Partial Replacement of Ordinary Portland Cement (OPC) with Natural Pozzolanas (Jebel Marrah) Volcanic Ash in concrete

Mona. A. Gumma [1], **Abdurahman A. Mohamed** [2]

[1] Lecturer, Faculty of Eng - Sudan University of Science and Technology, Sudan

[2] Professor of Structural Engineering –Sudan University of Science and Technology, Sudan

Received: 27/01/2016
Accepted: 05/04/2016

***ABSTRACT*:** Considering the need for low-cost construction materials in the rural areas in Sudan, especially in Darfur, this paper examines ordinary Portland cement (OPC). The use of as a replacement of Jebel Marrah volcanic ash in concrete. The ash is obtained from Jebel Marrah (mountains), west of Sudan. These materials have been chemically and physically characterized.

Concrete cubes measuring 150mm*150mm*150mm were made from four different concrete mixes prepared by using pozzolana to replace 0%, 10%, 20% and 30% of OPC by weight. The workability of the fresh concrete mixes were evaluated using the slump test and compacting factor test while compressive strengths of concrete cubes were evaluated at 7, 28, and 90 days. The maximum compressive strength at all ages of testing was obtained at 20% replacement. Workability increased with an increase in replacement percentage and the strength of cement/ash concrete increased with curing period but decreased with increasing ash percentage. The results obtained showed that Pozzolana can be used to partially replace up to 20% of OPC in the production of concrete without compromising strength.

المستخلص– هدفت هذه الدراسة إلى استكشاف مواد بناء قليلة التكلفة كالبوزولانا فى المناطق الريفية فى السودان وخاصة فى ولاية دارفور, وذلك بسبب ارتفاع أسعار الأسمنت البورتلاندى.كما ركزت الدراسة على استخدام الرماد البركاني المستخرج من جبل مرة غرب السودان كبديل للأسمنت فى الخرسانة. حيث أكدت النتائج الأولية للتحاليل الكيميائية والفيزيائية مطابقة المواد للمواصفات.

لمعرفة درجة فاعلية البوزولانا تم إعداد أربعة خلطات خرسانية مختلفة, باستخدام مكعبات مقاس mm(150*150*150) بنسب مختلفة 0%, 10%, 20% و 30% من وزن الأسمنت. تم تحديد قابلية التشغيل للخرسانة الطازجة باستخدام إختبار الهبوط (Slump Test) بينما تم قياس مقاومة ضغط الخرسانة فى 7 يوم, 28 يوم و 90 يوم باستخدام ماكينة الإختبار العالمية (Universal– testing machine). وقد تم الحصول على أعلى مقاومة في جميع الأعمار عند استبدال 20% من الأسمنت, زادت قابلية التشغيل مع زيادة نسبة البوزولانا بينما زادت المقاومة مع زيادة نسبة البوزولانا حتى نسبة 20% ثم انخفضت للنسب الأعلى. أظهرت النتائج أن البوزولانا (الرماد البركانى) المستخرج من جبل مرة يمكن استخدامه ليحل محل جزء من الأسمنت بنسبة تصل الى 20% دون تأثير سلبي في المقاومة.

Keywords: *Volcanic Ash, cement, Natural Pozzolana, concrete, compressive strength, workability.*

INTRODUCTION

Concrete is the world's most utilized construction material [1].The ordinary Portland cement (OPC) is one of the main ingredients used for the production of concrete and has no alternative in the civil construction industry. The construction industry relies heavily on cement for its operation in the development of shelter and other infrastructural facilities. It then becomes extremely difficult for majority of the people to own their own houses or many collapse structures in attempt to reduce cost. Away out to this is to replace cement by natural materials with less cost such as pozzolanic materials. Pozzolanic materials do not possess any cementing properties of their own, but they contain silica and alumina in reactive form as stated in ASTM C 618 (2005) [8] and by LEA (1970) [9]. Ancient People, Romans produced exceptional cement by mixing pozzolanic materials with lime to build structures some of which are standing up to date [2]. Pozzolanic materials chemically react with calcium hydroxide in the presence of water from compounds possessing cementations properties [2]. The pozzolanic reaction are silica reactions in the presence of calcium hydroxide and water to produce calcium silicate hydrates (C-S-H), [3], [4]. C-S-H creates denser microstructure that increases strength, reduces the permeability of concrete and improves its resistance to chemical attack of cement as shown by Muller 2005[10] . The partial replacements of OPC by Pozzolana are known to improve the resistance of concrete to sulphate [5]. Thus, additives in modern cement, pozzolanas improve mechanical strength and provide resistance to physical and chemical weathering [2]. The addition of Pozzolana, also reduces pore size and porosity leading to increase the strength [6]. No test measures workability directly, but there are tests that measure properties related to workability. Workability is related to the compatibility, mobility and stability of fresh concrete [14],[19],[20].

