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COMPRESSIVE AND FLEXURAL BEHAVIOR OF POZZOLAN FROM PUMICE-CEMENT MORTAR

Oseni O.* & Audu M.

Department of Civil Engineering, University of Abuja, Nigeria

*Corresponding Author: *engroluwillioseni@yahoo.co.uk*

Abstract: The need to find alternative cementitious material in concrete works is inevitable because of high cost of cement. Pumice ash is a possible material that could be used as partial or total replacement for cement provided the compressive and flexural properties of the concrete from it meet the ACI/ASTM specifications. This paper present the chemical composition of pumice ash and the mechanical properties of pozzolan from pumice ash. It showed how the partial replacement of cement with pumice powder (ash) affects the compressive and flexural properties of the pozzolanas from pumice-cement mortar. 50g of pumice was collected to make five samples for the chemical analysis. The samples were crushed and grounded to powdered form. Chemical analysis of the pumice ash sample was carried out using the X-ray florescence (XRF Spectra IQ) technique. For the mechanical properties of the mortar from pumice powder, three samples of cubes and three samples of beams were made from pumice ash mortar at 5 %, 10 % and 15 % replacement of cement. The compressive and flexural strengths of the cubes and beam samples were determined in accordance with ASTM C 109 and C 348 respectively. The results showed that combination of Silicon Oxide, Aluminum Oxide and Iron Oxide of the pumice ash is 78.86 % which is greater than 70 %, the minimum requirement of a good pozzolan manufacturing of blended cement should meet. It was observed that the compressive and the flexural strengths of the mortar increased with age but decreased with increase in percentage of pumice ash in the mortar. At 28 days, the compressive stress of 0, 5, 10 and 15 % replacement were 58.4, 35.2, 31.2 and 30.0 N/mm2. Similarly, the flexural strengths of 0, 5, 10 and 15 % replacement were 9.71, 6.90, 6.55 and 6.20 N/mm2 at 28 days. The mortar mix can be classified as type M (ASTM C 109) which is applicable in construction of moderate loading walls and structures.

Keywords: *Compressive strength, flexural strength, fly ash, mortar, pozzolan, pumice ash*

1.0 Introduction

The search for alternative and economic utilization of cement composites in construction remains an important area of research towards the development of any nation due to high cost of cement and consequently construction. In developing countries like Nigeria where structures are built on daily bases, there is a need to provide a supplement or an alternative to the cement consumption that serves as an economic advantage and still provide the required service in terms of strength and durability. The use of pumice powder is one of such solutions that needed deep research. Further research needed to be carried out to help in providing the country with the needed cement replacement.

The sustainability movement has spurred renewed interest in reducing the cement content of concrete mixtures by replacing an ever-increasing portion of the Portland cement with Supplementary Cementitious Materials (SCM's) including; fly ash, lime stone powder, natural pozzolan (such as pumice) slag, and silica fume (Abdeel-rahaman, 2014). One key characteristics of fly ash and natural pozzolan is their capability to undergo a pozzolanic reaction with the calcium hydroxide produced during conventional cement hydration to produce an increased quality of calcium silicate hydrate gel (C-S-H), often leading to long term benefits including increase in compressive strength and decrease in transport coefficients (Dele, 2011). Pumice is an extremely light, porous raw material of volcanic origin it can be found in many parts of the world including various developing countries with areas of past and present volcanic activities (Mertens *et al.*, 2009). The Biu Plateau is the largest area of volcanic rocks in Nigeria. However, the Biu Plateaus in Adamawa Plateau is of common line and many other smaller volcanic occurrences is situated away from the Cameroon line without an obvious structural control of its location. The Biu Plateau has not been extensively studied but some geologists have made an appreciable attempt at describing the rock type in the area (Gabriel and Ibrahim, 2014).

