AN EVALUATION OF NIGERIAN PUMICE TUFFS AS POTENTIAL POZZOLANIC MATERIALS FOR CEMENT BLENDING.

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Abstract

This work is an evaluation of the pozzolanic characteristics of concrete containing Nigerian pumice tuffs as potential cementitious materials in cement blending and concrete mix design. Arguably. Concrete globally is a material of choice for Housing Development. But the manufacture of its main constituent, cement, consumes about 2% to 5% of globally industrial energy and about 4,880MJ and 90-1300Kwh electricity are needed to produce one ton of cement. Furthermore, cement production is responsible to the release of 5% to 10% of annual global anthropogenic carbon dioxide emissions into the atmosphere. In Nigeria, the problem of cement productions also includes soaring energy cost, poor infrastructures and transportation costs of the finish products; which cement cost in the country as one of the highest in the world. There is the need therefore for the introduction of cheaper Pozzolanic Supplementary Cementitious Materials (SCMs) in cement blending. The study evaluated the oxide composition and Loss On Ignition of four Nigeria pumice tuffs; the compressive strength of concrete containing pumice tuffs and the Strength Activity of the pumice tuffs with Portland Cement. The results of the chemical analysis indicated that the sum oxides of Silica, Alumina and Iron were 80.87%. The evaluations of the compressive strengths of concrete cubes containing 5% of the pumice tuffs materials at 28 days curing showed an increase of compressive strength from 27.02 N/mm^2 to 31.79N/mm^2. The Strength Activity Index (SAI) at 28 days of concrete containing the pumice tuffs in 5, 10,15, 20 % for the four sample were all above 75%. ASTM C 618 (2005) specifies a minimum of 75% Strength Activity Index of potential pozzolan with Portland cement at 28 days curing for its utilisation in concrete. It is thus conclusive that the Nigeria pumice deposits possess pozzolanic characteristics as potential sustainable cementitious materials for use in cement blending. It is thus recommended that the Nigerian pumice materials be used in cement blending or for partial replacement of the palliated (OPC) concrete production as sustainable cementitious materials.

Key words: Nigerian pumice, Low Cost Housing and Supplementary Cementitious Materials.

INTRODUCTION

The provision of affordable housing in Nigeria as reported by Dadu *et al* (2017) remains a challenge owing to deficiencies in infrastructures such as roads, water, power and energy distressing the Nation. Wood (2020) reported that Nigeria is facing a housing deficit of more than 17 million housing units as of April 2015. It is obvious that any extensive housing activity for the country would require enormous financial commitments because of the high costs of conventional building materials such as cements and concretes. Concrete is a material of choice for housing globally, due to its versatility and flexibility in usage and applications. Altwair and Kabir (2010) averred that though concrete is superior to other materials such as steel and timber, the production of its main constituents (cement) is of interest to mankind. This is consequent of its production flaws in terms of environmental unsustainability; and its intense power and energy demand. The country is further saddled with cement shortage and also high cost of the commodity. But, this state of affairs notwithstanding, Dadu *et al* (2015) reported that Nigeria is endowed with volcanogenic deposits volcanic subregions formations across the country; and recommended the use of pozzolanic materials of volcanogenic origin in the concrete mixes which can reduce energy consumption, limit CO_2 release into the atmosphere, and also increase concrete strengths and enhanced its durability. What is needed is the assessment of the pozzolanic activity of the potential natural pozzolans as cementitious materials for use in the concrete mixes. The study accordingly assessed the Pozzolanic Activity (strength activity) with OPC in cement blending from four Local Governing Arears from three States in Nigeria.

LITERATURE REVIEW

Housing Provision

The provision of affordable housing has continued to pose a challenge to Nigeria as Nation. This is reflected in the shortfalls housing in both in the Urban and Semi- Urban Settlements of the Country. Oluwakiyesi (2011) asserted that this deficit between 16 and 18 million units and about ₦60 trillion is needed to remedy the gap. Dadu (2012b) reported that Nigeria could only boast of only two to three dwelling units per thousand as against the United Nations recommendations of eight to ten units. Jha and Prasad (2004) stressed that that for a developing community to address its housing shortfalls, costly conventional building materials such as the PC must be replaced with cheaper alternatives. Dadu (2010c) stated that the Nigeria volcanic deposits are potential materials that would provide this window of cheaper alternative cementitious materials for housing construction; and that what is needed is the evaluation the pozzolan activity of the volcanic deposits to ascertain the pozzolanic characteristics that would provide cheaper cementitious materials for reduction of the overall cost of housing.