The pozzolanas are classified into Natural and Artificial, the Natural Pozzolans (NP) are products of volcanogenic activities such as volcanic ash, volcanic tuff, pumice, shale and diatomaceous. Natural pozzolanas require no energy inputs prior to utilization, as stated by LEA (1970) [9] and Rafat (2011) [14]. Artificial Pozzolanas are residues of waste industrial and agricultural products such as fly ash and rice husk.

In Sudan volcanic deposits were reported by Suleiman, S.H.(2008) [22] to be found in Northern Bayouda, Gadarif, Miedob mountains, Tagabo, and Jebel Marra. Mamoun(2004) [15] characterized the volcanic ash from northern Bayouda and other natural pozzolanas such as (obsidian at Sabaloka, Natural burnt clay at southern bayoda, Diatomite at Gregrieb (gezira state). El-zamzami (2003) [16] studied and characterized kaolin from Dikera area in Eastern Sudan. Hamid (2002) [17] studied some fired clays pozzolanas (Blue Nile clay, kaolin clay, and black cotton clay). But as can be seen from available literature no researches have been carried out on the evaluation and characterization of Jebel marrah volcanic ash.

The main objective of this study is to investigate experimentally the effects of partial replacement of OPC with Pozzolana volcanic ash which is available in large quantities in Jebel Marrah [7], with reference to the effect on the workability and compressive strength of concrete.

MATERIALS AND METHODS

To reach the purposes of this research, an experimental laboratory study was adopted using the following materials, Outlines of the classification and properties of these materials are as follows:

1. Cement: The cement used was Ordinary Portland Cement OPC off strength class 42.5. Cement, procured from Berber Cement Company, was used throughout this research. It was standardized according to (EN-196-6 clause 4:1991, 2011/ 170-6) and BS 12:1996 [17].

2. Sand: White Nile sand, procured from Algitaina, was used in the study. The sand was washed, dried and sieved into different fractions. The sand was of a Specific gravity of 2.51 and Absorption of 0.9. It was standardized according to ASTM C-128[21].

3. Water: The Water from the public main supply was used for the production and the curing of the concrete cubes.

4. Course Aggregate: Uncrushed course aggregate, procured from Western Omdurman, normal size 20mm used with specific gravity of 2.53. It was standardized according to Bs 812 and ASTM-C172.

5. Volcanic ash (VA): The Pozzolana samples used in this investigation were collected from two regions of Jebel Marrah. They were classified by NVA and TVA for samples from, Nyertity area and Tina area respectively. Ashes from the two different sources were first studied for chemical composition. Then, the ash from Nyertity NVA was investigated in detail. The samples of NVA were obtained by pulverized quartering process, grounded and sieved to grain size of less than 45 µm, and then characterized using chemical, physical analysis. Table 1 shows the chemical composition of binder used in the study.

Four different mixes were used for the study. A mix of ratio 1:2:4 batched by weight using water- binder ratio of 0.47 was cast as a control mix. The control mix was produced using OPC only as binder while in other mixes, Pozzolana was used to replace 10%, 20%, and 30% of the mass of OPC in the mix. The details of mixes proportions are shown in Table 2. The slump test was used in assessing the workability of the fresh concrete mixes.

