# AN INVESTIGATION INTO THE POZZOLANIC PROPERTIES OF DUTSIN DUSHOWA VOLCANIC ASH OF JOS PLATEAU

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***ABSTRACT***

*This study investigates the pozzolanic properties of the volcanic ash (VA) sample obtained from Dutsin Dushowa, Kerang in Mangu Local Government Area of Plateau State. Chemical Analysis of the VA sample was carried out to determine the oxide contents, so also were some physical properties (specific gravity, fineness, soundness, consistency, and water requirement and setting times (initial and final)) tests carried out on the VA sample and VA-blended cement samples. The result reflects a Silicon Dioxide ($SiO_2$) content of 41.13% and a total Silicon Dioxide, Iron Oxide, and Aluminium Oxide ($SiO_2+Fe_2O_3+Al_2O_3$) content of 70.99%. The VA sample has a specific gravity value of 2.65 kg/m$^3$ while the VA-blended cement was noted to be finer than the control (Dangote - Obajana) cement. The soundness of the VA-blended cement ranged between 1.5 and 4.5 for replacement levels of 0% to 30%. The consistency increased from 30.0% to 31.5% as VA substitution increased from 0% to 30%. The water required for a standard consistency was noted to increase as the VA content increased. The initial and final setting times increased from 50 to 105 minutes and 135 to 180 minutes respectively for this replacement levels. All the VA-blended cements thereby satisfy the various code requirements up to the 30% replacement levels.*

***KEYWORDS**: Volcanic Ash (VA), Pozzolan, Oxide Contents, VA-blended cement, Setting times.*

## INTRODUCTION

The global campaign on Urban Governance proposes that good urban governance is characterized by sustainability, decentralization, equity, efficiency, transparency and accountability, civic engagement and citizenship, and security, and that these norms are interdependent and mutually reinforcing. While one of the practical ways highlighted to meeting the norms of sustainability in urban governance is engaging in consultative processes such as environmental planning and management (EPM) or Local Agenda 21s. These are geared at reaching agreement on acceptable levels of resource use, applying the precautionary principle in situations where human activity may adversely affect the well-being of present and/or future generations (UNCHS, 2000). Also of paramount importance in good urban governance is security that involves security of individuals and their living environment. Security also implies freedom from persecution, forced evictions and security of tenure. Every individual has the inalienable right to life, liberty and the security of person; while insecurity has a disproportionate impact in further marginalising poor communities.  Cities must strive to avoid human conflicts and natural disasters by involving all stakeholders in crime and conflict prevention and disaster preparedness. One practical way highlighted for addressing the norm of security is raising awareness about the risk of disasters and formulating local emergency management plans, based on reduction of risk, readiness, response and recovery for natural and human-made disasters and, where necessary, relocating residents of disaster-prone areas (UNCHS, 2000).

The recent global incidences of volcanic eruptions and ashes, earthquakes and tsunamis with serious cases of destruction of live and properties, displacement of inhabitants etc. are issues of concern. In the year 2010, the northern and central Europe suffered a lot of flight cancellations while flights were grounded for up to a fortnight in some places due to volcanic ash clouds in the air (The Telegraph of Thurs. 23rd June, 2011), while up to 4000 flights were cancelled with airspace closed in Norway, Sweden, Finland and Denmark amongst others (BBC News, Thurs, Apr. 2010). Japan seems to be the worst hit by earthquakes in the year 2011, experiencing a 9.0 magnitude in March while another 5.9 magnitude was recorded in April. Indonesia also had her share, having a 6.1 magnitude earthquake in April, 2011, while in Japan; about 12,000 people were noted as yet to be accounted for due to the earthquakes and tsunamis experienced (NTA Network News of 25th April, 2011). Of concern is the eruption experienced recently in Mkomon District of Kande Local Government Area of Benue State, here in Nigeria on November, 4th 2010 in which one person died while properties worth Millions of Naira were destroyed (Vanguard News Paper of 5th Nov. 2010 and The SaturdaySun Magazine, 5th Nov. 2010).