Cement

Cement is an essential building material. But the cement manufacture emits CO_2 into the atmosphere. These emissions, Obada *et al* (2008) are about 5% to 10% of the total greenhouse gases (GHG) releases to the atmosphere. Dadu (2011) reported that these levels of CO_2 emissions make the cement manufacturing unsustainable; and that as every ton of Portland cement produced, about CO_2 is released to the atmosphere by the burning fuels (for every 1ton of cement produced about to 1.25 tons is emitted). Thus, the potentials of volcanogenic materials such as pumice are potential materials for cement blending.

Cement Blending and Natural Pozzolanas.

American Society for Testing and Material (ASTM C 150, 2005) defined Blended Cements (BC) Portland cement containing cement mixtures of one or more SCMs. The benefits of the use of mineral admixtures such as pumice tuffs in cement blending or partial replacement of OPC in concrete mix design include, increased in compressive strength, autogenous activities and resistance to harsh weather conditions of the concrete. ASTM (C 595, 2006) recognises 5 classes of BC: Slag Cement; Portland Blast-Furnace Slag Cement; Slag - Modified Portland Cement: Portland Pozzolan Cements; and Portland- Modified Pozzolan Cement. Pumice tuffs are Natural Pozzolans products volcanic eruptions; and thus, highly rich in silica and are alternative SCM for cement blending.

The term pozzolan according to the American Concrete Institute (ACI, 2012) refers originally the deposits of volcanic material located near Pozzuoli, Italy. These deposits, consisted of volcanogenic ashes such as pumice tuffs volcanic and trachyte found near Naples and Segni, Italy. ACI (2012) stated further that pozzolans are siliceous or siliceous and alumi-nous materials that, in finely divided form, will react with calcium hydroxide to form cementitious materials. Kurtis (2002) classified the pozzolans into Natural and Artificial. The Artificial Pozzolanas are residues of waste products of Industrial Manufacturing Processes such as fly ash and rice husk ash; while the natural pozzolans are products of volcanogenic activities such as volcanic ash and pumice tuffs. Dadu (2012b) reported that Pumice Tuffs contain amorphous siliceous and aluminous materials are natural pozzolan; thus, needing only sorting and grinding and no energy inputs are required prior to utilisation.

Cement Hydration and Pozzolanic Activity.

When Cement hydrate; the chemical compounds of Dicalcium Silicate (C_2S) and Tricalcium Silicate (C_3S) produces Calcium silicate hydrate (C-S-H) and Ca(OH) plus water ($CaO.SiO_2.H_2O$+ Ca $(OH)_2$). Neville and Books (2008) asserted that addition of Pozzolana + $Ca(OH)_2$ + H_2O a gel of the cementitious substance of Calcium (a strong gel) is produced and represented thus:

$3CaO.Si0_2 – 2CaO.SiO_2 + H_2O \Rightarrow CaO.SiO_2.H_2O + Ca(OH)_2$ Eqn ---------- 1

$$C_2S/C_3S + H_2O \xrightarrow[\text{(Cement Hydration)}]{} \text{C-S-H} + CH$$

Calcium silicate hydrate (or C-S-H) is the main product of the hydration of Portland cement and is primarily responsible for the strength in cement-based materials. Addition of a pozzolan (in finely divided form) and in the presence of moisture they react with calcium hydroxide liberated from the hydration of cement to produce stable, insoluble silicate known as Calcium-Silicate-Hydrate (C-S-H) (which is a very good bonding material) as shown in Equation 2.

Pozzolanic Reaction of the Pozzolan.

This process of the gel formation as asserted by Neuwald (2004) is the Pozzolanic Reaction of the Pozzolan.

Pozzolana + $Ca(OH)_2$ + H_2O => C-S-H (a strong gel) Equation 2

$$CH + \text{silica} + H_2O \xrightarrow[\text{(Pozzolanic Reaction)}]{} \text{C-S-H}$$

Pozzolanic Reaction of the pozzolan.

