwo and Lawal (2017) today focused on ways of utilizing either industrial by-products or agricultural waste as a materials source of raw materials. The ash produced from various types of agricultural waste serves as pozzolans and can therefore be used effectively as a partial replacement of cement.

Supplementary cementitious materials are added to concrete as part of the total cementitious system. They may be used in addition to or as a partial replacement of Portland cement or blended cement in concrete, depending on the properties of the materials and the desired effect on concrete. Supplementary cementitious materials are used to improve a particular concrete property, such as resistance to alkali-aggregate reactivity.

Pozzolans are fine materials that contain silica and/or alumina. However, pozzolanic material does not exhibit any cementation properties of their own except in the presence of calcium oxide (CaO) or calcium hydroxide ($Ca(OH)_2$) (Anwar and Gaweesh, 2000). Banana leaf is an agricultural waste that has potential to replace cement. When this waste is burned under controlled conditions, it gives ash having amorphous silica, which has a pozzolanic reaction that usually occurs in Portland cement. Some researchers (Bajrang *et al* (2020), Musthafa *et al.* (2019); Afolayan *et al.* (2018); Olutaiwo and Lawal (2017)), evaluated the presence of pozzolanic activity in the deriving ash of banana leaves. This ash has a potential to improve the performance of the concrete. This study therefore deals with effect of banana leave ash on the micro, physical, and mechanical properties of cement paste and concrete.

Fourier Transform Infrared Spectroscopy (FTIR)

This technique is useful for analyzing the chemical composition of smaller particles, typically 10 -50 microns, as well as larger areas on the surface (RTI laboratories, 2021).

X-Ray Fluorescence (XRF) is a non-destructive analytical technique used to determine the elemental composition of materials. XRF analyzer determine the chemistry of a sample by measuring the fluorescent (or secondary) x-ray emitted from a sample when it is excited by a primary x-ray source (Karl and Andy, 2020).

X-Ray Diffraction Analysis (XRD)

X-ray diffraction analysis (XRD) is a technique used in materials science to determine the crystallographic structure of a material with incident x-ray and then measuring the intensities and scattering angle of the x-ray that leaves the material (Technical knowledge, 2021)

MATERIALS AND METHODS

Material

River sand was used as the fine aggregate while crushed granite of 20 mm nominal size was used as the coarse aggregate. Ordinary Portalnd cement of grade 42.5 in accordance to BS 12 (1996). The banana leave used was obtained from a Banana Plantation in Sabon Gari Local Government Area Zaria, Kaduna State Nigeria.

Sample Preparation

Banana leaves were sun dried for a period of 5 days as most of the leaves used were dried, since it was during the harmathan season. Open air burning was carried out in a control environment. The residual ash of the leaves with stem were sealed up in plastic bags and transported to the chemical engineering department of Ahmadu Bello University for calcination at 600 °C to obtain in an amorphous form (Plate I). The Banana Ash was then sieved through a BS No. 200 sieve (75 µ mm) to get it in fine powdered form. The BLA was then used in replacing cement partially with a proportions of 5 %, 10 %, 15 % and 20 %, in a concrete mixed ratio of 1:2:4 which is the mixed grade of M15. The experimental work was carried out at the concrete Laboratory, Civil Engineering Department, Ahmadu Bello University Zaria. Banana Leaf Ash passing the 75-micron sieve was prepared for FTIR (the microanalysis of the powdered banana leave ash and the hydrated mix of the cement and BLA at 28 days), XRF and XRD. Crushed samples of some selected mixes were taken to the Multi-user Laboratory, Chemistry Department for the FTIR test.

Methodology

Micro analysis and Oxide Composition

FTIR was conducted to identify the compounds in the sample through chemical analysis. Crushed samples of some selected mixes were taken to the Multi-user Laboratory, Chemistry Department for the FTIR test using the transmittance approach with an Agilent Cary 630 FTIR Spectrometer using the diffuse reflectance procedure (DRIFTS). The XRD of the Banana leaves (BLA) was carried out at National Geoscience Research Laboratories, Nigeria Geological survey agency in Kaduna. While the X-Ray Flourescence (XRF) technique (chemical analysis) of Banana Leaf Ash was carried out at the Department of Chemical Engineering Ahmadu Bello University Zaria using the Thermo Fisher Model ARL 9900.