It is in line with the global incidences of volcanic eruption, ashes, earthquakes and tsunamis that this paper views the assessment of the pozzolanic properties of the volcanic ash deposit in Jos plateau, Nigeria with a view to exploring its use as a partial replacement for ordinary Portland cement in building construction.

## LITERATURE REVIEW

**Volcanism** is the noun for volcanic activity referred to in Encarta Dictionary (2009), as the process involved in the formation of volcanoes and in the transfer of magma and volatile materials from the interior of the Earth to its surface. Volcano is therefore the mountain or hill formed by accumulation of materials erupted through one or more openings (called volcanic vents) in the Earth's surface. Volcanoes above the sea level are the best known, but the vast majority of the world volcanoes lie beneath the sea formed along the global oceanic ridge systems that crisscross the deep ocean floor.

Volcanic eruptions in populated regions are significant threat to people, property and agriculture. The danger is mostly from fast moving, hot flows of explosively erupted materials, falling ash and highly disruptive lava flows and volcanic debris flows. Explosive eruptions even from volcanoes in unpopulated regions can eject ash high into the atmosphere, creating drifting volcanic ash clouds that pose serious hazard to airplanes (Encarta, 2009). Volcanic eruptions and associated activity are classified as phreatic eruptions (steam-generated eruptions), explosive eruption of high-silica lava (e.g., rhyolite), effusive eruption of low-silica lava (e.g., basalt), pyroclastics flows, lahars (debris flow) and carbon dioxide emission. All of these activities can pose a hazard to humans. Earthquakes, hot springs, fumaroles, mud pots and geysers often accompany volcanic activity (en.wikipedia.org, 2011).

Wright (1970) observe that although a significant proportion of Nigeria's volcanic rock are found in the Jurassic younger granite province, the tertiary to quaternary phase of volcanism was most mid spread and voluminous in Nigeria. There are also other volcanic episodes which observe wider publicity. A summary of the spread is as provided in Table 1 as cited in Hassan (2006).

Salau (2008) also outlined the spread of Basalt formations in Nigeria, which he said are found in the South and West of Biu Plateau, Namu, Gindiri, Pankshin and Runka areas and also in Jos Plateau in Plateau State.
They also occur in Rabah, Gwaini, Wurno and Sokoto Plateau of Sokoto State. Traces of basalt can also be found in the Yoruba Plateau (Salau, 2008). This study hereby focuses on the Jos Plateau Volcano.

**Table 1: Summary of Volcanic Rocks in Nigeria**

| Approximate Age | Petrographic Affinity | Approximate Distribution |
|---|---|---|
| Jurassic (150Ma) | Alkaline to Tholeitic | Basaltic half of Runka (1), also Gazamma (G), Kinberlite of Kafur (K) and clays at Kankara (K) |
| Cretaceous (100Ma) | Alkaline to Calc Alkaline | Basic to intermediate laxias and proclactic and minor intrusive of Benue trough (2) |
| Lower Cenozoic (70 - 60Ma) | Rock too altered | Fluvio-volcanic series or laterized older basalts of Jos Plateau region (3) |
| Upper Cenozoic | Alkaline to per Alkaline | Basalts phlomolites, trachytes of Jos Plateau, Benue valley and Manbilla Plateau (4) |

**Source:** Wright, 1970

The **Jos Plateau** lies precisely within the North Central Basement Complex of Nigeria. The Basement Complex rocks of the lower Palaeozoic to Precambrian ages underlie about half of its entire landmass. These rocks are represented by gneiss-migmatites and intrusive into these Basement rocks are the Pan-African granites and the predominant Jurassic non-organic alkaline Younger Granites (Turner, 1976). Tertiary and Quaternary basaltic volcanoes are the youngest rocks in the area and overlie directly in the basement and in places of the Younger Granites (Wright, 1970). Two main basalt subtypes have been distinguished based on these periods of replacement and textural differences. They are the Older (Tertiary) and the Newer (Quaternary) basalts (MacLeod *et al.*, 1971).