The reaction in Equation 2 continues to produce additional C-S-H. This continuous production of C-S-H (reactivity of the OPC with the pozzolan) is termed the Pozzolanic Activity of the pozzolana. Dadu (2012b) reported that the Pozzolanic Reaction of the pozzolan continues with the production of additional gels of C-S-H; and that this continuous reaction of $Ca(OH)_2$ with the pozzolan is termed, the Pozzolanic Activity of the pozzolana. Dadu *et al* (2015) asserted that the Pozzolanicity of a pozzolan is the degree of the chemical reactions of the active constituents of the pozzolan at ordinary temperatures with $Ca(OH)_2$ from cement hydration, producing the cementitious compounds

EVALUATIONS OF POZZOLANA

Where a natural pozzolan is to be used with Portland cement in concrete, ASTM C 618 (2005) sets Chemical, Physical and Performance Requirements to be attained for the materials prior to their utilisation; and classified the Natural pozzolans are as Class N pozzolans. The Chemical characteristics of natural pozzolanas such as pumice as set out by ASTM C 618 (2005) are that the requirements are as follows: The sum of SiO_2 + AL_2O_3+ Fe_2O_3 = 70.0 min %; Maximum of Sulfur Trioxide, SO_3 = 4.0 max %; Moisture Content (105°C) =3.0 max% and Loss on Ignition at 950°C=10.0 max% max. The oxides composition evaluated in line with the requirements of ASTM Standards.

Oxides evaluation

The energy dispersive x-ray fluorescence (EDXRF) method according Omotola and Onojah (2009) provides one of the simplest, most accurate and economic analytical methods for the determination of the oxides of glass, ceramics and building materials; it is none-destructive and reliable for solids, liquids and powdered samples analysis. This is based on the measurement of x-rays intensities emitted by components of a target sample when excited by Silver-Potassium (Ag-K) X-rays (22.1 keV) from an annular excitation source of 25 mC_i Cadmium 109 (^{109}Cd). The system consists of the excitation source and a Silicon (Si) - Lithium (Li) semiconductor detector coupled to a computer-controlled Analog to Digital Control (ADC) Card.

Loss On Ignition

The determinations of Loss on Ignition of the samples are undertaken by the gravimetric method of analysis. The loss on ignition, report is a part of an elemental or oxide analysis of a mineral. The volatile material lost usually consists of “combined water” (hydrants and labile hydroxyl-compounds) and carbon dioxide from carbonates. It may be used as a quality test, commonly carried out for minerals such as iron ore. For example, the loss of ignition of a fly ash consists of contaminant unburnt fuel.

Compressive Strength

The production and the testing of the compressive strength of Portland Pozzolana Concrete are undertaken in accordance with the procedure set out in ASTM C 311(2005). The compressive strength and flexural strength will continue to increase for a long time. Jackson *et al* (2003) asserted that this unique characteristic of the pozzolan is one of the key reasons many great ancient structures have lasted for over two thousand years.

Strength Activity Index

Dadu (2012a) affirmed that the most important test in respect to the determination of the performance of the pozzolan is the assessment of its pozzolanic activity and these tests are carried out according to the test methods of ASTM C 109/C 109M (2002). ASTMC 618 (2005) provides for the measurement of the Pozzolanic activity index with Portland cement concrete. These are used for the evaluation of the strength of the concrete with zero pozzolan with the specific replacements at 28 days for all the samples investigated. According to Meral (2004), the pozzolanicity of the Natural pozzolan is determined by finding its strength activity index (this is the pozzolanic activity index with the Portland cement); this is the ratio of the specimen of concrete cubes' compressive strength with partial replacement of PC to control specimens prepared by 100% PC according to ASTM C 311 (2005).

The strength activity index calculated as follows:

Strength activity index (SAI) = $\frac{A}{B}100$ and be at least 75% (ASTM C 618)

Where: A - Average compressive strength of test cubes.

B - Average compressive strength of control cubes.

MATERIALS AND METHODS

The study evaluated the Oxides Composition and the Loss On Ignition (LOI) of Nigerian Pumice materials. The compressive strengths and the strength activity index of concrete containing these materials were also evaluated.

