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Evaluation of Jebel Marra Volcanic Ash as Supplementary Cementitious Material for Use in Blended Cements

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Abstract: - The increasing cost and scarcity of portland cement has impacted negatively on the delivery of affordable housing and infrastructural development in many parts in Sudan, especially in Darfur. This paper focused on the evaluation of the pozzolanic characteristics of the volcanic ash obtained from Jebel Marra (mountains) west of Sudan as potential Supplementary Cementitious Materials for use in blended cement and concrete. The study investigated the chemical, physical, and mineralogical characteristics of the volcanic ash and its reactivity toward lime and cement, in addition , the compressive strengths of blended mortar containing volcanic ash in percentage addition were tested at 7, 28, and 90 days. X-Ray Fluorescence and X-ray diffraction techniques were used for chemical and mineralogical analysis respectively. The results of the chemical analysis showed that the sum oxides of Silica, Alumina and Iron were 83.75%. The strength reactivity with lime was 4.2Mpa, while the 28-days compressive strengths for the replacement level with cement 10%, 20%, 30%, 40%, and 50% were 38.9, 35, 29.33, 28.64, and 25 Mpa respectively, against 41.33Mpa., for the control mix. These results indicated that the Jebel Marra Volcanic Ash possesses pozzolanic characteristics and is thus potential cementitious material for use in blended cement.

Keywords: - *Blended cements, Cementitious material , compressive strength , pozzolanic reactivity, volcanic ash.*

I. INTRODUCTION

Nowadays, pozzolanic materials are widely used as supplementary cementing material in Portland cements and may replace part of the clinker in order to enhance the performance of the hydrated cement. Such composite or blended cements are employed for their economic, ecological and technological benefits. Energy consumption as well as CO2 emission is reduced. Supplementary cementing materials reduce lime content in hydrated Portland cements and replace it with pore-filling cement hydrates, which are known to improve the ultimate strength, impermeability and durability to chemical attack of cement Muller (2005) [1]. Blended cements (Portland Pozzolona Cement) can generally be used wherever Ordinary Portland Cement is usable under normal conditions. It is particularly useful in marine and hydraulic structures and large mass concrete structures.

Considering the need for low-cost cementing materials especially in Darfur, the production, and the use of the low cost blended cement using materials such as volcanic ash which is available in large quantities in Jebel Marra [2], become of a very great importance. The partial replacement of Portland cement by volcanic ash in mortars and concrete, when available, may be better in practice and lead to an economic solution.

II. BACKGROUND

Pozzolanas are defined as siliceous or siliceous and aluminous materials, which in themselves possess little or no cementitious values but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties, (ASTM C618(2005) [3] and LEA (1970) [4]. The pozzolanas classified into Natural and Artificial; the Natural Pozzolans (NP) are products of volcanogenic activities such as volcanic ash, volcanic tuff, pumice, shales and diatomaceous. Natural pozzolanas requiring no energy inputs prior to utilisation. LEA (1970) [4] and Rafat (2011) [5], while the Artificial Pozzolanas are residues of waste industrial and agricultural products such as fly ash and rice husk. Definition of pozzolanic reaction is the chemically reaction between a pozzolana (S) and calcium hydroxide (CH) in the presence of water (H). It can be generalized by the simplified equation shown in Equation(1), Ridho (2011) [6]. S + CH + H = C-S-H ………………………………….(1)

There are many benefits of using pozzolanic materials in cement and concrete amongst them are:
1/ Their ability to convert calcium hydroxide to calcium silicate hydrate (C-S-H), therefore, the capillary voids are either eliminated or reduced in size. This in turn improves cement-concrete material such as strength and durability of the hydrated paste. 2/ Pozzolans can also be used as cement replacement material (it is also economical since most pozzolanas are cheaper than cement they are replaced).

