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Performance Evaluation of the Potentials of Volcanic Deposit (Biotite Granite Powder) as a Pozzolanic Material in Concrete.

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ABSTRACT

Ordinary Portland cement (OPC) is one of the most consumed materials after water. It is used as the main binding material in construction industries across the globe. However, it is liable for carbon to CO_2 emissions and so on. Besides it is one of the most energy intensive materials after aluminium and steel. This concern had since decades made researchers to develop other types of cement particularly the pozzolanic Portland cement (PPC). The PPC are admixtures to Portland cement in concrete aimed at better performance in concrete. The research was aimed at investigating the suitability of biotite granite as a pozzolana in concrete by evaluating the potential of the biotite granite deposit from Buji complex in Hwol Buji of Bassa LGA Plateau state, Nigeria. The objective of the research looks at the chemical and physical properties of the volcanic deposit in view of variations between the OPC and the volcanic deposit. It also evaluated the workability and soundness of the volcanic deposit/cement. The work was concluded by evaluating the pozzolanic activity index of the volcanic deposit with cement by investigating the compressive strength of the hardened concrete produced with the partial replacement of OPC with biotite granite powder. The chemical properties of the material were determined by Energy Dispersive X-Ray Fluorescence (EDXRF) technique. Lech atelier method was used to determine the soundness of cement paste containing the volcanic deposits; the characteristics of concrete made with the materials in partial replacement of OPC in the concrete samples were also evaluated. A standard mix proportion of 1:2:4 was adopted and water cement ratio kept constant at 0.53 for all the concrete mixes. A total of 54 cubes of 150 mm x 150 mm x 150 mm were produced with 15%, 20%, 30% and 50% of OPC/BGP respectively. Compressive strength test was performed on the samples at 7, 14 and 28 days of curing in water. The results of the chemical analysis showed major and minor oxides of the volcanic deposit. The properties of biotite granite powder evaluated showed substantial presence of the oxides of silica, aluminium and iron with $SiO_2 + Al_2O_3 + Fe_2O_3$ content of 90.65% by weight. The findings also showed that the material is free from carbon materials; the minor oxides identified summed up to 0.34% in value. It has a specific gravity of 2.71 and a Pozzolanic Activity Index with Portland cement of 77%. The result of soundness test was 0.82 mm expansion. The work shows that compressive strength of 84.3%,

77.1% and 69.4% of the control (0%) can be achieved at the 28th day by replacing cement with 15%, 20% and 30% of BGP respectively. From the results of the tests; it was concluded that the Biotite granite of the younger granite contains potential pozzolanic properties for concrete production. Thus, it is recommended that it should be used as a partial replacement of OPC in masonry, concrete and block productions. The study also calls for further research to be carried out to determine the durability properties of concrete containing biotite granite powder.
Key words: Biotite Granite Powder, Compressive strength, Concrete, Pozzolans, Pozzolanic Activity Index.

INTRODUCTION

As a crucial raw material for civilization, cement-based materials, e .g. concrete, are second only to water in terms of the amounts that are most used by mankind (Manzano, Enyashin, Dolado, Ayuela, Frenzel and Seifert, 2012). Ranging from the 2,000-year-old Pantheon in Rome to modern skyscrapers and highways, cement composites occupy a most important position in the history of human development (Wei, 2014). An unprecedented demand and output of cement was driven by the on-going construction boom in developing nations such as China, Brazil and India. However, the increased production and demand for Portland cement means an increase in environmental pollution. In 2004, cement consumption rose from 2.1 billion tonnes to 2.83 billion tonnes and further to approximately 3.77 billion tonnes and 4.0 billion tonnes by 2012 and 2013 respectively (Global Cement Report, 2013). For a tonne of cement produced approximately one tonne of carbon dioxide and other greenhouse gases are released into the atmosphere (Gartner and Macphee, 2011). With cement production, CO_2 emissions are obtained through the combustion and calcination processes of the calcareous and argillaceous materials that led to clinker formation. The cement industry contributes between 5 - 10% of global CO_2 emissions (Alwood, Cullen and Milford, 2010). The consequences of global warming is associated with melting of glaciers, occurrence of cyclones (hurricanes, tsunamis and other intense rotating storms), drought which is prevalent in some Asian and African counties. With the increasing demand of Portland cement for infrastructural developments in the industrialized countries, the booming infrastructure development in the large economic nations, the cement production is projected to reach 5 billion tonnes by 2030 (Potgieter,