Pumice is usually white or grey and a highly vacuolated pyroclasic material which at the moment of effusion was almost liquid. It has a forth-like appearance that results from the sudden release of dissolved vapors on solidification. Just as pumice is discovered, the history of pozzolanic materials goes back to Roman time (Alp *et al.* 2009). Pozzolan is a natural or artificial material containing silver as a reactive form. As per ASTM specification (ASTM C 270, 2012), a pozzolana is a siliceous and aluminous material which in itself processes little or no cementations' properties but in finely divided form and in the presence of moisture, it chemically reacts with calcium hydroxide at ordinary temperature to form compounds processing cementitious properties (Gupta, 2012)

Pozzolan are known to increase the durability, lower the heat of hydration, increase the resistance to sulphate attack and reduce the energy cost per cement unit (Jayewardene *et al.*, 2012). However, their influence on early and final strength development of the cement is not straight forward and seems to depend on a number of parameters such as; the texture of the material, the percentage composition of the chemical compounds, method of combustion, duration of time of storage and the reactive elements. The compressive strength properties of concrete are substantial factors in the design and construction of concrete structures. Compressive strength directly affects the degree to which the concrete can be able to carry load over time (Kauim, 2012).

In a research done by Jehad and Al-Zhoon (2014) it was reported that the chemical properties of pumice will vary from deposit to deposit but essentially pumice is primarily silicon dioxide (Amorphous aluminum silicate) some aluminum oxide and small amount of other oxides. Pumice “naturally calcine” which means that pumice has already had its time in the furnace, a volcanic furnace. Unlike metaloline, silica fumes and fly ash (artificial pozzolan), pumice is a natural pozzolan which does not need to be heated or calcined to change its chemical composition and make it useful as Pozzolan. According to the study by Khandaker and Hossaini (2004); high percentage of siliceous oxide gives the pumice its abrasive quality, thus it exhibits a chemical composition which can erode steel quality. The Al_2O_3 in the structure makes the pumice highly resistant to fire and heat. Na_2O and K_2O are the minerals which give the pumice the reaction sought after by the textile industry.

Abdeel-Rahman (2014) in a bid to determine the physical-mechanical characteristics of pozzolanic cement studied the effect of some artificial pozzolan as such as Fly ash (FA), Silica Fume (SF) as well as Nano-Silica (NS) on the hydration characteristics of blended cement pastes up to 90 days of hydration. Blended cements containing 10, 20 and 30 % by weight of fly ash as well as 5, 10, 15 % by weight of silica fume of Ordinary Portland Cement (OPC). The hydration and physical-mechanical characteristics of cement paste were investigated by the determination of water of consistency (W/C %), setting time, compressive strength. The results revealed that he substitution of 10 % of OPC by FA as well as 10 % gives good physic-mechanical properties. According to Alp *et al.*, (2009), while testing on pumice power for physical, chemical and pozzolanic activity test on samples, it was discovered that the raw material met the requirement of a natural pozzolan for use in the production of blended cement. The raw materials, acidic in character with $SiO_2 + Al_2O_3 + Fe_2O_3$ content of 78.86 % and a reactive silica content of 33.62 % was found to exhibit high pozzolanic activity in compression and flexural strength of 2.5 and 3.3 times higher respectively than those without silica content, showing that the material is a suitable for use in the manufacture of blended cements.

Considering the results of different tests obtained by Jayawardane *et al.* (2012) in determining the physical and chemical properties of fly ash based Portland Pozzolanas Cement, ordinary Portland cement has higher early strength while the blended cement has higher later strength.

2.0 Experimental Details

2.1 Determination of the Constituents of Pumice Powder

In other to determine the constituents of pumice powder i.e. characterization of pumice, X-ray florescence was used. The method was based on ASTM D 5381-93 (2014) (Standard guide for X-ray florescence (XRF) spectroscopy of pigments and extenders). The X-ray analysis with spectrometer, SIEMENS fluorescence X-ray, SRS 3000, was carried out at Nigerian Institute of Mining and Geoscience, Jos Plateau state.

2.1.1 Sample Preparation

50 g of pumice was collected. The sample was crushed and grounded using laboratory Dodge jaw crusher, roll mill and ball mill to reduce their size 200 mesh (74 µm) for chemical analysis. Five hand samples were prepared for thin section studies cutting, polishing and thinning process where performed using oil system. Glue that hardened under UV (ultraviolent) light was used.