Preliminary tests

The particle size distribution of the aggregates were prepared, measured and checked for conformity respectively satisfying BS EN 12620, BS EN 933-1 and BS 882 (1992). ACV (Aggregate

Crushing Value) and AIV (Aggregate Impact Value) respectively to BS 812-110 (1990) and BS 812-112 (1990). The silt and clay content test was performed par Clause 7.2.5 of BS 812 -1 (1975). Test on cement inform of consistency test determined using the Vicat Apparatus according to EN196-3:2005 standard for OPC Grade 42.5 with BLA. The slump test was performed on the fresh concrete mix in accordance with BS EN 12350-2 (2009) as shown in Plate II.

Compressive Strength Test

This was performed on the hardened concrete in accordance with BS EN 12390-3 (2009) (Plate III) at the end of 7th, 14th and 28th day of curing the cubes Cube specimens were tested for compressive strength under compression testing machine (Plate IV). Rate of loading was maintained at 400kg/sq.cm/min. the average of 3 cubes was taken as compressive strength.

RESULTS AND DISCUSSION

X-ray diffraction (XRD) of the Banana Leave Ash

The results of Microanalysis by X-ray diffraction for the BLA is shown in Fig. 1. Calcite, quartz, sylvite and Magnetite were found in the resulting banana leave ash to be 56, 25, 13 and 6 % respectively.

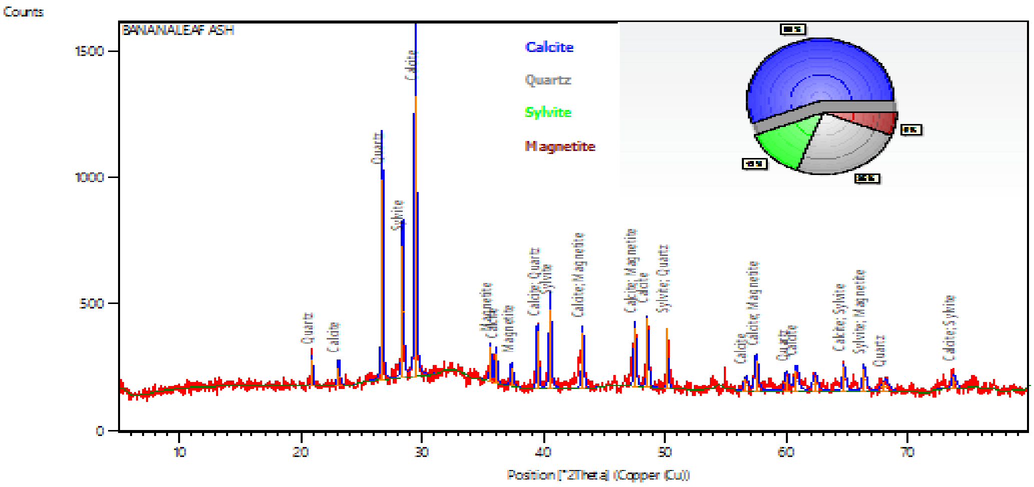

Fig 1: Diffraction of rays X of the raw banana leaf ash

However, according to Rodrygo, Jeanette and Dos (2011) the presence of calcites and quartz reduces the reactivity of the pozzolanic material. Rodrygo *et al.* (2011) explains that, the crystalline form most likely probably the calcite was obtained due to burning and the slow cooling of the ashes of banana leaf inside the oven at temperatures of 80 ° C after burning until its withdrawal.

Fourier Transform Infrared Spectroscopy (FT-IR) of the Banana Ash and Cement

The FT-IR spectra of the powdered banana leave ash is presented in Fig. 2. The presence of iron, aluminum, and silicon oxides or hydroxides is confirmed by studying spectral peaks. The bands at 3,365.8 cm^{-1} signify the presence of OH group of Si, Al. The band at 1796.6 cm^{-1} represents the presence of inner layer water molecules. The bands at 1,028.7, 928.1, and 711.9 cm^{-1} could be due to the presence of CO=O=CO anhydride.