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2012). This trend will have a significant impact on the worldwide level of harmful anthropogenic greenhouse gases (GHG) emission. The trend of cement consumption looks very unpleasant for the future of global environment and therefore has prompted the cement industries to approach this matter with all seriousness in minimizing cement plants emissions. The progressive increase of cement use in the country is attributed to demand for shelter due to population increase and other infrastructural developments for a nation that has attained a lower middle income status. Similar to the world's trend on cement production, the Nigerian consumption trend cannot insulate itself as a contributor to carbon dioxide and other greenhouse gas emissions. Global harmful anthropogenic gas emissions could best be dealt with through local or country interventions. Supplementary cementitious materials utilization is known to reduce CO_2 emissions and consequently a significant reduction on the threats of global warming. Supplementary cementitious materials according to Dadu (2012) are materials that contribute to the properties of hardened concrete through hydraulic or pozzolanic activity. Typical examples are fly ash (FA), ground granulated blast furnace slag (GGBFS), silica fume (SF), natural pozzolans such as biotite granite powder (BGP), rice hush ash (RHA) etc. These can be used individually with Portland or blended cement or in different combinations. Supplementary cementitious materials are often added to concrete to make concrete mixtures more economical, reduce permeability, increase strength, or influence other concrete properties. A replacement of 50% of cement worldwide among cement consuming countries with cementitious materials will reduce CO_2 emissions by more than one million tonnes (Cordeiro, Tolêdo Filho, Tavares, and Fairbain, 2012).

Biotite is a rock-forming mineral found in a wide range of crstalline igneous rocks such as granite, diorite, gabbro, peridotite and pegmatite. It also forms under metamorphic conditions when argillaceous rocks are exposed to heat and pressure to form schist and gneiss. A generalizes chemical composition for the biotite group is: $K(Mg,Fe)_{2-3}Al_{1-2}Si_{2-3}O_{10}(OH,F)_2$ The biotite granite which possesses high silica content is known to belong to the younger granite of the igneous rock (Gumwos, 2010). The Biotite granite has also been found to exist in large proportions in Kwall (Bassa Local Government Area), Ropp (Barkin Ladi Local Government Area), Ganandaji and Ganawuri (Riyom Local Government Area) all in Plateau state, Nigeria (Gumwos, 2010; Alu, 2009). The Buji complex, the host of the biotite granite is one among many other rock complexes on the Plateau located at Hwoll Buji village in Bassa Local Government Area of Plateau State. The complex originated as deposit on the earth surface as a result of long aged volcanic eruption on the area, as part of the Benue valley Trough. The major rock type is the younger granites composed of igneous rocks of different types such as plutonic, hypabysal and volcanic. These rocks are Jurassic and are intrusive into the basement complex. The younger granites are believed to have intruded from the older granites and the basement, all of which belong to the general granite rock family.

Geographically, the area where sample of the rock were obtained is located at the corner area of the village, behind the Sertzen quarry with GPS location mapped N10°.02′21′′>30°.6, E08°51′23.8''>22°6' with an elevation of 1142m. The part of the study revealed that biotite granite among related stones such as basalts, micro granites as well as pyroxene granite could be polished to enhance their aesthetic qualities and used to produce decoration and dimension stones for terrazzo floor and wall tiles as part of finishing in building and construction works (Gumwos 2010; Dadu (2012). This is apart from applying them for the production of rock (coarse) aggregates for civil engineering and building works. The challenges posed by both lime saturation factor of the ordinary Portland cement (OPC) and the constituents' effects in concrete as well as the current increasing cost of the Portland cement give rise to the need for the studies as a contribution to the numerous research works on way forward to having alternatives to the Portland (Girard, 2011). Also, the low rate of silica in the Portland cement, is said to be responsible for shrinkage and cracking on the concrete giving rise to the need for pozzolanic material' which has the ability to convert calcium hydroxide $Ca(OH)_2$ to Calcium Silicate Hydrate (C-S-H), thereby reducing or eliminating the voids.