2.1.2 Characterization of Pumice Sample

Chemical analysis of the pumice sample was carried out using the X-ray florescence (XRF Spectro IQ) technique, in accordance to ASTM D 5381- 93. The composition of the pumice sample was checked by the X-ray powder diffraction, by comparing of diffraction peaks against those of the ICDD cards. The target material was identified. The XRD data were collected using the Rigaku X-ray diffractometer with Cu ka (30Kv, 15mA, ^ = 0.154051nm) radiation at room temperature, scanning was done between 5^0 - 70^0 C. The measurements were made with 0.01 and 0.05 degree steps and 1 degree / minute. The divergence slit was variable. The scattering and receiving slit were 4.2 degree and 0.3mm.

As further characterization method, the FTIR analysis carried out in other to investigate functional groups of pumice. The IR spectrum material was measured in the rage of 400 to 4000 cm^{-1} by the KBr pellet method using Perkin Elmer spectrum one device. IR pellet was prepared using spectroscopic grade KBr with a sample (KBr – to sample ratio of 100mg: 3mg) KBr was dried at 180^0c for 12 hours before preparation of pellet. Surface area of the porosity value of the pumice sample was determined using a Tristar 300 (micro meritics instruments Co. USA). Surface Analyzer which was used to measure Nitrogen absorption isotherm at 77 Kelvin in the range of relative pressure from 10^0 to 1. Before measurement the sample was degassed at 400^0c for 2 hrs.

In other to investigate the morphology of the pumice sample, the Leo Evo 40 scanning electron microscope which does not need palletizing was used. SEM images where obtained from the pumice in powder form.

2.2 Percentage Replacement of Cement with Pumice Powder

Clean River sand was collected at the field in Gwagwalada and transported to the Julius Berger Plc (JBN Plc) quality assurance and control (QA & C) laboratory in Mpape, Abuja. Using ASTM standard ASTM C 778 (2014) (specification for sand). The particle size analysis carried out in accordance to ASTM D 422 (2014) (standard test method for particle size The cement that was used was the Dangote cement (Cem II) it is an Ordinary Portland Cement that has met the required ASTM standard ASTM C91 (2010) (specification of Masonry cement).The pumice which was obtained from Suleja, Niger state was transferred to the quarry, crushed to give a finer particle (powder) with a fineness that passes through sieve 0.63 mm. The water that was used was gotten from the borehole at the Julius Berger Nigeria, Mpape Quarry, ASTM D 1193 (2014) (Standard specification for reagent water) was used, pH value was checked and the other traces of anions was checked etc. contamination and presence of microbiological elements were checked.

2.2.1 Batching

The proportions of the materials by mass were one part of cement, three part of sand half (1:3) and Water/cement ratio of 0.5. The measurement was done using the weight balance with an accuracy of ± 1g. Each batch consists of 450g of cement, 1350g sand and 250ml of water.

2.2.2 Mix Design

The mortar mix design was done in accordance to the ASTM C270 (2014) (standard specification for mortar for unit masonry). This method gives the proportion in terms of quantity of the materials that was used. The percentage replacement of cement in the mixture was done at 5 %, 10 % and 15 % replaced of cement by pumice powder. The water cement ratio of 0.5 was used in the mixture, while the mixing of the different materials was done with an electric mixer using ASTM C305 (2012) (practice for mechanical mixing of hydraulic cement paste and mortars of plastic consistency).

After it was properly mixed, the mortar was poured into the beam moulds each of 40 x 40 x 160mm size. Each mould was filled to capacity, leveled and placed on an electric vibrator to remove voids. It was vibrated for 90 seconds. For each of the percentage mix nine cubes were produced. The beam moulds were taken and kept for 24 hours before the moulds were removed and the cubes were kept in the curing tank. The curing was done for 7, 14 and 28 days, after each of the curing days, part of the cubes were collected and allowed to day for about 2 hours before they are subjected to the tests. Figure 1 and Figur**e** 2 showed samples of pumice cubes and pumice beams for compressive and flexural strength tests.