The Newer basalts occupy nearly 150 $km^2$ in the western and southern Jos Plateau. They also extend towards the Kafanchan area and Southwards down to the Shemankar valley. They occur as cones and lava flow characterised sleep-sided central craters rising a few meters above their surroundings. The Newer Basaltic cones are aligned in NNW-NNE direction, corresponding to the trend of dolerite dykes (MacLeod *et al.*, 1971). They are mainly built of basaltic scoria and pyroclastics, with the vesicles filled with a variety of inclusions (olivine, Iherzolite, websterite etc).

**Volcanic ash** referred to as "original pozzolan"[Neville and Brooks, 2002], is a finely fragmented magma or pulverised volcanic rock, measuring less than 2mm in diameter, which is emptied from the vent of a volcano in either a molten or solid state. The most common state of ash is vitric (glass like), which contains glassy particles formed by gas bubble busting through liquid magma [Encarta, 2009]. It comprises small jagged piece of rock minerals and volcanic glass that was erupted by a volcano [Shoji *et el*, 1993]. Volcanic ash is opined not to be a product of combustion like soft fluffy material created by burning wood, leaves or paper. Volcanic ash is hard, does not dissolve in water and is extremely abrasive, mildly corrosive and conducts electricity when wet. In their opinion, the average grain size of rock fragment and volcanic ash erupted from an exploding volcanic vent varies greatly among different eruption. Heavier and large size rock fragment typically fall back to the ground or close to the volcano while smaller and lighter fragments are blown farther from the volcano by wind.

## MATERIALS AND METHODS

### *Materials Collection*

The Volcanic Ash used was obtained from the foot of Dutshin Dushowa (a hill) at Kerang in Mangu Local Government Area of Plateau State. This was dug from the foot of the volcanic deposit as solid mass, pounded and grounded to very fine particles and sieved with 75µm sieve before use in Minna. The cement used was obtained from the building materials market in Minna and was that produced by the Obajana factory of Dangote Cement whose properties conform to the requirements of BS EN 197-1:2000 (which replaces BS 12 (1991)) for Ordinary Portland Cement.

### *Experimental Procedure*

The chemical analysis of Volcanic Ash was carried out at the Sagamu Works Department of Lafarge Cement (West African Portland Cement Company -WAPCO) via an X-ray Fluorescent Analysis using a Total Cement Analyser model ARL 9900 XP. The pounding and grinding of the Volcanic Ash was carried out in the Department of Building laboratory, FUT, Minna and at a local shop in Minna. So also were physical properties tests carried out on the VA sample and the VA-blended cements. Furthermore all mass measurements were taken on weighing balances available in the various Laboratories of the Federal University of Technology (FUT), Minna.

***Determination of Chemical Composition of Volcanic Ash***

The VA sample was prepared in F.U.T, Minna and then taken to WAPCO, Sagamu Works for analysis. About 150 g of the prepared sample was involved. The VA sample was pounded, ground and sieved using a 75µm sieve before the 150 g was packaged in small nylon bag.
The determination of the chemical composition at WAPCO using an X-ray Fluorescent Analyser called Total Cement Analyser (Model ARL 9900 XP) connected to a computer system. This involved drying, grinding, pressing and analysing. The materials were dried in an oven at 100 ±$10^0$C for about two hours until a constant weight (±0.01 g) was obtained after which the sample was placed in a desiccator to cool for about 30 minutes before grinding commences. In order to aid grinding and to prevent sticking of the sample to dish, 0.8 g of stearic acid was weighed into sample dish before adding 20.0 g of the material (VA sample) into it. Grinding was done on a gyro-mill grinding machine (Model HSM 100H, Serial Number MA 11566-5-1, 2004), which stops automatically after grinding for a pre-set time of 3 minutes. The sample is then ready for pressing.
The ground sample plus 1.0 g of stearic acid to ensure adequate binding, was used to fill the pellet cup to the brim. The pellet cup was then placed in an automatic hydraulic press (Model TP 40/2D), with 20 tons load applied for a 30 seconds hold time. The pressed pellet after removal was placed in the X-ray analyser sample holder ready for analysis.
The pressed pellet was loaded in the sample port of the analyser and the assembly left for about three minutes after which the values of oxides concentration were displayed on the monitor. The computer automatically prints the result of the analysis.

