Utilization of Jebel Marra Volcanic Ash as Low Cost Material in Concrete Hollow Blocks in Darfur, Sudan

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ABSTRACT Concrete hollow blocks (CHB) have an important place in modern building industry, and although the CHB is considered a better alternative to fired bricks from the ecological and economical points of view, however, its prices are still high, since the main cost-factor is the ordinary Portland cement (OPC). This study is mainly focusing on the utilization of volcanic ash (VA) from Jebel Marra as a low cost material for CHB. In this study a VA sample from Jebel Marra (Al-malam area) was investigated for its physical and chemical properties, different substitution levels of 10, 20, 30, 40, and 50% of the OPC with pozzolanas were tested. Combined aggregates of locally available sand and stone aggregates were also tested for their economical value of fineness modulus. Then the potential use of these materials was implemented in (CHB) with different blends and mix ratios. The results of the chemical and physical analysis of the VA showed their compliance to the international specifications. The strength activity index of the mix containing 20%VA of the OPC weight at 28 days was 87%. If consider 3.5 MPa as the minimum compressive strength of load bearing CHB required by the Indian standard, it can be concluded that the VA can be used successfully as low cost material in the CHB with the substitution level up to 40%, 30%, and 20%, for binder aggregates ratio by volume 1:6, 1:7, and 1:8, respectively, with subsequent reduction in binder cost by 34, 26, and 17%, In addition, increasing the compressive strength of blocks can be achieved by using high pressure blocks making machine.

Keywords: Blended Cement, Fineness Modulus, Hollow Blocks, and Volcanic Ash.

1. INTRODUCTION

The concrete hollow block (CHB) is the main building material for walls of single-storey buildings (such as houses and schools in Nyala) South Darfur State. Measured strengths of commercially available CHB in Nyala was found to be between 0.5 and 2 N/mm², which is well below the 3.5 N/mm² that is required there [1]. This may be due to the need of the manufacturers to keep the price low, and since the main cost-factor is the ordinary Portland cement (OPC), they reduce the OPC content results in a block that starts behaving more like loose sand. since the price of OPC in Darfur (about more than 1000 km from the capital Khartoum) is very high comparing with the cost found in the rest of

Sudan. Therefore, viable alternatives need to be found to keep the production cost of concrete hollow blocks competitive. Lime, volcanic ash, and other pozzolana are viable alternative binders, and several deposits of limestone and pozzolanas exist in Darfur [2].

2. BACKGROUND

The OPC has a clearly defined role as a binder in fulfilling the functional requirements for high-strength applications. However, in actual construction practice, has become a ubiquitous material, largely as a result of its wrong application in construction. The OPC is predominantly used in low-strength applications, i.e. for non-structural uses such as plasters, mortars, and soil stabilization. This improper

application of the OPC is not only unnecessarily costly but, more important, technically defective.

The degree to which Portland cement is wrongly applied in construction has reached alarming proportions, and it is estimated that only 20 per cent of the worldwide use of cement requires the strength of Portland cement [2].

A Pozzolan is defined as “a siliceous or siliceous and aluminous material that in itself possesses little or no cementitious value but that will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide (this can be a free lime from cement hydration reaction or added lime (Ca(OH)_2)) at ordinary temperatures to form compounds having cementitious properties” [3] – [5]. The quantification of the capacity of pozzolana to react with calcium hydroxide or the OPC and water is given by measuring its pozzolanic activity. Natural pozzolanas are abundant in many locations in Darfur and are extensively used as an addition to the OPC.

The CHBs have an important place in modern building industry. They are better alternative to burnt clay bricks from the ecological and economical points of view, if pozzolanic materials are used to replace a part of Portland cement, which considered as the main cost-factor in the production of CHB. Fired clay bricks continue to be the preferred construction material in Darfur and widely used, despite its serious environmental consequences. Environmental problems associated with fired clay bricks is deforestation, as a result of the massive use of firewood in its production. It is estimated by different sources that one third of the forests in Darfur was lost between 1973 and 2006.[6]. If all estimated 400,000 families currently displaced in Darfur return to their places of origin and reconstruct their destroyed homes utilizing the traditional building practices, with wood as the main structural element, they will need to find and cut an estimates of 16 million mature trees. In light of the ongoing documented deforestation, this would be an environmental and economic disaster that must be avoided [6].