Figure 1: Pumice cubes

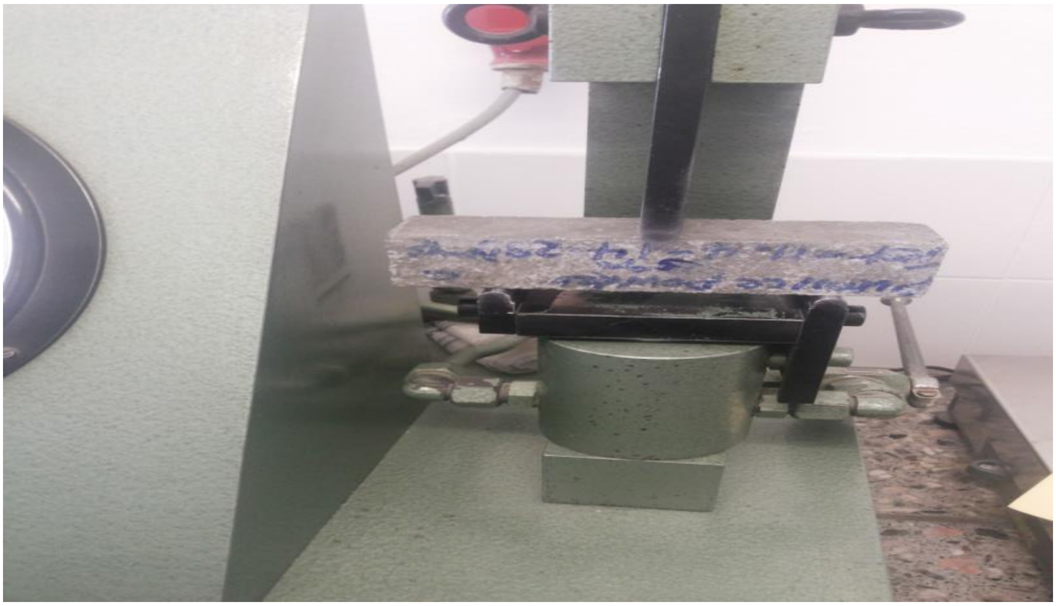

Figure 2: Pumice beam.

2.3 Tests for Compression and Flexural Strength

The compressive strength of the cube samples was determined in accordance with the procedure of ASTM C345 (2013) on compressive test machine as shown in Figur**e** 3. For each percentage replacement, three cubes were tested based on their maturity at; 7 days, 14 days and 28 days respectively. The flexural strength of the beams was gotten after subjecting it to mid-point line load on the compressive strength machine as shown in plate 4. Each of the cube samples were taken at 7 days, 14 days and 28 days to be tested for the flexural strength. The test was based on the ASTM C348 (2013) standard.

Figure 3: Compressive test on pumice cubes

Figure 4: Flexural strength test on pumice ash beam

3.0 Results and Discussions

Table 1 presents the results of chemical analysis of pumice ash. The materials are acidic in character with SiO_2 + Al_2O_3 + Fe_2O_3 content of 78.86 % and a reactive silica content of 33.62 %. Pumice ash is primarily silicon dioxide (Amorphous aluminum silicate) some aluminum oxide and small amount of other oxides. The high percentage of siliceous oxide gives the pumice its abrasive quality, thus it exhibits a chemical composition which can erode steel quality. The Al_2O_3 in the structure makes the pumice mortar highly resistant to fire and heat.

The results of compressive and flexural tests, as presented in Figure 5 and Figure 6, showed that there was an increase in compressive and flexural strength of the control mix (0 % pumice) from 45.8 N/mm^2 at 7 days, to 58.4 N/mm^2 at 28 days, and from 8.37 to 9.71 N/mm^2 at 28 days respectively. The results of the mix with 5 % pumice powder indicate that there was a discus in strength (compressive and flexural) when compared to that of the control mix. The 5 % mix shows compressive strength of 28.8 N/mm^2 at 7 days and 35.2 N/mm^2 at 28days strength. This showed a decreased of 17 N/mm^2 at 7 days and a decreased of 23.2 N/mm^2 at 28 days compared to the control mix.