***Determination of Physical Characteristics of Volcanic-Ash Blended Cements***

The following physical characteristics of the volcanic ash blended cements were considered:

i. Fineness (Sieving Method)
ii. Consistency
iii. Soundness and
iv. Initial and final setting times.

***a) Fineness (Sieving Method)***

The fineness of cement is measured by sieving it on standard sieves. The proportion of cement of which the grain sizes are larger than the specified mesh size is thus determined (BS EN 196 – 6:1992).
This test was carried out to determine cement residue as specified in BS EN 196 – 6:1992 using a 53µm and 75µm sieve since the volcanic ash sample being used are those passing 75µm sieve.

***b) Consistency Test***

The consistency of standard cement paste was determined using Vicat apparatus with a 10 mm diameter plunger as specified in BS EN 196 – 3:1995. 500 g of cement sample (also the blended cement) was weighed and spread out on steel plate; in case of the volcanic-ash blended cement the appropriate percentage of replacements was noted and weighed as required with everything thoroughly mixed together. Using the measuring cylinder, 125 g of clean tap water was added and mixing with trowel was done for 4 ± 0.25 minutes to give a paste. The paste was then tested for consistency using the Vicat apparatus in accordance to the requisite British Standards.

***c) Initial and Final Setting Times***

The setting times tests were carried out using the Vicat apparatus. The temperature of the test room was kept at 27 ± $5^0$C. Cement paste of standard consistency as described above and the two types of setting time tests (Initial and Final) were carried out on the cement pastes of the four different levels of percentage replacement of cement by volcanic ash (0%, 10%, 20% and 30% respectively) in accordance to BS EN 196 – 3:1995 as discussed below:

i. ***Initial setting time***: - For the determination of the initial set, a round needle with a diameter of 1.13± 0.05 mm was used. The needle, acting under a prescribed weight, was used to penetrate the paste of standard consistency placed in the Vicat mould. When the paste stiffens sufficiently for the needle to penetrate no deeper than to a point 5± 1 mm from the bottom, initial set was recorded. Initial set is expressed as the time elapsed since the mixing was added to the cement.
ii. ***Final setting time***: - Final set was determined by a similar needle fitted with a metal attachment hollowed out so as to leave a circular cutting edge 5 mm in diameter and set 0.5 mm behind the tip of the needle. Final set is said to have taken place when the needle gently lowered to the surface of the paste, penetrates it to a depth of 0.5 mm but the circular cutting edge fails to make an impression on the surface of the paste. The final setting is reckoned from the moment when mixing water was added to the cement.

***d) Soundness Test***

The soundness or cement expansion test was performed using the Le-Chatelier apparatus. A cement paste of standard consistency was prepared and used to fill the expansion mould on a glass plate, keeping the split of the mould gently closed. The top of the mould was smoothened and levelled and a glass top end applied. The assembly was then placed in water at $27 \pm 5^0$C with a small weight placed on the top end plate. The mould was removed after 24hours and the distance between the two points (i.e. the split opening) was measured to the nearest 0.5 mm (say A mm)
The mould was then placed in a heating bath and the temperature raised to boiling point within 15 minutes and then allowed to boil for 1 hour. The mould was thereafter removed from the bath and allowed to cool for 1 hour after which the distance between the two pointers was measured again to the nearest 0.5 mm (say B mm). The difference between the two measurements (B – A) was recorded as the expansion of the cement.

## RESULTS AND DISCUSSION

***Chemical Analysis of the Volcanic Ash Sample***

The result of Chemical analysis of the Volcanic Ash sample is as shown in Table 2.
This reflects a Silicon Dioxide content of 41.13% which is greater than BS EN 197-1(2000) minimum requirement of 25.0% and a total Silicon Dioxide, Iron Oxide, and Aluminium Oxide ($SiO_2$+$Fe_2O_3$+$Al_2O_3$) content of 70.99% which is slightly higher than the values gotten in earlier studies 63.74% by Lar and Tsalha (2005) and 67.14% by Hassan (2006).