Casting of concrete was done in iron moulds measuring 150mm* 150mm* 150mm internally. Total of thirty six cubes were made. After casting the modules were covered with plastic sheet to prevent water loss through evaporation. Demoulding was done after 24 hours and the specimens immersed in curing tank containing clean water to cure for strength gain. Curing improves both the physical and mechanical properties of concrete. The compressive strength of the cubes were obtained from the crushing test at ages of 7,28 and 90 days of mixing was determined by ELE(UK) Auto test 2000 KN compression testing machine.

Before crushing the concrete cubes were removed from the curing tank and placed in open air in the laboratory for about two hours. The results presented are the average of three tests. All tests were conducted at the Concrete laboratory of the Department of Civil Engineering of Sudan University of Science and Technology.

RESULTS AND DISCUSSION

Chemical Properties of OPC, NVA and TVA:

The results of the chemical analyses of the NVA and TVA, shown in Table 3 with OPC results, indicated that the principal oxides: Silica oxide (SIO2), Alumina oxide (AL2O3) and Iron oxide (Fe2O3) were substantially present in the samples investigated with the sum of 86.75% and 87.03% for NVA and TVA respectively. The analyses also showed the presence of minor elements, within the limitations of ASTM-C618 for Pozzolana. The composition of volcanic ash suitable for use as a Pozzolana according to ASTM C618. Is (Silica = 45 - 65%), (Alumina + Iron oxide = 15 - 30%), (Calcium + Magnesium oxide + Alkalis ≤ 15%) and (loss on ignition ≤ 12%). These are satisfied by both NVA and TVA.

Physical properties of OPC and NVA:

The physical properties such as specific gravity and fineness (by sieving) of the cement and pozzolana used in this study were determined in accordance with ASTM-C 593-95.Table 4 shows the results obtained for OPC and NVA.

Workability:

The results of workability test are presented in Table 5 and Figure 1.

It can be seen from the results that as the percentage replacement of OPC with Pozzolana increases, the workability of concrete increases. This shows the effectiveness of Pozzolana, where it is working to generate a similar consignment and different from the consignment of cement. And their spherical morphology, Pozzolana materials are particularly beneficial to workability. The spherical particles act as small ball bearing to reduce interparticle friction and thus improve the workability.

Compressive Strength:

The results of compressive strength tests are presented in Table 6.

It is seen that from Figure 2. the average rate of strength growth is nearest for the normal mix for the first seven days, after which, the average rate of growth reduces to a constant, but relatively lower rate. The rate of strength gain with respect to time is highest for concrete with 20% replacement of OPC by NVA. This is due to optimum reactions which take place at 20% replacement.

The variation of compressive strength of the concrete mixes are presented in Figure 3. It is seen that the variation of strength shows similar trends with respect to Pozzolana replacement. In general, the compressive strength increases with age. Rise in replacement increases the compressive strength until a maximum strength was reached at 20% replacement of OPC with NVA. On further increase, the strength reduced as percentage replacement increased. This trend is similar at all ages of testing.

Pozzolanic reaction begins immediately after hydration of cement and continues for a long time, thereby increasing strength.

Concrete attained its maximum strength at a NVA replacement of 20%, corresponding to an increase of 13% in the 28-days strength compared to the control mix as can be seen from Figure 3. Similarly, the 7-days and 90-days compressive strength respectively show increases of 8% and 7% compared to the compressive strength of the control mix (Figure 3).

Concrete derives its strength from the Pozzolana reaction between silica in Pozzolana and the calcium hydroxide liberated during the hydration of OPC.

At low percentage of replacement, the quantity of silica is low, therefore only a limited quantity of (C-S-H) is formed, although a large quantity of calcium hydroxide is liberated due to the relatively large quantity of OPC. However, at high percentage replacement, the quantity of Pozzolana in the mix increases. (C-S-H) that can be formed reduces due to liberation of small quantity of calcium hydroxide from the hydration of the relatively small quantity of OPC available. The strength of concrete at both low and high percentage replacement is therefore low. An optimum level of replacement exists at which compressive strength is maximum. [9]

The variation of the relative compressive strength of concrete with time is presented in Figure 3. It can be seen that, with the exception of concrete with 20% Pozzolana replacement, as the age increases the strength ratio decreases even though the strength of concrete increases with age. This due to the rate of increases of the compressive strength of control concrete, which is higher than concrete at all Pozzolana replacement level with the exception of 20% replacement.