The flexural strength of 5 % pumice was 5.83 N/mm^2 at 7 days and 6. 90 N/mm^2 at 28 days, thus a decreased in flexural strength of 2.54 and 2.81 N/mm^2 for 7 days and 28 days respectively. The 10 % pumice powder mix indicated a decrease in strength as compared to the control mix, with the compress strength of the mix being at 25.0 N/mm^2 at 7 days and 31.0 N/mm^2 at 28 days. This indicates a further decrease in compressive strength when compared to the control mix of 20.8 N/mm^2 at 7 days and a decrease of 27.4 N/mm^2 at 28 days. The flexural strength of the 10% pumice powder mix was 4.91 N/mm^2 at 7 days and 6.55 N/mm^2 at 28 days. At 15 % pumice powder, there is a decreased in compressive strength as compare with the control mix of 23.0 N/mm^2 and 30.0 N/mm^2 at 7 days and 28 days respectively. The flexural strength of the mix was 5.15 N/mm^2 at 7 days and 6.20 N/mm^2 at 28 days.

The result showed that the compressive strength of the pumice ash mortar is within the limits specified by the ASTM C 109 (2013) standard, which states that the minimum compressive strength of cement mortar type N, S and M of 28 days strength should be 750 psi (5.2 N/mm^2), 1800 Psi (12.4 N/mm^2) and 2500 Psi (17.2 N/mm^2) respectively

Table 1: Chemical characterization of pumice powder

ELEMENTS			OXIDE		
NAME	**SYMBOLS**	**%**	**NAME**	**SYMBOLS**	**%**
Potassium	K	1.517	Potassium oxide	K_2O	1.827
Titanium	Ti	0.791	Titanium dioxide	TiO_2	1.319
Magnesium	Mg	0.323	Magnesium oxide	MgO	0.536
Sulfur	S	0.090	Sulfur Trioxide	SO_3	0.225
Manganese	Mn	0.084	Manganese dioxide	MgO_2	0.133
Barium	Ba	0.086	Barium oxide	BaO	0.096
Strontium	Si	0.066	Strontium oxide	SrO	0.078
Zirconium	Zi	0.037	Zirconium dioxide	ZrO_2	0.050
Vananium	V	0.015	Divanadium Pentaoxide	V_2O_5	0.027
Cronium	Ci	0.016	Cronium (III) Oxide	CrO_3	0.023
Niobium	N6	0.011	Niobium (V) Oxide	Nb_2O_5	0.019
Hafnium	Hf	0.016	Hafnium (IV) Oxide	HfO_2	0.016
Rubidium	Rb	0.007	Rubidium Oxide	RbO	0.008
Nickel	Ni	0.004	Nickel (II) Oxide	NiO	0.007
Tunsten	W	0.005	Tungsten trioxide	WO_3	0.006
Tantanium	Ta	0.003	Tantalium (V) Oxide	Ta_2O_5	0.004
Silicon	Si	21.512	Silicon dioxide (Silica)	SiO_2	46.018
Alluminium	Al	10.718	Aluminium (III) oxide (Alumina)	Al_2O	20.252
Iron	Fe	6.206	Iron (III) oxide	Fe_2O_3	8.862
Calcium	Ca	2.133	Calcium oxide	CaO	2.984