This new value is noted to be slightly above the code (ASTM C618 – 2008) requirement of 70% minimum for a pozzolan. The $SO_3$ content is -0.13 which is below the maximum value of 4.0% as specified for Class N pozzolan to which it belongs; in ASTM C618-2008. The loss on ignition (8.60) though higher than the value (2.71) gotten in earlier study by Hassan (2006), is also below the maximum allowable (10.0) specified. The Volcanic Ash sample from Kerang, in Mangu Local Government Area of Plateau State, Nigeria; which was used for the research work can then be said to be a pozzolan on basis of Chemical composition.

**Table 2: Result of Chemical Analysis of the Volcanic Ash Sample**

| Elements | % Composition by weight |
|---|---|
| $SiO_2$ | 41.13 |
| $Al_2O_3$ | 18.36 |
| $Fe_2O_3$ | 11.5 |
| CaO | 6.57 |
| MgO | 4.24 |
| $SO_3$ | -0.13 |
| $K_2O$ | 1.12 |
| $Na_2O$ | 1.29 |
| $Mn_2O_3$ | 0.29 |
| $P_2O_5$ | 1.00 |
| $TiO_2$ | 3.56 |
| Cl- | 0.00 |
| SUM | 88.92 |
| LSF | 4.64 |
| SR | 1.38 |
| AR | 1.60 |
| $C_3S$ | -430.78 |
| $C_2S$ | 439.08 |
| $C_3A$ | 29.21 |
| $C_4AF$ | 34.95 |
| L.O.I | 8.30 |
| $SiO_2+Al_2O_3+Fe_2O_3$ | 70.99 |

***Physical Properties of the VA-Blended Cement***

The physical properties of the VA-Blended cement are presented in Table 3.

**Table 3: Summary of Physical Properties of VA-Blended Cement**

| Parameters | Percentage Replacement by VA | | | |
|---|---|---|---|---|
| | 0 | 10 | 20 | 30 |
| Fineness (% Residue on 75µm Sieve) | 12.5 | 11.0 | 8.5 | 7.0 |
| Fineness (% Residue on 53µm Sieve) | 52.0 | 39.0 | 34.5 | 33.5 |
| Soundness ( mm) | 1.5 | 2.5 | 3.5 | 4.5 |
| Consistency (% ) | 30.0 | 30.0 | 31.0 | 31.5 |
| Water Requirement (% of control) | 100.00 | 100.2 | 104.2 | 104.8 |
| Initial Setting Time (min) | 50 | 75 | 83 | 105 |
| Final Setting Time (min) | 135 | 165 | 175 | 180 |

The Fineness Test (residue on75 µm and 53 µm sieve) shows that the blended cements were finer than the control (Dangote - Obajana) cement. Both 75 µm and 53 µm sieve was used since the VA had been made to pass a 75 µm, hence using a 90µm as specified by BS EN 196 – 6:2005 will be in-appropriate and a 45 µm was not available in the laboratory in F.U.T Minna. The higher the VA content in the blended cement the lower the residue observed in both cases. The Table also reveals that the soundness of the cement ranges between 1.5 and 4.5 for replacement levels of 0% to 30%. These values are far lesser than the 10 mm limiting value recommended by both NIS 439:2000 and BS EN 197 – 1:2000; hence the blended cement did not show any appreciable change in volume after setting.

The consistency increases from 30.0% to 31.5% as VA substitution increases from 0% to 30%. The water required for a standard consistency was noted to increase as the VA content increases, although this was noted to be within the limit of 115% as specified for Class N pozzolan in ASTM C618:2008.