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Above all, the current economic inflation on all goods and services, the high dependency on the use of Portland cement, the non-readily available raw material for the production of Portland cement among other factors have caused an increasing hike in the prices of Portland cement, giving rise to high cost of housing in Nigeria and also creating a barrier for the provision of affordable housing for the average man in the country (Amadei, 2003). Furthermore, it is apparent that the application of volcanic materials for cement blending by partial replacement of ordinary Portland cement would reduce the cement content in the concrete mixture and invariably reduce the cost of housing in Nigeria, considering the availability of these volcanic deposits. Thus the study of the potential utilization of volcanic deposits would transform the volcanic materials into an alternative and cheaper cementitious material for the production of low-cost housing but will also provide socio-economic benefits. It is equally important to note that the utilization of the volcanic deposits (the natural pozzolanas) for the partial replacement of Portland cement would serve as a means of generating employment opportunity within the host communities or localities.

LITERATURE REVIEW

Incorporation of pozzolan in concrete production improves many properties of concrete which include plasticity and workability of fresh concrete, low heat of hydration, low thermal shrinkage, reduced permeability, shrinkage reduction, Alkali-Silica Reactivity (ASR) inhabitants, dam proofing, improved resistance to sulphate and other chemically aggressive agents, and increased long term strength of hardened concrete (Kumar, Singh and Singh, 2012). Natural pozzolans owe their activity to five substances, namely: volcanic glass, opal, clays, zeolites, and hydrated aluminum oxides (Lea, 1998). Each active substance contributes characteristic properties to the pozzolan; consequently, the quality of proposed materials, and need for special processing usually can be predicted from petro graphic analyses.

Seco, Ramirez, Miqueeliz, Umeneta, Garcia, Prieto and Oroz (2012) asserted that pozzolanic reactions take place when significant quantities of reactive CaO, $A1_2O_3$ and SiO_2 are mixed in the presence of water. In this reaction, the hydration of CaO liberates OH ions, which causes an increases pH values up to approximate 12.4. Under these conditions pozzolanic reactions occur. The Si and Al combine with available Ca, resulting in cementitious compounds called Calcium silicate hydrates (CSH) and Calcium Aluminate Hydrates (CAH). According to Dadu (2012); prior to the utilisation of a pozzolan in concrete either in partial replacement or in cement blending, the pozzolanic activity of the pozzolan with the Portland cement (PC) can first be assessed by determining the compressive strength of the mixtures with the specified replacement of the cement with the pozzolana. The Pozzolana content usually varies from 10% to 25% by weight of cement. ASTM C 618 (2005) specified the measurement of pozzolanicity of the pozzolan by evaluation of the pozzolanic activity index with cement and lime. Dadu (2012) further affirmed that the Pozzolanic Activity Index (PAI) with Portland cement is the ratio of the compressive strength of the mixture with a specific replacement of cement by the pozzolana to the strength of the mix without replacement. Patel and Pitroda (2013) examined the possibility of using stone waste powder as replacement of cement in the range of 5%, 10%, 30%, 40% and 50% by weight of M25 grade concrete. They reported that stone waste of marginal quantity as partial replacement to cement had beneficial effect on the mechanical properties of concrete. Sengottaiyan, Muthumurugan and Anitha (2017) studied the strength characteristics of concrete with partial replacement of cement with granite powder and fine aggregate by quarry dust. The cement was replaced with granite powder in the percentages of 10%, 20%, 30% and the fine aggregate with 15%, 30% and 45%. The results proved that 20% replacement of cement with granite powder gave the maximum strength than the control mix.