In the Sudan, both natural and artificial pozzolana were reported, and the first attempt to use pozzolana in Sudan dates back to the period

1919–1925, during the construction of Sennar dam. Reference [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). The existence of VA in Marra mountain, Miedob mountain, and Tagabo were reported [8] – [10]. Jebel Marra is the name given to a very large complex of volcanic rocks, about 100 km north to the town of Nyala in South Darfour State, which extend for over 200 km to the north. It is 80 km wide at its broadest part. The southern area of the volcanic rocks is generally known as Jebel Marra after the highest ground, while the northern parts are centered around Jebel Gurgei [11], Tagabo and Miedob Mountains are the extension of these mountains. Its Reported that the area covered by VA in Jebel Marra is estimated to be 3700 sq. km.[12].

3. MATERIALS AND METHODS

3.1 *Materials for manufacturing Concrete Hollow Blocks (CHB)*

In Darfur, the most common and readily available material that can be used to partially replace cement without economic implications are VA, from Jebel Marra. The Materials used for making CHB in this study are OPC, VA, sand, stone chips, and water.

1. *Cement:* The OPC procured from Atbara cement company was used throughout this research, the cement was tested according to Indian standard [13] for its consistency, setting times and fineness.

2. *Pozzolana:* Jebel marra volcanic ash from al malam areas was used in this study. The samples were ground and sieved to desired fineness using grinding machine to a grain size less than 45 micro meter and then characterized using chemical and physical analysis. According to (IS 1727) [14].

3. *Combined aggregates*

The proportion of fine aggregate to coarse aggregate affects the strength of concrete hollow blocks. The local manufacturers are not aware of this factor, although the locally available aggregates have various grading. In this study the sand from different sources and stone chips have been analyzed for grading and fineness modulus

to obtain the optimum fine to coarse aggregate proportions for manufacturing CHB.

Fineness Modulus (FM) is a term used as an index to the fineness or coarseness of aggregate. This is the summation of cumulative percentage of materials retained on the standard sieves divided by 100. In general, a smaller value indicated a fine material while a larger value indicates a coarse material. The value for fine aggregates commonly ranges from 2.00 to 4.00 and for coarse aggregate from 6.50 to 8.00 when all the material is finer than the (38.1-mm) sieve [15]. Combinations of fine and coarse aggregates have intermediate values.

Representative samples from Wadi Bugos sand, and stone chips were sieved to obtain their FM. Three trial mixes of combined aggregates obtained from Wadi Bugos sand, and stone chips were sieved to obtain the intermediate value of combined aggregates FM (Table 1). The FM = 4.81 was achieved from the 3:4 (sand: stone chips) ratio by weight, is considered as the optimum mix proportion of fine to coarse aggregates. The economical value of FM for combined aggregates is ranging from 4.7 to 5.1 for aggregate size less

than 20 mm [16] (Table 2). The ratio 3:4 by weight gives approximately 2.5:3.5 ratio by volume.

According to the standard [1], combined aggregates shall pass through I.S. sieve 12.85 mm and not more than 12 per cent shall pass through I.S. sieve 300 micron. In addition at least 15% shall be retained on I.S. sieve 10mm and 40 per cent on I.S. sieve 4.75mm. As per Indian Standard [1], the combined aggregate content in the concrete mix used for making hollow blocks should not be more than 6 parts to 1 part by volume of the OPC. If this ratio, is taken in terms of weight basis this may average approximately at 1:7 (cement: aggregate). However, there have been instances of employing a leaner mix of as high as 1:9 by local manufacturers where the CHB are compacted by power operated vibrating machines. The water cement ratio of 0.62 by weight basis can be used for concrete hollow blocks.

4. *Water*: Tap drinking water from the public main supply was used for mixing and the curing of the mortar cubes and the CHB.

TABLE I: FINENESS MODULUS OF COMBINED AGGREGATES

Fineness modulus Sieve Apparature	% retained	% cum retained	% retained	% cum retained	% retained	% cum retained
Combination ratios	4.5:2.5		1.5:4.5		3:4	
12.5					0.23	0.23
10	0.71	0.71	2.1	2.1	2.96	3.19
4.75	27.83	28.54	46.83	48.93	46.88	50.07
2.36	23	51.54	22.7	71.63	17.5	67.57
1.18	21	72.54	12	83.63	12	79.57
0.6	14.5	87.04	8	91.63	7.6	87.17
0.3	8.5	95.54	5.3	96.93	6.86	94.03
0.15	3.8	99.34	2.7	99.63	5.16	99.19
pan	0.46	435.25 FM=4.35	0.31	494.48 FM=4.95	0.66	481.02 FM=4.81