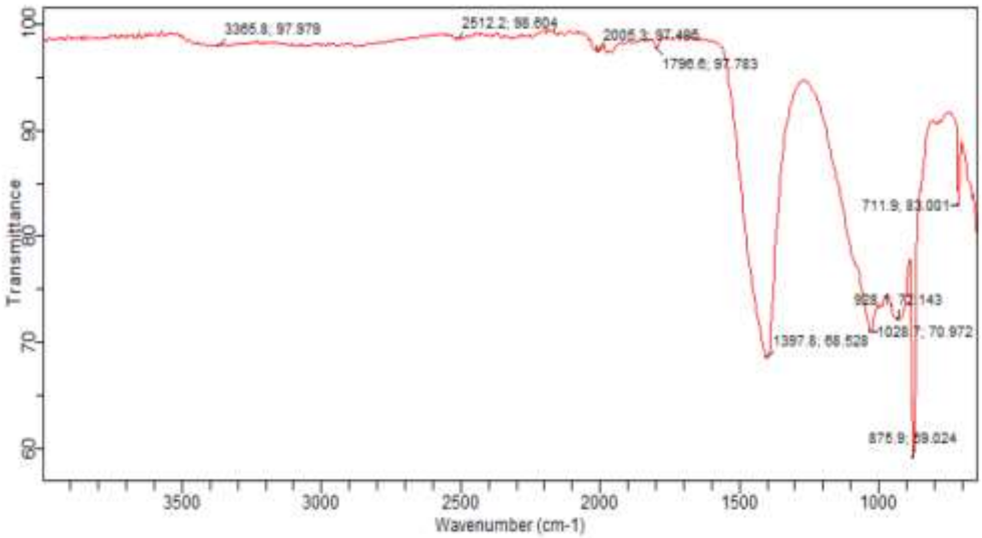

Fig 2: FTIR spectrum of banana leaf Ash with cement

The FT-IR spectra of the hardened cement paste containing 5 % BLA is shown in Fig. 3. The presence of iron, aluminum, and silicon oxides or hydroxides gets confirmed by studying spectral peaks. The bands at 3753.4 and 3,380.7 cm^{-1} signify the presence of OH group of Si, Al. the band of 2885.0 and 2821.6 signify the presence of C=H alkyne. The band at 1,654.9 cm^{-1} represents the presence of inner layer water molecules. The bands at 1,982.9, 1830.1, and 1796.6 cm^{-1} are due to the presence of N=C=S isthiocyanate and conjugate acid.