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MATERIALS AND METHODS
MATERIALS
Cement

Dangote brand of ordinary Portland cement produced from the cement factory at Obajana, Kogi State was used as the binding material and having physical properties shown in Table 1. It conforms to type 1 cement as specified by BS 12: 1978.

Aggregates: The fine aggregate was naturally occurring sand obtained from PW site Rayfield Jos with a specific gravity of 2.73, while the coarse aggregate was made of crushed granite with a maximum size of 20mm obtained from PW site in Rayfield, Jos, Plateau State and with a specific gravity of 2.61.

Water: Colourless, odourless and tasteless fresh potable water free from any type of organic matter was used.

Table 1: Constituent Composition of OPC

Constituent	Percentage Composition
Lime	60% -67%
Silica	17% -25%
Alumina	3%- 8%
Iron oxide	0.5% - 6%
Maynesia	0.1% -4%
Soda & potash	0.2%-1%
Sulphur trioxide	1%-3%
Free lime	0%- 1%

Source: Syal & Goel (1991) in Cheje, 2016

Volcanic Deposit (Biotite granite):

The volcanic material was obtained from the Setzen quarry, which had earlier been obtained in bulk from the volcanic hill. The rocks were bagged in boulders and transported to rock and clay industries in Barkin- Ladi, where the stones were milled into powder fineness form and it was sifted with 75μm sieve. The milled powder were packaged into bags and transported to the concrete laboratory of PW construction company, Rayfield Jos, for further laboratory tests.

METHODS

Physical and chemical analysis of volcanic deposit (biotie granite)

The chemical properties of the volcanic material was analyzed by Energy Dispersive X-Ray Fluorescence (EDXRF) techniques at Nigeria Institute of Mining and Geosciences (NIMG), Tudun Wada, Jos Plateau State.

Sieve analysis of Aggregates

Sieve analyses tests were conducted in accordance to BS 812: Part 103.1. The results of analyses are shown in Tables 4 and 5 respectively

Soundness test: Le Chatellier's apparatus was used for the test as prescribed in BS 4550: Part 3: section 3.7 and BS 812: part 121: 1989.

Mix proportion

A concrete mix of ratio 1:2:4 was adopted for the production of concrete cubes at constant water/cement ratio of 0.53.

Workability of OPC/BGP concrete

The workability of each mix was assessed using the slump test in accordance to BS 1881: Part 102; 1983; and the result is presented in Table 8

Compressive Strength of Portland Cement Concrete

A total of 54 cubes were cast and cured in the curing tank for 7, 14 and 28 days, using a mould of 150mmx150mmx150mm. Three specimens were crushed at the end of each curing regime and the average value recorded as the strength achieved. The procedure for testing and crushing were conducted in accordance to BS 1881: Part 116: 1983 and the results are shown in Figure 1. The crushing was carried out using ELE 2000kN motorized compression testing machine at concrete laboratory, PW construction company, Jos Plateau State.

Pozzolanic Activity Index with Portland Cement

The measurement of the pozzolanic activity index with Portland cement concrete was determined in accordance to ASTM C 618 (2005). These were established by evaluating and comparing the strength of

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the concrete without pozzolan and those with the specific replacements of the biotite granite powder materials at 28 days of curing. The expression for the determination of pozzolanic activity index with cement is given as $\frac{Po}{Co}$ and the result is shown in Figure 2

Where:

po - average compressive strengths of test cubes (N/mm^2)

co - average compressive strengths of control cubes (N/mm^2)