The Study Area

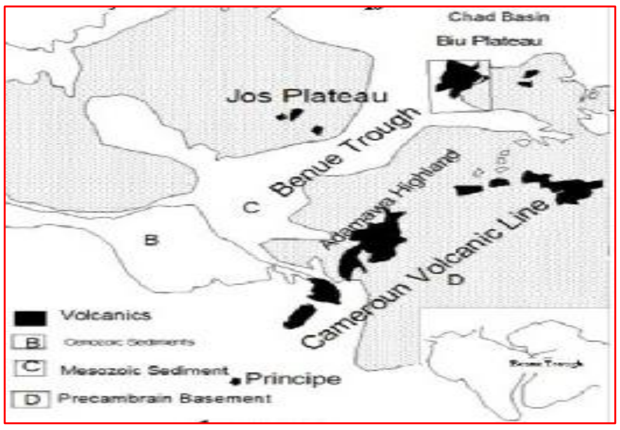

Plate 1: Benue Trough - Volcanic Rocks in Nigeria (Wright, 2005)

The study area is the Jos and Biu Plateaux (Plate 1: Benue Trough); and Southern Kaduna. Wright (2005) asserted that the geology of these areas is made up of Tertiary and Quaternary volcanic deposits volcanic lavas and ash, basalts and pumices. Dadu (2010c) reported that the Jos Plateau Volcanic Region is one of the major volcanic formations in Nigeria and made up of volcanic deposits of complex rock formations with standing land marks of many volcanic features covering over 3,000m^2 miles with outstanding land mark such as the Kwi Hill (Plate II). The Biu Plateau (Plate: I) is in the Upper Benue Valley covering overs about 5,200 km^2 and has an average elevation of 700 m from Wikipedia, the free encyclopedia. As for Kajuru, until recently not much has been researched on the volcanogenic activity of this area. The pumice tuffs were found in quantities dotting these localities.

Plate II: Kwi Conical Hill
Source; Ministry of Information Jos (2005)

Materials.

The Pumice Tuffs materials were obtained from four locations in four LGA and from three states of Nigeria as presented in Table. 1.The materials were grounded manually to powder with an agate mortar. The sieving was carried out in accordance with the ASTM C 136 (2006) until all material passed 90µm (sieve no 170). The *Dangote* cement was used for the concrete cubes. The sands used were quartzite river sands; and the crushed granite stones were obtained from a Local Quarry. The Crushed stones and sands met ASTM C33 (2002) specifications. Water from the university public main supply was used for the production and the curing of the concrete cubes.

Table. 1: Sources of Nigeria Pumice Tuffs Samples

S/N	ID	State	LGA	Location
1	**N1**	Kaduna	Kajuru	Kajuru

2	**N2**	Plateau	Riyom	Danwal Hill
3	**N3**	Plateau	Mangu	Niyes Volcanic Hill
4	**N4**	Borno	Biu	Miriga

Methods

Evaluation of Oxides composition

Dadu (2012) reported that the preparation of the natural pozzolan for oxide evaluation by the Energy Dispersive X-Ray Fluorescence is thus: The Pumice tuffs were grounded manually to powder form with an agate mortar and pestle to grain size of less than 125 µm. A pellet of 19 mm diameter was prepared with 0.5g of the powdered materials. Three drops of organic liquid binder were applied and pressed afterwards with a 10 tons hydraulic press. The pellet of the sample was introduced into the Excitation Source X-Ray Fluorescence Generator for the analysis. The annular 25mCi ^{109}Cd with a Si (Li) detector source emits Ag-K X-ray (22.1keV) in which all elements with lower characteristic excitation energies in the sample were accessible for detection.