The initial and final setting times increased from 50 to 105 minutes and 135 to 180 minutes respectively when percentage VA replacement increased from 0% to 30%. All the cement satisfy the NIS 439:2000 and BS EN 197 – 1:2000 requirements of 45 minutes minimum initial setting time and maximum of 10 hours final setting time as spelt out by NIS 439:2000 and the 375 minutes maximum specified for final setting time by ASTM C150. The variation of setting times with percentage VA replacements shows that both initial and final setting times increased as the percentage VA increased. As a result, the hydration process is slowed down in consonance with the views of Hossain (2003). The slow hydration means low rate of heat development which is one of the notable characteristics for which pozzolanic cements are known. This is of great importance in mass concrete construction where low rate of heat development is very essential as it reduces thermal stress.

A plot of the initial setting time against the final setting time as shown in Figure 1, indicates a very strong linear relationship with $R^2 = 0.891$ thereby giving $R = 0.944$. As stated by Johnson (1994), a strong relationship exists between two variables when $0.5 < /r/ < 1$. Thus an estimate of the final setting time can be calculated from equation 1 when an initial time has been obtained.

$$y = 0.838x + 98.71 \quad \ldots\ldots (1)$$

Where: y = final setting time, x = initial setting time

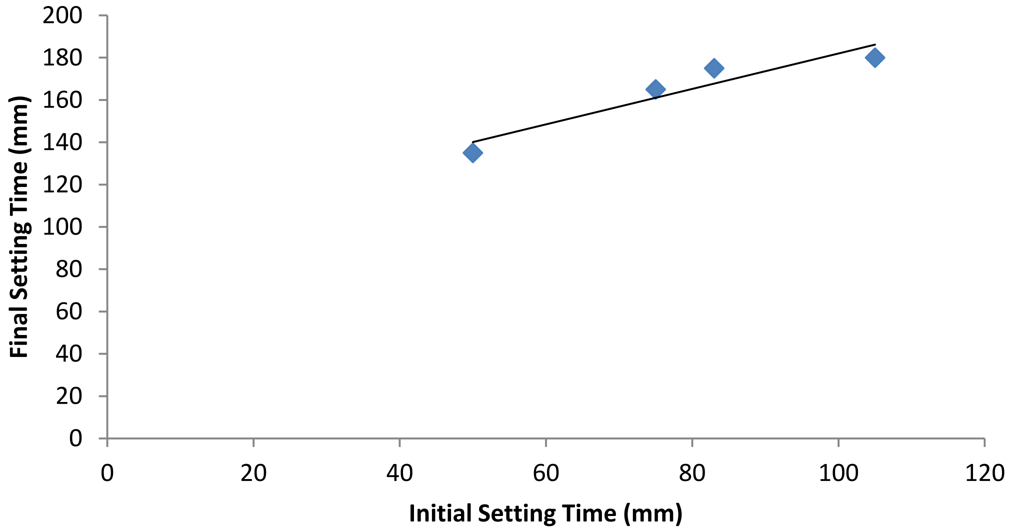


***Fig. 1: Relationship between Initial and Final Setting Times of VA-Blended Cement***

**CONCLUSION**

The volcanic ash sample obtained from Dutshin Dushowa (a hill) in Kerang Local Government Area, Jos, Plateau State, Nigeria is a suitable material for use as a pozzolan, since it satisfied the

requirements for such a material as spelt out in ASTM C618-2008 by having a combined $SiO_2$, $Al_2O_3$ and $Fe_2O_3$ of 70.99% which is more than the required 70%.
The VA-blended cement satisfies the NIS 439:2000; BS EN 196 – 6:2005 and ASTM C618:2008 requirements (for class N pozzolanas) even up to 30% substitution on the basis of fineness (residue on 53 µm sieve), soundness, consistency, and ASTM C150 :2008 for setting times.
The VA-blended cements have higher setting times than the control; hence, they are most applicable where low rate of heat development is required such as in mass concreting. This shows that VA-blended cement is good as low heat cement.
Efforts should be made at exploring the utilisation of the abundant deposit of volcanic ash spread over wide areas around Jos plateau with a view to its adoption as a supplementary cementitious material. The excavation and utilisation have to be controlled to avoid environmental degradation trends.

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