RESULTS AND DISCUSSION

Physical and Chemical Properties of Buji Volcanic Deposits

Table 2: Specific Gravity of the Volcanic Material

S/N	Determination No	1	2	3
1.	Weight of density bottle W_1 (g)	367.7	369.3	369.5
2.	Weight of bottle with material W_2 (g)	625.2	622.9	623.8
3.	Weight of bottle with material and water W_3 (g)	983.4	982.4	982.9
4.	Weight of bottle full of water W_4 (g)	822.3	821.8	822.1
5.	Weight of dry soil $(W_2 - W_1)$ (g)	257.5	253.6	254.3
6.	Weight of an equal volume of water $(W_4 - W_1) - (W_3 - W_2)$ g	96.4	93	93.5
7.	Specific gravity G_S =[5]/[6]	2.67	2.73	2.72

$$\text{Average} = \frac{2.67 + 2.73 + 2.72}{3} = 2.71$$

Physical properties such as specific gravity and fineness by sieving were determined as per ASTM C127-93 and BS 812-103.1 (1985) respectively and results of the specific gravity are presented in Table 2. The chemical composition of the volcanic ash was determined as per IS: 1350 (Part III) and result presented in Table 3. Table 2 and 3 shows the physical and chemical composition of biotite granite powder. The specific gravity test of the biotite granite powder (BGP) material indicates a specific gravity of 2.71 which falls within the limit for natural granite with value of specific gravity between 2.6 and 2.7 as reported by Neville (1996).

Table 3: Chemical Composition of the Volcanic Deposit (Biotite Granite Powder)

Oxides	% composition
SiO_2	68.34
Al_2O_3	68.34
Fe_2O_3	2.46
CaO	1.63
MgO	0.89
Na_2O	1.62
K_2O	3.98
LOI	0.89

The total percentage of SiO_2 + Al_2O_3 + Fe_2O_3 is 90.65% which is greater than the minimum specified in ASTM C-618. The results of the X-Ray fluorescence oxides analysis indicated that the oxides of silica, aluminium and iron are substantially present in the material investigated. The results in Table 3 also established the presence of minor and trace elements CaO, Na_2O, K_2O, MgO in varied percentages in the samples studied. The minor oxides detected in the biotite granite powder summed up to 0.34% from the analysis presented. The presence of these minor elements is important to strength and durability of concrete. The amount of lime is small 1.63% and the MgO percentage from the study is insignificant. The excess of this oxide may cause unsoundness in cement as reported by Neville and Brooks (2008). The loss on ignition for the sample assessed was 0.89% which explains the possible traces of rare earth elements such as TiO_2, MnO and Cr_2O_3. The effects of these oxides can be significant if their concentration is beyond the recommended value of 5% maximum by weight (ASTM C618, 2005). Increase in the level of TiO_2 is said to improve the compressive strength of cement Clinkers, Cr_2O_3 accelerates the hydration of paste and improve the early strength of concrete.

Particle size Distribution

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Tables 4 and 5 shows the particle size distribution carried out on both fine as well as coarse aggregates in accordance with BS 812: Part 103.1.

Table 4: Sieve Analysis of the Fine Aggregate

BS sieve size	Weight of retained(g)	Sum of weight retained (g)	% Weight retained	Cumulative % retained	%Passing
10mm	0	0	0	0	100%
5.0mm	35	35	3.5	3.5	96.5
2.36mm	149	184	14.9	18.4	81.6
1.18mm	285	936	18.3	93.6	6.4
600um	284	753	28.4	75.3	24.7
150um	50	986	5.0	98.6	1.4
75um	12	998	1.2	99.8	0.2
Total	99.8		99.8		

Table 5: Sieve Analysis of Coarse Aggregate

BS sieve sizes	Weight retained (g)	Sum of weight retained (g)	% Weight retained	Cumulative % retained	%Passing
28mm	0	0	0	0	100%
20mm	84	84	3.83	3.83	96.17
14mm	1,480	1,564	67.46	71.29	28.71
10mm	588	2,152	26.80	98.09	1.91
6.3mm	32	2,184	1.46	99.55	0.45
Total	2,184		99.55		

The sieve analysis results obtained for the fine and coarse aggregates shows that both aggregates are suitable for concrete production according to BS 812 (1985). The fine aggregates satisfied the conditions of zone 1 while the coarse aggregates were found within the range of 19mm and 20mm. Similarly, the sieve analysis result of the volcanic material showed that all the particles passed the 75 microns sieve standard BS sieve No. 200 (ASTM C 618, 2005) hence, meeting the requirement of being a pozzolanic material.