In Sudan volcanic deposits were reported, in Northern Bayouda, Gadarif, Miedob mountains, Tagabo, and Jebel Marra. Mamoun(2004) [7] 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) [8] studied and characterized kaolin from Dikera area in Eastern Sudan, and Hamid (2002) [9] studied some fired clays pozzolanas (Blue Nile clay, kaolin clay, and black cotton clay), but there are not any researches have been carried out on evaluation and characterization of Jebel marra volcanic ash.

III. MATERIALS AND METHODS

3.1. Materials

To reach the purposes of this research, an experimental laboratory study was developed using the following materials:

3.1.1. Cement and sand

Ordinary Portland cement (OPC) procured from Atbara cement company was used throughout this research . River sand procured from Wadi Nyala, was used in present study. The sand was washed, dried, and sieved into different fractions, it was standarized according to IS: 650 (1991) [10] to three grades - fine (90 µm to 500 µm), medium (500 µm- 1mm) and coarse (smaller than 2mm-and greater than mm) fractions.

3.1.2. Volcanic ash (VA)

Samples used in this investigation were collected from two regions of Jebel Marra. They were classified by KVA and MVA from Kass area (latitude 12°31'28.65"N, longitude 24°17'7.39"E), and Malam area (latitude 12°43'23.45"N, and longitude 24°51'38.08"E) respectively. Ashes from two different sources were first studied for chemical composition. Then, the ash from Kass area KVA was investigated in detail, The representative samples of the KVA was obtained by pulverized quartering process and grounded and sieved to grain size of less than 63 µm, and then characterized using chemical, physical, and x-ray diffraction analysis .

3.1.3 Lime

Lime used in this study is Hydrated lime(CH), the source of raw material for the production of lime (CH) is the Marble procured from Juruf area 60 km North to Nyala city latitude (12°32'1.12"N) longitude (25° 1'30.82"E). The raw material was calcined at 975 c for 3 hours, the produced quick lime (CaO) was slacked and ground to pass 90 micron sieve.

3.1.4. Water: Water from the public main supply was used for the production and the curing of the mortar cubes.

3.2 Methods

3.2.1 Testing of pozzolanic reactivity

As a primary step in this investigation, the pozzolanic reactivity of KVA with lime and Portland cement was examined in the term of compressive strength following the procedures described in IS:1727 (1967) [11]. For determining the reactivity of the pozzolanic material with hydrated lime, the standard mortar cubes of 50mm was prepared, cured, and tested accordingly. The mix of CH: KVA: standard sand in proportion (1: 2M: 9) by weight was used, where M :is the ratio of Specific gravity of pozzolana to Specific gravity of lime.

For the pozzolanic activity with OPC, A control mix was prepared in 50 mm cubes moulds. The control mix was produced using OPC only as binder, while in other mix, KVA: OPC: standard sand in proportion(1: 2N: 9) by weight were casted, cured, and tested at 7, and 28days, where N is the ratio of Specific gravity of pozzolana to Specific gravity of cement. The details of mix proportions are shown in Table 1.

Table1. Mix proportions for pozzolanic reactivity with CH and OPC following IS: 1727 (1967) [11]

Control Mix		Pozzolana-cement mix		Lime – pozzolana mix	
Component	Amount (g)	Component	Amount (g)	Component	Amount (g)
OPC	450	OPC	400	Lime – $Ca(OH)_2$	150
KVA	0	KVA	82	KVA	136.5
Standard sand	**1350**	Standard sand	**1350**	Standard sand	**1350**
flow	**105 ± 5**	flow	105 ± 5	flow	**70 ± 5**

3.2.2 Preparation of blended cement mortar

A control mix was prepared in 70.7 mm cube moulds (area of face 50 cm^2) composed of one part of cement, three parts of standard sand by mass, and (P/4 + 3.0) percent (of combined mass of cement and sand) water, (where P is the standard consistency), and prepared, stored and tested in the manner described in IS 4031:

Part 6 (1988) [12] The ground KVA was used to replace 10%, 20%, 30%, 40% and 50% of the mass of ordinary cement in the control mix., compressive strengths of all the mixes were measured at 7,28, and 90 days. The details of mix proportions are shown in Table 2.