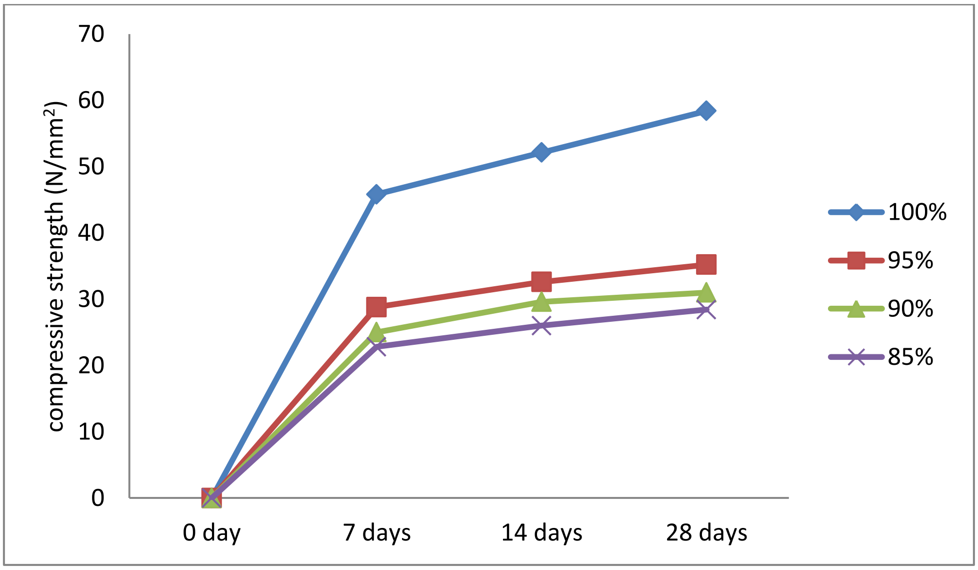

Figure 5: Compressive strength of various percentage replacements.

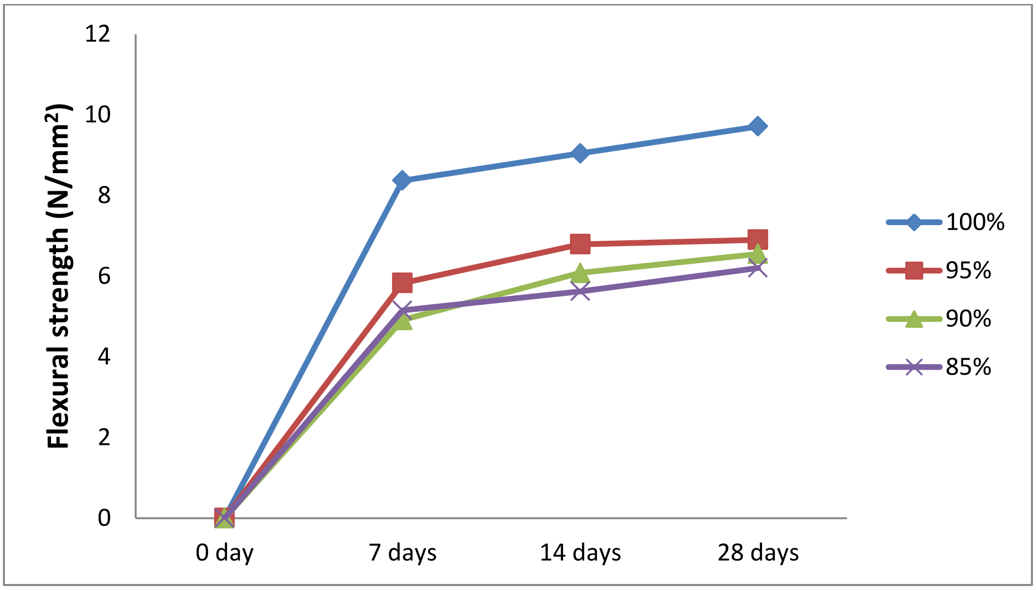

Figure 6: Flexural strength of various percentage replacements.

4.0 Conclusions

Since mortar mixes are classified basically on the compressive strength and their flexural properties at 28 days, the compressive and flexural strength results on the pumice ash mortar showed that the pumice mortar can be classified as type M (ASTM C 109) which is applicable in construction of moderate loading walls and structures.

- Pumice powder can be use as pozzolan due to its readily reactive aluminum and silicon content.
- Pumice powder can be used as partial replacement of cement in mortar mix.
- At 5% pumice powder replacement of cement, it exhibits its highest compressive and flexural strength as compared with 10% and 15% replacement.
- The percentage of cement replaced by pumice powder decreases the mortar strength when compared with 0 % pumice powder in the mixture.