CONCLUSION

From the results of the tests and analysis carried out in this study, the following conclusions can be drawn.

1. There exists a high possibility of reducing the cost of concrete partial replacement of cement with (Jebel Marah) natural Pozzolana volcanic ash.
2. Replacement of cement with pozzolana significantly increased the workability of concrete.
3. Partial replacement of Ordinary Portland Cement with about 20% natural Nyrtity volcanic ash (Jebel Marah) in concrete enhances both workability and strength.
4. Replacement of 20% of the mass of cement with NVA resulted in the maximum value of compressive strength.
5. The 7-days, 28-days and 90-days compressive strengths at 20% replacement respectively showed increases of 7%, 14% and 9% compared to the compressive strength of the control mix.
6. NVA can lower heat hydration in concrete thus it can used in mass concrete structures such as dams, retaining walls, bridge abutments, and rafts wherein the rate of dissipation of heat of hydration from the surface is much lower than that generated.
7. The high increase in workability with replacement indicates the possibity of production of self compacting concrete using NVA.

REFERENCES

[1] British Standard Institution, BS 3148: Part 2 :1980, *Test of Water for Making Concrete*, BSI, London.

[2] Chengzhi Z., Aiqin W., Mingshu T. and Xiaoyu L, *Cement and Concrete Research, 1996, 26(6), 943-947.*

[3] British Standard Institution. BS 1881: Part102:1983.*Method for determination of slump, BSI. London.*

[4] British Standard Institution, BS 12:1996, *Specifications for Portland cement, BSI, London.*

[5] Jackson, P. J., (2004), “Portland Cement: Classification and Manufacture, Leas Chemistry of Cement and Concrete". 4 the, Ed, London: Arnold, pp. 61.

[6] Mindess, Sidney, Young J.Francis, Darwin, David(2003) Concrete 2nd edition Prentice Hall,pearson Education,Inc Upper Saddle River,NT 07458 U.S.A.

[7] “Jebel Marra Investigation, Report on Phase 1”, Studies for Ministry of Irrigation, Sudan. (Hunting Technology Services Ltd .London 1958)

[8] ASTM C618-(2005), Standard Specification for Fly Ash or Raw or Natural Pozzolan for Use as a Mineral Admixture in Portland cement Concrete, American Society for Testing and Materials,

[9] LEA, F.M. (1970), the chemistry of Cement and Concrete, 3rd. Edition, Edward Arnold, London.

[10] Muller C.J. (2005), Pozzolanic activity of natural clay mineral with respect to environmental geotechnics, doctoral diss., Swis Federal Institute of Technology, Zurich, Switzerland.

[11] Neville A.M. (2000), Properties of Concrete, 4th Edition Pearson Education Asia Publishing Limited, England, Produced by Longman Malaysia, VVP 2000.

[12] Naik, T.R., Practice Periodical on Structural Design and Construction. 2008,13(2),98-103.

[13] Ramezanianpour, A.A.(2014), "Cement Replacement Materials Properties, Durability, Sustainability", Springer-Verlag Berlin Heidelberg , P157.

[14] Rafat, S. (2008), "Engineering Materials Waste Materials and By-Products in Concrete". Springer-Verlag Berlin Heidelberg.

[15] Mamoun,E.M. (2004),"Natural pozzolanas in Sudan : characterization and factors affecting compressive strength of lime/pozzolana mortar", MSc thesis doctoral diss., University of Khartoum, Sudan.

[16] El Zamzami M.A., Mohamed E.A, (2006)." High temperature transformation in kaolinite reaction", *journal of BRR, vol. 7*, 24- 38 U. of K., Sudan.

[17] Hamid, M.H.(2002), "The Use of Fired Clays as a Pozzolanic Materials", *journal of BRR*, Vol.4, 67-74 U of K., Sudan,(In Arabic).

[18] British Standard Institution, BS12:1996, *Specifications for Portland cement. BSI, London.*

[19] British Standard Institution. BS 1881: Part 102:1983. *Method for determination of slump, BSI. London.*

[20] British Standard Institution. BS 1881: Part 103:1983. *Method for making test cubes from fresh concrete*, BSI. London.