Table 2. mix proportions of blended mortar

Mortar Code	Blending ratios (by weight %)	
	CEMENT	VOLCANIC ASH
CTR	100	0
KVA 10	90	10
KVA20	80	20
KVA30	70	30
KVA40	60	40
KVA50	50	50

IV. RESULTS AND DISCUSSIONS

4.1 Chemical properties

The results of the chemical analysis of the KVA and MVA as shown in Table.2 indicated that the principal oxides of Silica (SIO_2), Alumina (AI_2O_3) and Iron (FE_2O_3) were substantially present in the samples investigated with the sum oxides of 83.75% and 76.33%, respectively. The analyses also showed the presence of minor element, while the LOI of the sample evaluated was 2.2% and 6.6% KVA and MVA respectively. These results are within the limitations of IS: 1344 (1981)[13]. The chemical analysis results of marble and OPC are also within the limitations of IS: 712 (1984) [14] and IS: 8112 (1998) [15] respectively. The Composition of volcanic ash suitable for use as a pozzolana is (silica = 45-65%), (Alumina + Iron Oxide =15 -30%), (Calcium + Magnesium Oxide + alkalis ≤15%), and (Loss on ignition ≤ 12%).

Table 3. Chemical properties of OPC, KVA, MVA, and Marble

Material	Chemical Composition (%)								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	LOI
OPC	18.4	5.6	3.0	66.8	1.4	2.8	0.5		2.0
KVA	63.1	15.3	5.33	0.864	0.291	0.022	5.23	2.35	2.2
MVA	56.5	15.5	4.33	2.22	0.6522	----	3.90	4.3	6.6
Marble	2.823	1.301	1.156	56.117	0.485	0.007	0.081	0.273	37.5

4.2 Physical properties of materials

The physical properties such as specific gravity and fineness (by sieving and specific surface) of the cement, pozzolana, and lime used in this study were determined in accordance with IS 4031: (1988) [12]

Table4. Physical Properties of OPC, KVA, and Marble

Material	Specific Gravity	Fineness measured			Fineness Requirements	
		Passing sieve No %		Blaine Surface area cm^2/g	IS: 8112-- (1998) [15]	IS: 1344- (1981)[13]
		90 micron	45 micron		cm^2/g	cm^2/g
OPC	3.15	94	-	2650	2250	
KVA	2.4	100	87	5753		3250
lime	2.4	98	-	2028		

4.3 X-ray diffraction (XRD)

X-Ray Diffraction (XRD) technique is used to analyze the crystalline phases of a material. A representative XRD pattern of the KVA sample was shown in Figure 1. The gradual dense scatter of XRD graph for the KVA mineral (quartz and anorthite) indicated the amorphous state of a material.