5.0 Recommendations

The effectiveness at which the addition of pumice to mortar mix determines the compressive and flexural strength has been demonstrated. This enables the economical attainment of relatively low cost of construction. The value or percent at which pumice powder should be used to replace cement in mortar mix should be adequately assessed to determine the particular percentage needed to give required strength in any given circumstance.

References

Abdeel-Rahman, R,K. (2014) The Physico-mechanical Characteristics of Pozzolanic Cement; AThesis submitted in partial fulfillment of the requirement for Degree of Master Science in Inorganic Chemistry, Chemistry Department, Faculty of Science, Fayoum University Egypt.

Alp, I.; Devici, H. and Sungun, Y.H. (2009) Pozzolanic Characteristics of a Natural Raw Materials for use in Blended Cement, Iranian Journal of Science and Technology, Vol. 33 No. B4 pp 291 – 300.

ASTM C 91(2010) American Society for Testing Materials Specifications for Masonry Cement Mortar, ASTM International, West Conshohocken, PA, www.ASTM.org.

ASTM C109 (2013) American Society for Testing Materials, Standard Test Method for Compressive Strength of Hydraulic Cement Mortar, ASTM C109 / C109M – 13, ASTM International, West Conshohocken, PA, www.ASTM.org.

ASTM C 150 (2012) American Society for Testing Materials, Standard Specification for Portland Cement, ASTM C 150 / 150M -13, ASTM International, West Conshohocken, PA www.ASTM.org.

ASTM C 270 (2012) American Society for Testing Materials ,Standard Specification for Blended Hydraulic Cement, ASTM C 270, ASTM International, West Conshohocken, PA. www.ASTM.org.

ASTM C 345 (2013) American Society for Testing Materials, Standard Test Method for Compressiveal Strength of Hydraulic Cement Mortar, ASTM C 345, ASTM International, West Conshohocken, PA www.ASTM.org.

ASTM C 348 (2013) American Society for Testing Materials Standard Test Method for Flexural Strength of Hydraulic Cement Mortar, ASTM C 348, ASTM International, West Conshohocken, PA www.ASTM.org.

ASTM C 778 (2014) American Society for Testing Materials, Standard Specification for Fine Aggregates, ASTM C 778, ASTM International, www.ASTM.org

ASTM D 5381 (2014) American Society for Testing Materials, Standard Guide for X-ray Fluorescence (XRF) spectroscopy of pigments and extenders, ASTM D 5381 – 93. ASTM International, www.ASTM.org.

Dele, P.B. (2011) Comparison of ASTM C311, Strength Activity Index testing Vs testing based on Constant Volumetric Proportion. Journal of ASTM International Vol. 9(1) .

Gabriel, I.O. and Ibrahim S. K. (2014) Geochemical and Mineralogical Composition of Biu Basalt Deposit, Biu NE Nigeria. Research Journal of Environment and Earth Sciences 6 (5) 241-250.

Jayawardane, D.L.; UKwatha, U.P.; Weerakoon, W.M. and Pathirana, C.K. (2012) Physical and Chemical Properties of Fly ash based Portland pozzolana Cement, Civil Engineering Research Symposium

Jehad A.K.and Al-Zhoon, K. (2014) Effect of Volcanic tuff on the Characteristics of Cement Mortar Ceramica.

Khandaker, M. and Anwar H. (2004) Properties of Volcanic Pumice posed Cement and Lightweight Concrete; Cement and Concrete Research 34:283 – 291.

Kauim, M.R.; Zain, M.F.; Jamil, M.; Lari, M. and Islam, M.N. (2012): Strength of Mortar and Concrete as influenced by Rice Husk Ash; A Review . World Applied Sciences Journal 19(10) 1501 – 1513.

Mertens, G.; Snellings, R.; Van Balen, K. and Bicer-Simir, B. (2009) Pozzolanic Reactions of Common Natural Zeolites with Lime and Parameters affecting their Reactivity, Cement and Concrete Research 39: 233 – 240.