The quantification of the elements was then carried out using the Emission-Transmission Method. This method involved the use of Molybdenum (Mo) as a target material as the source of monochromatic X-rays, which is excited through the sample by primary radiation and then penetrate on the way to the detector. The spectra for the samples were collected with the ^{109}Cd source and evaluated using the analysis of X- ray Spectra by Iterative Least Squares Fitting (AXIL); a software program used for the analysis of the oxide samples. The quantification of the elements is then carried out using the Emission-Transmission Method. This method involved the use of Molybdenum (Mo) as a target material as the source of monochromatic X-rays, which is excited through the sample by primary radiation and then penetrate on the way to the detector. The spectra for the samples were collected with the Cadmium 109 source and evaluated using the analysis of X- ray Spectra by Iterative Least Squares Fitting (AXIL) a software program used for the analysis of the oxides of SiO_2, Fe_2O_3, Al_2O_3, MgO, CaO, SO_3, TiO_2, Na_2O, Mn_2O_3, CrO, Y_2O_3, and SrO.

Loss On Ignition

The Loss on Ignition of the pumice samples were evaluated according to ASTM C 25 (2008) standard. A furnace capable of reaching a temperature of 1500^{o}C was utilised. The samples were placed in a porcelain crucible and fired at 950^{o}C for a period of 1 hour after which it was cooled in a silica gel desicator and the weight loss of the sample subsequently taken.

Determination of Compressive Strength.

The pumice tuff materials were grounded manually to powder with an agate mortar and the sieving were carried out in accordance with the ASTM C 136 (2006) until all material passed 90µm (sieve no 170). *Dangote* cement was used for the concrete cubes. The sands used were quartzite river sands; and the crushed granite stones were obtained from a local quarry. The Crushed stones and sands met ASTM C33 (2002) specifications. Water from the public main supply was used for the production and the curing of the concrete cubes.

The concrete cubes were prepared in 150 mm steel moulds and tested in accordance to ASTM C 109 / 109M (2001) standards. Three test and reference cubes were cast and crushed at curing periods of 7,14 and 28days. The materials were batched by volume. The water/cement ratio of 0.55 was used for all the mixes. The ground pumice materials were added to the concrete mixes in partial replacements of 5, 10, 20, 30 and 40% of the OPC in the concrete mix. The control cubes specimens were also treated identically to the test specimens and compressive strengths of all the cubes were measured at 7, 14 and 28-days curing. The compressive strength of concrete containing pumice materials was evaluated.

Strength Activity Index

The Strength Activity Index (SAI) is the ratio of compressive strength of the mixture with a specific replacement or addition of the OPC of the pozzolana to the strength of the mix without the replacement or addition (Neville and Books, 2008). ASTM C 618 (2005) provides the determination as SAI = $\frac{A}{B}$ 100. 'A' is the average compressive strengths of test mix cubes (N/mm^2) and 'B' is the average compressive strengths of control mix cubes (N/mm^2) were evaluated.

RESULTS AND DISCUSSION

Oxides Composition of Pumice Tuffs

The result of the chemical analysis of the pumice tuffs as shown in Table.1 indicated that the principal oxides of Silica (SiO_2), Alumina (AI_2O_3) and Iron (Fe_2O_3) were substantially present in the sample investigated with the sum oxides of 86.09%. The analyses also showed the presence of minor element of Calcium (CaO), Potassium (K_2O) and titanium (TiO_2) with a summed value of 8.79%.

The LOI of the sample evaluated varied from 2. 45 to 15.06% with an average of 8.79% of the samples. ASTM C 618(2005) recommendations are that 70% minimum (for the main oxides) and 5% maximum (for the minor oxides) by weight are required for a pozzolan to be used in concrete; and a maximum LOI of 10% for a material to be used as a pozzolana.

Table. 2: Chemical Analysis of Nigeria Pumice Tuffs.

Elements	Oxides Composition and Loss on Ignition												
Sample	Major Oxides				Minor Oxides								LOI
	SiO_2,	Fe_2O_3	Al_2O_3,	∑MO	Na_2O	MgO	CaO	SO_3,	Mn_2O_3	K_2O	TiO_2	∑MI	
Kajuru	44.18	21.11	18.05	82.34	0.17	ND	10.44	ND	ND	1.34	3.11	15.06	2.45
Danwal	64.31	14.97	12.87	93.15	0.08	0.01	ND	ND	0.01	0.05	0.09	0.24	7.0
Niyes	42.36	15.82	27.92	86.10	ND	2.11	3.12	0.42	0.42	1.54	2.74	10.35	7.56
Miriga	40.24	25.87	16.64	82.75	0.69	1.76	8.24	ND	0.34	2.01	1.89	14.93	4.0
Average	46.02	19.45	19.37	86.09	0.11	0.78	4.42	0.11	0.11	1.26	2.0	8.79	5.5