TABLE II: ECONOMICAL VALUE OF F.M. FOR COMBINED AGGREGATE

S. No.	Particle size (mm)	Fineness modulus		Average F.M.
		Minimum	Maximum	
1	20	4.7	5.1	4.90
2	25.4	5.0	5.5	5.25
3	31.5	5.2	5.7	5.45
4	38.1	5.4	5.9	5.65
5	40	5.7	6.3	6.00
6	80	6.5	7.0	6.75

Source: [16]

3.2. Methods

3.2.1 Method of preparing Blended cement (BC) mortars

The materials used in this investigation were OPC used as a base for all blends, OPC was blended with VA. Several mixes were prepared utilizing various OPC:VA proportions to produce in all (6) types of mixes including the control mix without replacement, with the total of 54 specimens. The details of the BC mortars are given in Table III

3.2.2. Method of preparing CHB

Trial mix ratio 1:6, 1:7, 1:8, and 1:9 (blended cement: combined aggregates) by volume were used for CHBs. Batching was by volume with different weight substitution VA levels of 10, 20, 30, 40, and 50% of OPC weight. Twenty four (24)

mixes (five blocks for every mix) with the total of (120) CHBs with dimensions 400 mm x 200 mm x 200 mm were produced. These included (100) blocks with BC, and (20) concrete blocks were also produced with 100% OPC i.e. 0% replacement with VA to serve as control. The mix proportions for the CHBs are presented in Table IV.

3.2.3 Curing

The CHBs were removed from the mould and protected for about 24 hours in a shelter away from sun and winds. Then were cured by immersing in a water tank for 14 days. Afterwards, they were removed from the water tank and followed by 7 days regular spraying with water and 7 days air curing [17].

TABLE III: MIX PROPORTION FOR BLENDED MORTAR

Mortar code	Blending ratio by weight%		B:AG	No. of specimens	Test Age (Days)
	OPC	VA			
MCTR	100	0	1:3	9	7,28,90
MVA10	90	10	1:3	9	7,28,90
MVA20	80	20	1:3	9	7,28,90
MVA30	70	30	1:3	9	7,28,90
MVA40	60	40	1:3	9	7,28,90
MVA50	50	50	1:3	9	7,28,90

TABLE IV: RATIOS USED IN THE CONCRETE HOLLOW BLOCKS (BY VOLUME)

Mortar code	Blending ratio (by volume)											
	1:6			1:7			1:8			1:9		
	OPC	VA	Sand: S chips	OPC	VA	Sand: S chips	OPC	VA	Sand: S chips	OPC	VA	Sand: S chips
CBCTR	1	0	2.5:3.5	1	0	3:4	1	0	3.4:4.6	1	0	3.8:5.2
CHB10	0.9	0.1	2.5:3.5	0.9	0.1	3:4	0.9	0.1	3.4:4.6	0.9	0.1	3.8:5.2
CHB20	0.8	0.2	2.5:3.5	0.8	0.2	3:4	0.8	0.2	3.4:4.6	0.8	0.2	3.8:5.2
CHB30	0.7	0.3	2.5:3.5	0.7	0.3	3:4	0.7	0.3	3.4:4.6	0.7	0.3	3.8:5.2
CHB40	0.6	0.4	2.5:3.5	0.6	0.4	3:4	0.6	0.4	3.4:4.6	0.6	0.4	3.8:5.2
CHB50	0.5	0.5	2.5:3.5	0.5	0.5	3:4	0.5	0.5	3.4:4.6	0.5	0.5	3.8:5.2

3.2.4 Testing

Eight CHBs for each BC mix and the control were tested for compressive strength at age of 28 days. The tests were according to [1].

4. RESULTS AND DISCUSSIONS

4.1. Chemical properties

Chemical analysis of the VA as shown in Table 5 indicates that the principal oxides of Silica (SiO_2), Alumina (Al_2O_3), and Iron (Fe_2O_3) were substantially present in the samples investigated with the sum oxides of 81.57%. The analyses also showed the presence of minor element, while the (Alkalis = % $\text{Na}_2\text{O} + 0.65\%\text{K}_2\text{O}$) of the sample evaluated were 5.3. These results are within the limitations of [18] and [19].