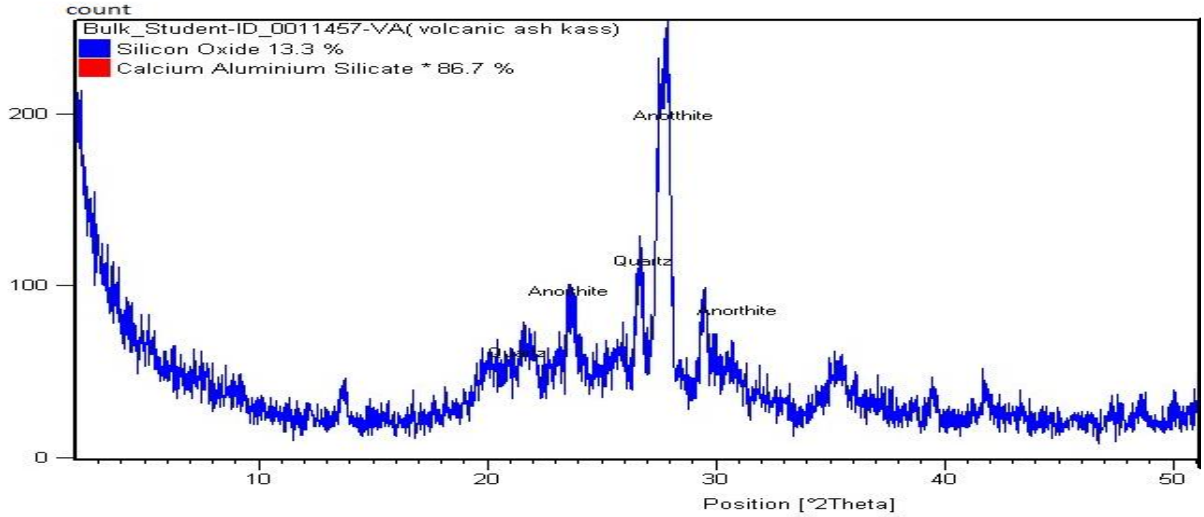

Figure 1. XRD graph of KVA

4.4 Reactivity test results

The reactivity of KVA toward lime and OPC is measured through the compressive strength of standard mortar tests according to IS: 1727-(1967) [11]. The results of the KVA reactivity with lime is 4.2 Mpa. at age of 8 days, IS-1344 (1981)[13] required a minimum of 4.0 Mpa., while the compressive strength with OPC were, 34.67, and 37.73 Mpa , at 7, and 28 day respectively, against 37.67, and 43.34 Mpa, for the reference mortar. The strength reactivity of KVA at 28 days is therefore 87%. IS-1344 (1981)[13] required a minimum of 80% of the strength of corresponding reference mortar in case of pozzolana to be used for manufacture of Portland pozzolana cement.

4.5 Physical properties of blended mortars

4.5.1 Water consistency and setting time limits

The results presented in table 5, indicated that addition of KVA retarded the setting; however this retardation was negligible and was within limits as specified in IS: 4031 (1988) [12]. It could have been caused due to the adsorption of water at the surface of KVA with higher surface area. The higher the proportion of KVA, the higher was the adsorption of water and hence higher amount of water retarded the setting time. Most natural pozzolanas tend to increase the water requirement in the normal consistency test as a result of their microporous character and high surface area ACI 232.1R(2000}[16].

Table 5. Water consistencies and setting times for control and blended mortar

Mix	Water consistency (%)	Initial Setting time (min)	Final setting time (min)
CTR	0.320	75	150
KVA 10	0.325	75	160
KVA20	0.328	80	165
KVA30	0.332	85	175
KVA40	0.335	95	185
KVA50	0.34	100	190
IS:4031(1988)[12]		60	600

4.5.2 Compressive strength results

The results of the compressive strength tests shown in Figure 2 and table 6, indicated that 10, 20, 30, 40, and 50 % addition of the KVA provided 38.9, 34.66, 29.33, 28.64, and 24.67 Mpa respectively compared with 41.33 Mpa of the control cubes compressive strengths tested at 28 days curing. However 10 % and 20% addition of the KVA provided 94 and 84 % respectively of the control cubes compressive strengths at 28 days. These percentages additions met the IS: 1344 (1981) [13] specifications. From the results of compressive strength, the use of volcanic ash at 10%, and 20% substitutions showed minimal depression of compressive strength when compared with the compressive strength of reference mortar for all ages. Lower strengths were obtained for those blends with higher substitution levels at 7, and 28 day. A similar growth rates to the reference mortar were observed for 10%, 20%, and 30% substitution levels. However for 40%, and 50%, the growth rates were identical for all ages.