[21] ASTM C128- Test Method for density specific gravity, and absorption of fine aggregate.

[22] Suleiman,S.H. (2008) Geological Report on Pozzolana Quarry Sites in the Bayuda Volcanic Field. Unpublished report Prepared for Nevkar sand for Investment Industry Transport& Construction Co. Ltd.

Table 1. Chemical Composition of OPC and Pozzolana

Component	Ordinary Portland cement % (by mass)	ASTM Type N Pozzolana% (by mass)
LOI	2.04	1.18
SiO2	18.24	78.71
CaO2	60.82	> 0.01
AL2O3	4.88	12.72
Fe2O3	3.47	4.49
MgO	3.20	0.33
SO3	3.25	> 0.01
Na2O	0.02	0.31
K2O	0.44	0.91

Table 2. Concrete Mix Details

Percentage replacement (%)	Mass of constituents(kg)			
	Cement	Pozzolana	Sand	Course Aggregate
0	7	0	14	28
10	6.3	0.7	14	28
20	5.6	1.4	14	28
30	4.9	2.1	14	28

Table 3: Chemical Properties of OPC,NVA,TVA

Materials	Chemical Composition %								
	SiO_2	**AL_2O_3**	**Fe_2O_3**	**CaO**	**MgO**	**SO_3**	**K_2O**	**Na_2O**	**LOI**
OPC	20.62	4.38	3.62	62.58	2.77	2.42	0.41	0.28	2.3
NVA	64.558	16.313	5.879	1.300	1.068	0.027	5.065	4.151	2.2
TVA	62.461	18.471	6.095	1.286	0.709	0.030	4.614	4.892	6.6

Table4. Physical Properties of OPC and NVA

Material	Specific Gravity	Fineness measured		Fineness Requirements	
		Passing sieve No %		BS-12 1996	ASTM-C 595
		90 micron	45 micron	%	%
OPC	3.15	98	-	10	-
NVA	2.5	-	86	-	34

Table 5: Result of Workability Test

Workability	**Cementing Replacement %**			
	0	10	20	30
Slump (mm)	30	55	60	70

Table 6: Compressive Strength (N/mm²) of Mixes

Age at Testing(days)	Pozzolana Replacement %			
	0	10	20	30
7	27.5	26	29.6	24
28	34.6	34.5	38.9	29.6
90	41.8	41.3	44.6	37.6