4.2. Results of compressive strength of BC

The results of compressive strength tests (table VI) indicated that the replacement 10,20,30,40, and 50% of pozzolana sample provided 38.6 , 36, 29.21, 28.17 and 25.41 MPa respectively compared with 42.86 MPa for the control mix, tested at 28 days, and the strength activity index of VA at 28 days was 87%, [18] and [5] , required a minimum of 80% and 75% respectively of the strength of corresponding reference mortar in case of pozzolana to be used for manufacture of BC

4.3 Results of compressive strength of CHB

The average compressive strength – at 28 curing age – of the CHB for various substitution levels and mix ratios are presented in Table VII. As

shown in Figure 1, they exhibited a tendency to be within the minimum requirement of the Indian standard [1] for the mix ratios 1:6, 1:7, and 1:8, up to substitution levels 40%, 30%, 20% , and 10% respectively, whereas for the control CHB, up to 1:8 mix ratio produced the minimum 3.5 MPa required by the standard. This may due to the VA quality and the optimum fine to coarse aggregates ratio obtained by the economical value of fineness modulus. Therefore, according to these results, it is possible to produce CHB with high partial Portland cement replacement. In addition, increasing the compressive strength of the CHBs can be achieved by using high pressure blocks making machine. Finally, it can be concluded that VA can be used successfully as low cost material in CHB with the substitution levels up to 40%, 30%, and 20%, for binder aggregates ratio by volume 1:6, 1:7, and 1:8, with subsequent reduction in binder cost by 34, 26, and 17%, respectively. It is noteworthy that none of the mixes including the control OPC have achieved the required 3.5MPa for the 1:9 volumetric binders: aggregates ratios.

TABLE V: CHEMICAL COMPOSITION OF VA

Material	Chemical Composition (%)								
	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	SO ₃	Na ₂ O	K ₂ O	LOI
VA	57.96	13.82	9.79	3.69	2.25	0.13	2.35	4.54	6.65

TABLE VI: RESULTS OF COMPRESSIVE STRENGTH OF BC

specimens code	at 7 days(MPa)	at 28 days(MPa)	at 90 days (MPa)
CTR	36.67	42.86	51
MVA10	35	38.6	50.1
MVA20	33	36	48
MVA30	27.73	29.21	47.3
MVA40	20.67	28.17	45.4
MVA50	18	25.41	34.4
[20]	22	33	-
[21]	20	25	-

TABLE VII: RESULTS OF COMPRESSIVE STRENGTH OF THE CHB

Mix ratio	Compressive Strength – at 28 curing age (MPa)					
	CHBC	CHB10	CHB20	CHB30	CHB40	CHB50
Mix 1:6	4.22	3.92	4.19	3.8	3.6	3.12
Mix 1:7	3.92	3.94	3.77	3.56	3.28	2.84
Mix 1:8	3.67	3.51	3.55	3.21	2.92	2.36
Mix 1:9	3.12	2.85	2.72	2.06	1.93	1.5

5. CONCLUSION

Chemical analysis of the studied volcanic ash from Jebel Marra (VA) sample indicated that the principal oxides of Silica (SiO_2), Alumina (Al_2O_3), and Iron (Fe_2O_3) were substantially present in the samples investigated with the sum oxides of 81.57% complying to minimum required value of ASTM C618.

From the results of compressive strength tests of blended cements (BC), it was found that the OPC replacement by 10, 20, 30, 40, and 50% of VA provided 38.6, 36, 29.21, 28.17, and 25.41 MPa respectively compared with 42.86 MPa for the control mix, tested at 28 days, and the strength activity index of 20% VA at 28 days was 87%.

According to the compressive strength results of CHB, it is possible to produce CHB with high

partial Portland cement replacement, if a good quality VA is used with an optimum fine to coarse aggregates ratio obtained by the economical value of fineness modulus. In addition, increasing the compressive strength of CHB can be achieved by using high pressure blocks making machine. Finally it can be concluded that volcanic ash can be used successfully as low cost material in CHB with the substitution level up to 40%, 30%, and 20%, for binder aggregates ratio by volume 1:6, 1:7, and 1:8, with subsequent reduction in binder cost by 34, 26, and 17%, respectively.

None of the mixes including the control OPC have achieved the required 3.5MPa for the 1:9 volumetric binders: aggregate ratios.

Figure 1: Compressive strength of CHB

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