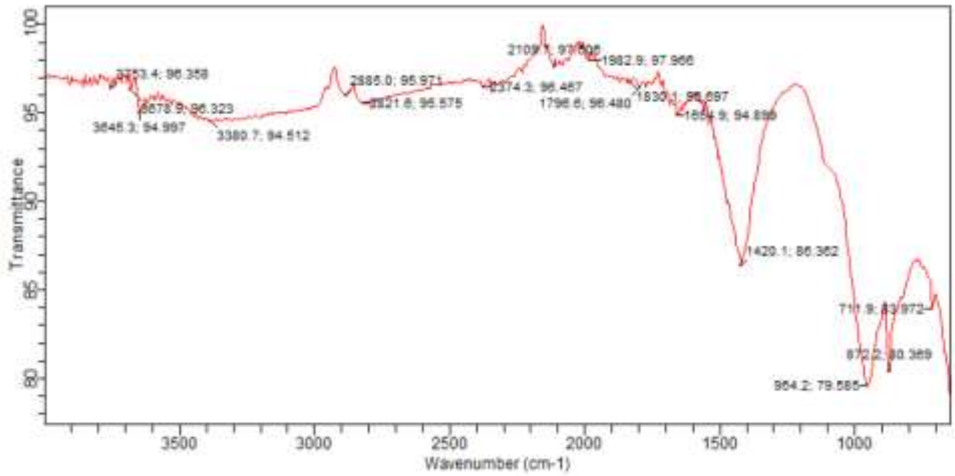

Fig 3: FTIR spectrum of 5% banana leaf Ash with cement

The FT-IR spectra of 10 % banana leave ash is shown in Fig 4. The presence of iron, aluminum, and silicon oxides or hydroxides was confirmed by studying spectral peaks. The bands at 3641.6 and 3391.9 cm^{-1} signify the presence of OH group of Si, Al. The band at 1,640.16 cm^{-1} represents the presence of inner layer water molecules. The bands at 711.9 cm^{-1} signify the presence of Hematite (Fe–O bond stretching).

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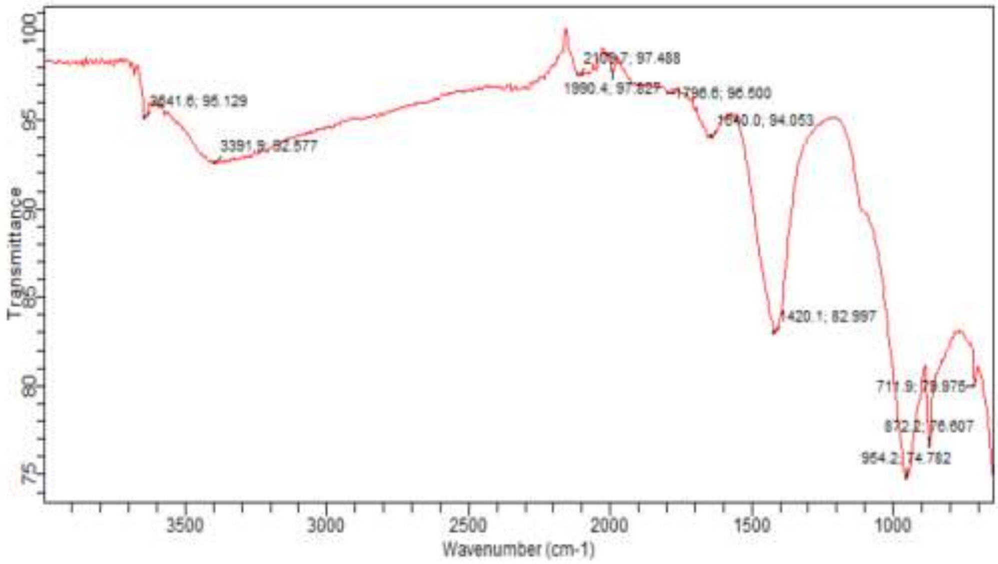

Fig. 4: FTIR spectrum of 10 % banana leaf Ash with cement

Oxide Composition of Cement and Banana Leave Ash

The oxide composition obtained from the Chemical Analysis of Banana Leave Ash and cement is presented in Table 1. The oxide composition of BLA shows that it contains 27.37 % silica which is higher than 20.05 % (Emeka and Olufikayo, 2016) for cement and this is an important ingredient as it imparts strength to the cement due to the formation of Dicalcium and Tricalcium Silicates. The amount of silica can be characterized as relatively low as compared to other pozzolana such as Rice Husk Ash, Fly Ash, and Slag (Malhorta and Mehta, 1996) baggash (Otoko, 2014). The low silica content in BLA could be attributed to the method of burning the banana leave in which in this study, the banana leave were burnt in an uncontrolled environment. The result shows that the combined total of silicon oxide, alumina oxide, and ferrous oxide of BLA is 30.99 % and it is lower than the amount obtained by Olutaiwo and Lawal (2017) of 50.8 %, Musthafa *et al.* (2019), of 52.7 %, Kamau *et al.* (2016) of 54.1 %. This signifies that locally found BLA as used in this study is even lower than the Class C pozzolana as per the requirements of ASTM C618 in which the minimum combined total of the three major oxides ($SiO_2 + Al_2O_3 + Fe_2O_3$) of 50 % is required. This shows that it has pozzolanic compounds but lower than that recommended by the codes.