Soundness of Concrete Containing Biotite Granite Powder

The soundness of cement specimen were measured based on expansion of cement paste gauged in Le-chatelier mould before immersion, before and after boiling and the result is presented in Table 6.
The result obtained from soundness test showed that the material is sound because it met the requirement for soundness of cement stated in BS EN 196-3 (2000) that the limit of expansion in Le' chartelier mould should not be greater than 10mm beyond which the material is said to be unsound due to the lime (CaO) Magnesium (MgO) and Gypsum ($CaSO_4$) content which are deleterious to concrete. From Table 6, the volcanic material had the value of 0.82% expansion. This indicates that the concrete containing volcanic material ash has an excellent sulphate resistant proportion which if absent, sulphate combines with free lime to cause spalling of the concrete and thereby reduce durability.

Table 6: Soundness of Cement Paste Containing Biotite Granite Powder (BGP)

Sample No.	Distance between pointer ends		Difference (D_2-D_1)	Average (mm)
	Before heating D1 (mm)	After heating D2 (mm)		
A	2.1	3.0	0.9	
				0.82
B	10.10	11.10	1.0	
C	10.05	10.60	0.55	

Mix proportion

Table 7 gives the mix proportion used for the research. Biottite granite powder was used to replace cement at various levels of 0%, 10%, 20%, 30%, 40% and 50% by mass of cement. The mixing of ingredients was performed in a tilting drum mixer in accordance with ASTM C305-14

Table 7: Mix Proportion for Biotite Granite Powder (BGP) – Concrete

Powder(%)	Cement (Kg)	Fine aggregate (Kg)	Coarse aggregate (Kg)	Water (Kg)	W/C
0	14.03	31.15	32.43	7.44	0.53
15	12.12	31.15	32.43	7.44	0.53
20	11.23	31.15	32.43	7.44	0.53

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30	9.82	31.15	32.43	7.44	0.53
50	7.02	31.15	32.43	7.44	0.53

Workability of Biotite Granite-OPC Concrete

Table 8 shows the water/cement ratio and slump values for the fresh BGP/OPC concrete. The slump ranges from 7mm to 14mm; 15 and 20% replacement of cement with biotite granite powder (BGP) has slumps of 11mm and 10mm respectively while 30 and 50% replacement has 7mm and 14mm respectively. The control mix has a slump of 5.5mm. It can be deduced that BGP increases the workability of concrete because as the percentage replacement of cement with BGP increases, the slump also increased at a constant free water/cement ratio of 0.53.

Table 8: *Workability of Concrete (slump)*

% Replacement	*Water Cement Ratio*	*Slump(mm)*
0	0.53	5.5
15	0.53	11
20	0.53	10
30	0.53	7
50	0.53	14

Compressive Strength

Figure 1 shows the effect of curing on compressive strength. An increasing trend in the strength of the BGP/OPC concrete as the days of curing increases as indicated. The compressive strength decreases as the percentage of BGP increased. It is observed that as the age of curing increases the difference in strength between 0% BGP (control) and the various percentage replacements tend to decrease. From Figure 1, the percentage strength gained at 28 days for 15%, 20% and 30% to the control are 84.3%, 77.1% and 69.4% respectively. This process of growth in strength beyond 28 days is believed to continue as long as the curing period is prolonged to allow the hydration process to be complete.