Table 6. Compressive Strength of KVA blended mortar at 7, 28, and 90 days (Mpa)

Mortar Code	Age of specimen		
	days 7	28 days	91 days
CTR	36.67	41.33	51
KVA 10	35	38.9	50.7
KVA20	33	35	48
KVA30	27.73	29.33	46.3
KVA40	20.67	28.64	44.4
KVA50	18	25	33.4
IS: 1489-1981 [17].	22	33	

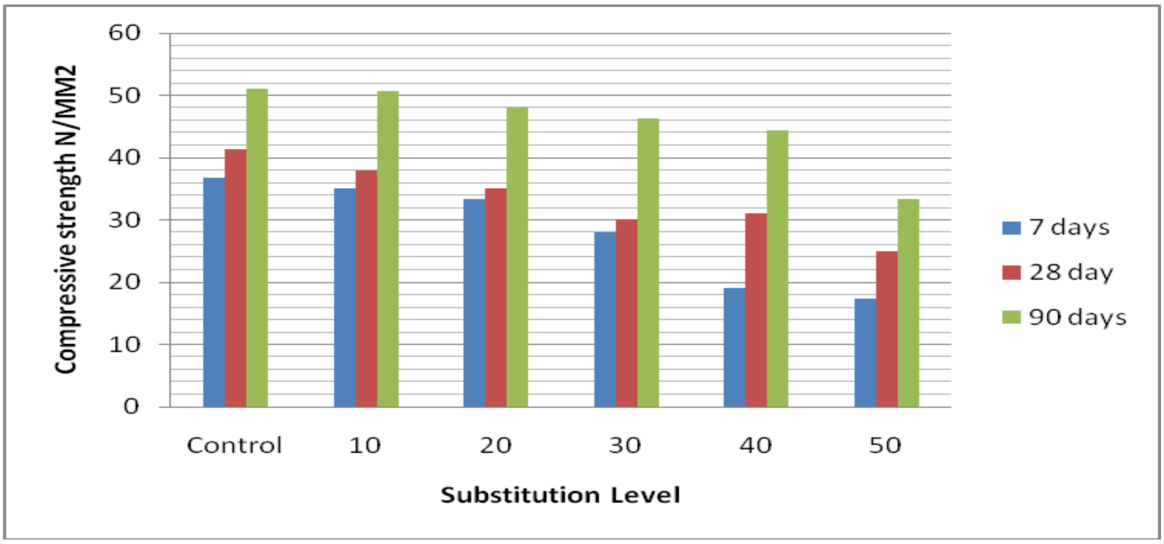

Figure 2. Compressive Strength of KVA Blended mortar

4.5.3. Normalized compressive strengths

For the purpose of considering the normalized plot, it is useful to consider the contribution of the pozzolanas relative to the level of substitution. That is, an "inert" strength would be that of the cement if the pozzolana addition did not contribute any improvement in compressive strength. An inert strength for a 20% substitution would be less than 80% of that determined on the control cement (considering the change in binder to aggregate ratio).

The results of volcanic ash blends (table 6 and figure 3) showed increased normalized compressive strengths levels over the inert strength for the 10%, and 20%, blends at all ages. For the 30% blend, the 7 day strength was in line with inert strength, but 28 and 90 day were higher. For the 40%, and 50% blends, the 7 day strength was behind the inert strength, but 28 and 90 day were higher.

Table 7. Normalized Compressive Strength of KVA blended mortar at 7,28, and 90 days

Specimen	Age of specimen			
	days 7	28 days	91 days	Inert Strength
CTR	100	100	100	100
KVA 10	95	94	99	90
KVA20	90	85	94	80
KVA30	75	70	91	70
KVA40	56	69	87	60
KVA50	49	60	65	50