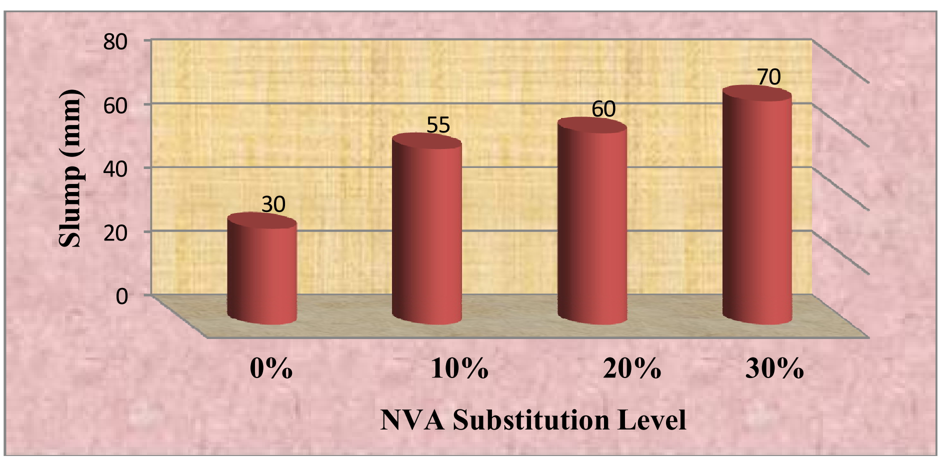

Figure 1. The effect of NVA replacement on workability

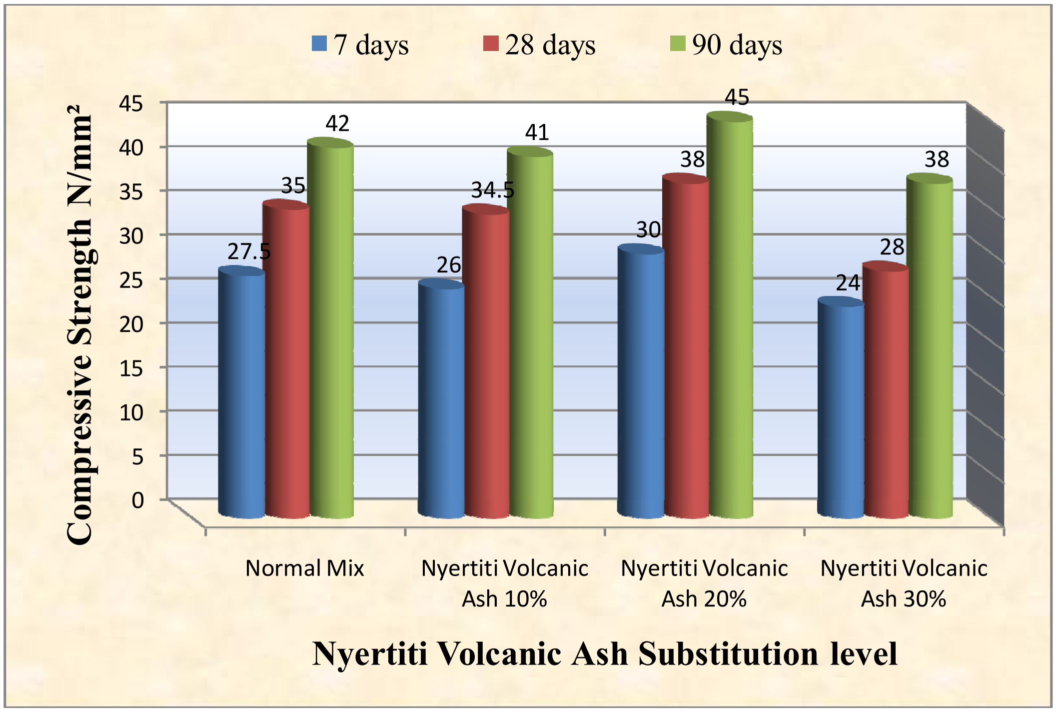

Figure 2. Compressive strength of mixes

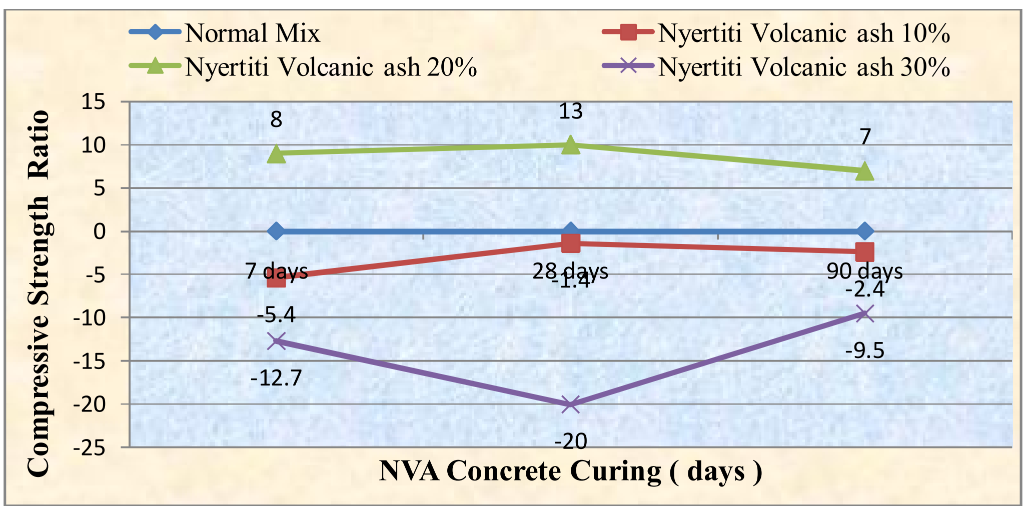

Figure 3. Variation of Relative compressive strength of concrete