Table 1: Chemical composition for Banana Leave Ash and Cement

Chemical composition oxides	Banana Leave Ash Values (%)	Cement **(Emeka and Olufikayo, 2016).**
SiO_2	27.37	20.05
Al_2O_3	2.21	6.47
Fe_2O_3	1.41	2.79
K_2O	9.42	
P_2O_5	1.34	
SO_3	2.28	0.35
CaO	47.07	60.83
ZnO	0.061	0.51

Ag_2O	0.016	
Cl	5.28	
MgO	1.25	3.02
Na_2O		0.48
TiO_2	1.44	0.38

Preliminary Test of the Concrete Composition

The average aggregate crushing Value (ACV) obtained was 22 %. This is according BS 812-110 (1990) is excellent (0-30 %). Therefore the coarse aggregate has a lower crushing value and it will give a longer service life and has a more economical performance. The average aggregate impact Value (AIV) obtained was 17.82 %. This is according BS 812-112 (1993) is exceptionally strong. Therefore the coarse aggregate can resist any sudden impact or shock which it may be subjected to. The value obtained for the silt – clay test is 4.17 % and the permissible silt content should not be greater than 6 % which is satisfactory and can be used for any engineering works. The soundness test is presented in Table 2 and it shows a soundness of 2 mm this compared to EN 197-1 standards requirements of not more than 10 mm. All cement samples are within limits stated by EN 197-1.

Table 2: Preliminary Test of the Concrete Composition

Description	Test
Specific Gravity (coarse Aggregate) kg	2.86
Specific Gravity (Fine Aggregate) kg	2.27
Soundness test %	2
Aggregate Impact Value %	22 %
Aggregate Crushing Value %	17.82
Percentage of silt	4.17

Consistency Test

The setting time for cement with different percentages of BLA is presented in Fig. 5. From the results, it can be concluded that the initial settings and final time increased by replacement of cement with 5 %, 10%, 15 % and 20 % BLA. Initial setting time of the samples lies between 140 - 195 minutes while final setting time occurs between 195 - 200 minutes. According to EN 197-1(2000) standards requirements, initial setting time should be higher than 60 minutes. Final setting times should be less than 600 minutes according to old BS 12 (1996) requirements. However, no value is specified for Final setting time in EN 197-1(2000).

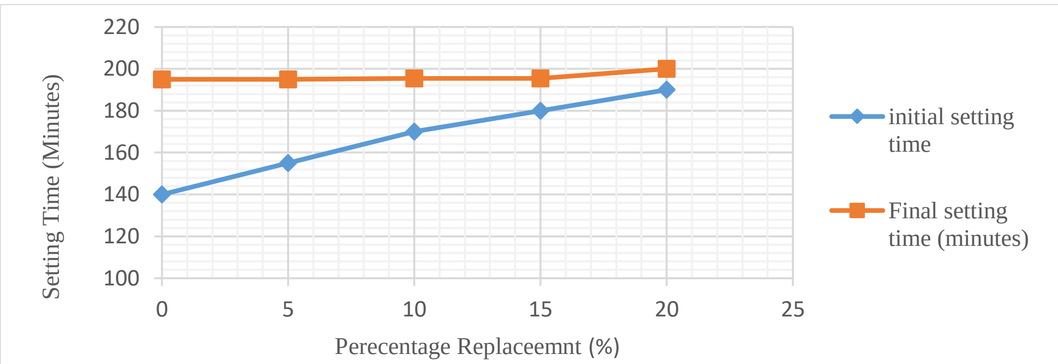

Fig. 5: Setting time at BLA replacement levels

Slump Test of the freshly made Concrete

The result of the slump test for the concrete and the BLA replacement of the cement is shown in Table 3. The slump result indicates true slump which shows that the concrete is workable.