Loss on Ignition of Pumice Tuffs

Loss on Ignition of the pumice sample was 2.65%. ASTM C 109/C 109M (2001) recommend a maximum 10 % for a material to be used as a pozzolana. The Loss on Ignition of the pumice sample was evaluated according to ASTM C 25 (2005) standard. A furnace capable of reaching a temperature of 1500°C was utilised. The sample was placed in a porcelain crucible and fired at 950°C for a period of 1 hour after which it was cooled in a silica gel desicator and the weight loss of the sample subsequently taken.

Compressive strengths Analysis

The results of the compressive strength tests shown in Table 3 indicated that an increase varying from 8 to to 17% above the control concrete cubes was obtained with 5% pumice addition tested at 28 days curing. These percentages additions met the ASTM C 618 (2005) specification that a minimum of 75% compressive strengths of the control cubes be realised at 28 days curing for pozzolan to be used in concrete. Partial replacements of OPC up to 20% provided compressive strength above 75% meeting (ASTM requirements).

Table. 3: Compressive Strength and Strength Activity Index

% Replacement of OPC	Compressive Strengths (N/Mm^2) 7-Day Crushing	14-Day Crushing	28-Day Crushing	75% Of Control	SAI
0	**21.19**	**24.24**	**27.02**	**20.27**	-
Sample N1					
5	24.16	26.57	29.46	✓	1.09
10	21.18	24.98	28.67	✓	1.06
15	20.1	23.66	26.53	✓	0-98
20	18.66	21	23.73	✓	0.88
30	14.70	16.51	18.82		0.70
40	11.09	13.08	14.33		0.53
Sample N2					
5	23.91	25.54	29.19	✓	1.1
10	22.01	24.13	25.36	✓	1.1
15	18.89	21.44	24.29	✓	1.0
20	16.17	19.09	22.03	✓	0.80
30	12.76	13.93	15.98		0.60
40	10.02	10.93	13.05		0.50
Sample N3					
5	23.91	25.54	29.19	✓	1.1
10	22.01	24.13	25.36	✓	1.0
15	18.89	21.44	24.29	✓	1.0
20	16.17	19.09	22.03	✓	0.8
30	12.76	13.93	15.88		0.6
40	10.02	10.91	13.05		0.5
Sample N4					
5	23.67	27.24	31.79	✓	1.2
10	21.31	24.26	27.65	✓	1.0

15	19.78	22.85	25.67	✓	1.0
20	15.92	18.63	24.02	✓	0.9
30	14.01	14.79	16.83		0.6
40	11.21	11.96	13.65		0.50

STRENGTH ACTIVITY INDEX

The results of the strength activity index (Table 3) at 28 days of concrete containing the pumice rocks in 5, 10,15, 20, 30 and 40 %. The SAI were 90 to 110% for replacement of OPC up to 20%; While replacements of 30 and 40% had its SAI from 50 to 70%. ASTM C 618 (2005) specifies a minimum of 75% Strength Activity Index of potential pozzolan with Portland cement at 28 days curing for its utilisation in concrete.

CONCLUSION

The evaluations of the chemical characteristics of the Nigerian pumice tuffs; and compressive Strengths and the Strength Activity Index of concrete containing the material Tuffs indicated that the materials met the ASTM C 618 (2005) Specifications for a Natural Pozzolana to be use in as a mineral admixture in Portland cement blending and partial replacements in concrete mix design. It is conclusive that the Nigeria pumice deposits possess pozzolanic characteristics as sustainable cementitious materials for use in cement blending.

RECOMMENDATIONS

It is thus recommended that the pumice materials from Nigeria be used in cement blending or for partial replacement of the OPC concrete production as sustainable cementitious materials. This save a lot of energy as pumice require no burning of any sort; and would curtail the CO_2 release to the atmosphere.

The establishment of Blending Plants for the production of Portland Pozzolan Cements is recommended; since there are economic, technical and environmental benefits from the utilisation of volcanic deposits as cementitious materials in providing cheaper housing.

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