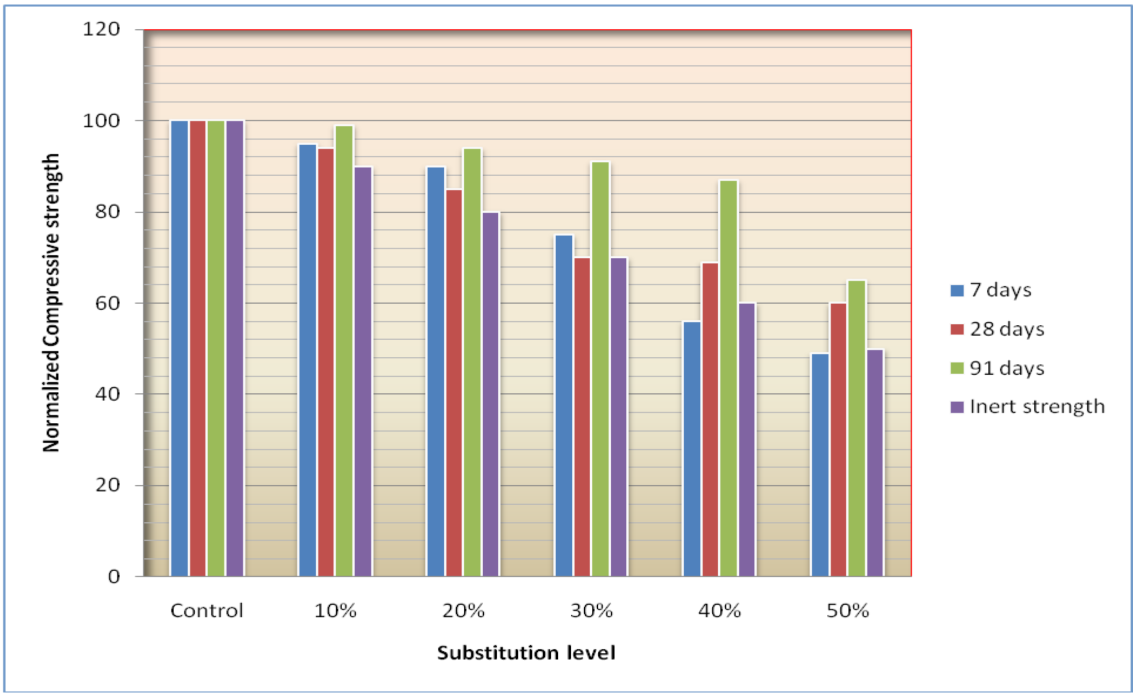

Figure 3. Normalized compressive strengths

4.6. Summary of findings

(1) The oxides of SiO2, Al2O3 and Fe2O3 were 63.123, 15.3, and 5.327 % respectively with a sum average of 83.75%.

(2) The presence of Alkalis - Na2O (2.35%) and K_2O (5.23%) was 7.58 %.

(3) The presence of (Calcium (0.864%) + Magnesium Oxide (0.291%) + alkalis (7.58 %.)), were ≤15%

(4) Loss on Ignition of the kva sample was 2.2 %. IS: 1344 - 1981 recommend a maximum 12% for a material to be used as a pozzolana

(5) The strength reactivity of KVA with lime was 4.2 Mpa, IS:1344 (1981)[13] specifies a minimum of 4.0 Mpa

(6) The strength reactivity of KVA with OPC at 28 day was 37.73 Mpa, against 43.34 Mpa for control mix, with a ratio of 84%. IS:1344 (1981)[13] specifies a minimum of 80% of the reference for pozzolana to be used for manufacture of Portland pozzolana cement

(7) The compressive strengths at 28 day of mortar containing the KVA materials in 10, 20, 30, 40, and 50 % additions were 38.9, 34.66, 29.33, 28.64, and 24.67 Mpa, respectively as against 41.33 Mpa of control cubes at 28 days crushing.

V. CONCLUSIONS

The evaluations of the chemical and physical characteristics of the KVA, beside the reactivity and compressive Strengths of blended mortar containing the KVA material, indicated that the materials met the IS: 1344 (1981) [13] Specifications for a Pozzolanas to be used in blended cements. It is thus conclusive that the Jebel Marra Volcanic ash possesses pozzolanic characteristics as supplementary cementitious materials for use in cement blending.

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