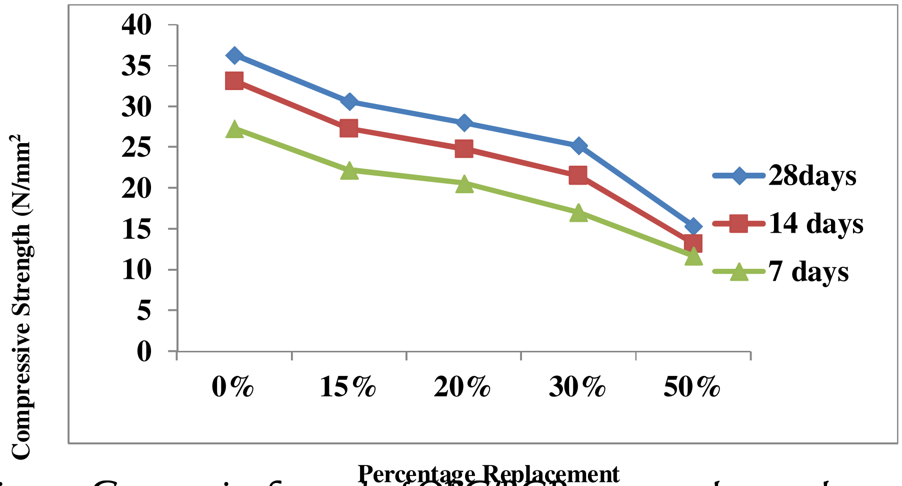

Figure 1: Compressive Strength of OPC/BGP concrete cubes cured at 7, 14 and 28 days

Pozzolanic Activity Index of Concrete Containing the Buji Volcanic Material

The result in Figure 2 showed the pozzolanic activity index of the OPC at 15%, 20%, 30% and 50%. The average pozzolanicity index for the 15% and 20% replacements was found to be 84.3% and 77.13% respectively. This satisfied the ASTM C 595 (2006) 75% minimum requirement for a pozzolana to be used as a constituent of Portland pozzolana cement in concrete production.

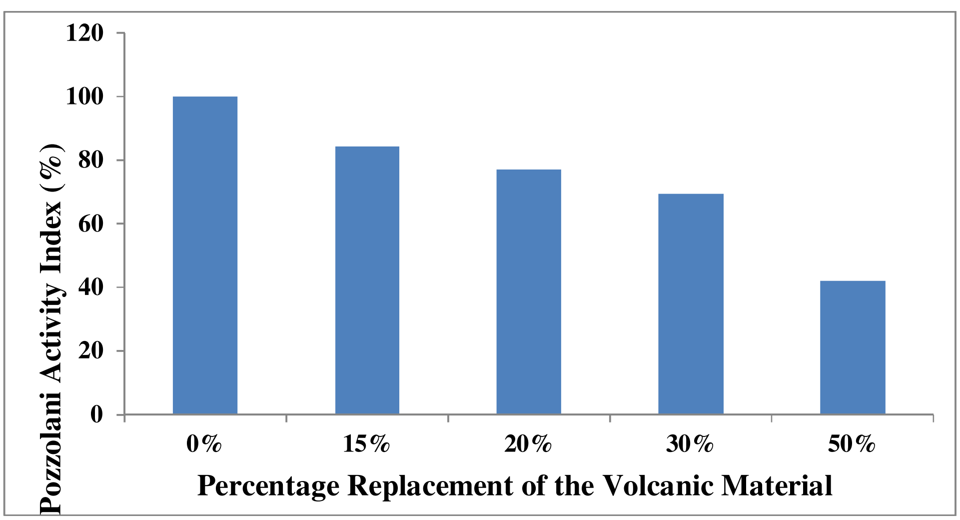

Figure 2: Pozzolanic activity index of OPC/BGP concrete

CONCLUSIONS AND RECOMMENDATIONS

Based on the various tests carried on the biotite granite powder (BGP), satisfactory results were obtained with respect to physical, chemical and mechanical properties. The properties evaluated satisfied the minimum standard for biotite granite powder as a pozzolana. The compressive strength of the BGP/OPC concrete at the end of the 28th day curing for 15%, 20% and 30% replacement of cement are 84.3%, 77.1% and 69.4% of the control respectively. It is thus concluded that Buji biotite granite are good potential natural pozzolans for cement blending or for partial replacement of ordinary Portland cement. Further tests are however, necessary to find the specific surface area of the material in order to know its actual fineness, water absorption, porosity and durability of concrete and mortar products made with this material.

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