Table 3: Concrete Slump at various BLA Replacement levels

Percentage replacement of cement with Ash	height of sample cone (cm)	height of Slump	Remark
0	30	29.91	True Slump
5	30	28.90	True Slump
10	30	29.10	True Slump
15	30	29.00	True Slump
20	30	30.00	True Slump

Compressive Strength of the BLA and Cement Concrete mix

The variation of concrete compressive strength with BLA at varying curing period is shown in Fig. 6. The general trend is that compressive strength steadily decreases with increase in the percentage of replacement of cement with BLA in the concrete. 0, 5 and 10 % at 28 days was 24.89, 22.20 and 19.21 N/mm² respectively. The decrease could be due to pozzolanic level of the BLA. However, the use of 5 % BLA replacement value up for 28 days will reduce the cost of cement in concreter.

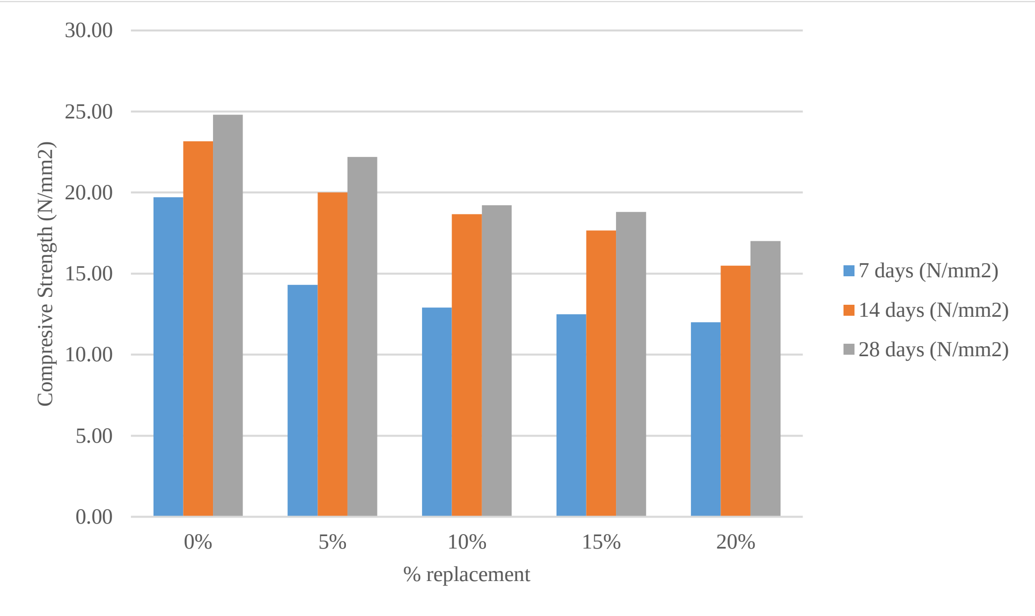

Fig. 6: Compressive Strength of the BLA and Cement Concrete mix

Conclusions

The following conclusion can be drawn:

1. Banana leave Ash was found to have SiO_2 at 27.37 %, Al_2O_3 of 2.21 and Fe_2O_3 of 1.41. It contains pozzolanic oxides but does not meet the 50 % pegged by ASTM C618. Hence, it can be termed weak pozzolan. The XRD microanalysis test shows the presence of calcite, quartz, Sylvite and Magantite at 56 %, 25 %, 13 % and 6 %

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2. The initial setting time increases as the percentage BLA replacement increases. While the final setting time remain relatively constant except for that of 15 and 20 % BLA replacement. Indicating that BLA act as a retarder.
3. Workability of the concrete mix is also not affected by the presence of BLA in the mix as it remains relatively constant from control up – to maximum replacement
4. All other preliminary test met the requirement
5. Thus, use of BLA in concrete helps to transform it from an environmental concern to a useful resource for the production of a highly effective alternative cementing material.

Recommendation

1. The usage of Banana leave ash in concrete mixes is recommended especially in tropical regions as a retarder to curtail the effect of cement flash set
2. In concrete mix, BLA can be replaced up to 5 % mix
3. Further studies can be done between 5 % and 10 %

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Plate I: Oven dried banana Ash

Plate II: Slump Test

Plate III: Casting of the Cubes

Plate IV: Compressive Strength Test