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Effects of Binary and Ternary Blend of Fly Ash and Calcined Waste Crushed Clay Bricks as Pozzolanas in Cementitious Matrix

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Abstract

This paper presents the results of the experimental investigation of the effects of binary and ternary blend of fly ash (Fa) and calcined waste crushed clay bricks (CWCCB) on the properties of the pastes and the compressive strength of concrete. The amount of ordinary Portland cement (OPC) substitution in both blends was 50%. The calcium hydroxide (Ca $(OH)_2$) content of the hardened pastes were determined and analysed with the aid of Energy Dispersive X-Ray Spectrometry (ED-XRFS). The results showed that in both blends, there was remarkable reduction of Ca $(OH)_2$ with curing age. The amount of Ca $(OH)_2$ in OPC, CWCCB and Fa binary blends at 7days curing age, were 14.70%, 12.72% and 7.65% respectively, and 20.80%, 7.20% and 3.49% respectively, at 90days curing age. Similarly, significant reduction was recorded in the ternary blended pastes. The highest compressive strength of 21.33N/mm^2 at 90days curing age was recorded for ternary concrete of 30%Fa + 20%CWCCB blend. The properties of ternary concrete can be improved with the optimum blend of Fa and CWCCB.

Key words: Ternary Blend, (Ca $(OH)_2$), Fly Ash, Calcined Waste Crushed Clay Bricks.

1. INTRODUCTION

Ordinary Portland cement constitutes the most commonly and extensively used construction material in the world and only second to water. It is either used as binding agent in mass concrete, steel or fibre reinforced concrete or as cementitious pastes. It is common knowledge that when water is added to OPC, hydration takes place and during this hydration, compounds such as C_3S and C_2S present in OPC react with water of hydration to form calcium silicate hydrates (CSH) and calcium hydroxide (Ca $(OH)_2$) (Neville, 2002) [1]. As a result of this reaction, approximately 70% CSH, 20% Ca $(OH)_2$, 7% sulfoaluminates and 3% secondary phases are formed in the hydrated cement paste (Ngun et al., 2000) [2]. Calcium hydroxide is soluble in water and of very low strength, leading to its hydrolysis and increase in cement paste porosity. The presence of porosity encourages ingress of other aggressive chemicals and consequently promoting degradation of concrete and its reinforcement (Haga et al.2005a [3], Haga et al. 2005b [4])

The main draw back in the application of vegetable fibres in the reinforcement of cementitious composites made with ordinary Portland cement is the low durability of the composites. This durability problem is associated with the weakening of fibres by the combined effect of alkali (Ca $(OH)_2$) attack and fibre mineralization, resulting in an increase in fibre fracture and decrease in fibre pull-out. The migration of hydration products to the fibre structure *(lumen*), middle lamella and the interface zone (*cell wall*) is believed to be the key mechanism of deterioration of the fibres. Subsequently the hydrolysis of the cellulose chains results. Malquori, (1960), Turrizani, (1964), De Siva et al. (1990) and Dunster et al. (1993) discussed the chemical reaction that takes place when calcined clays are added to OPC concrete as pozzolanas. The chemical reaction that takes place with the addition of pozzolanas such as fly ash and calcined waste crushed clay bricks to OPC have also been discussed by Nwankwo (2013). The key reaction is between the AS_2 and Ca $(OH)_2$ from the cement hydration when water is added. As a result of this reaction, more CSH and other crystalline products are formed resulting in increased density. The ratio of AS_2/Ca $(OH)_2$ and the reaction temperature determines the crystalline products formed (Kinuthia et al. 2000).

Cement blended with pozzolanas such as fly ash, silica fume etc, have been used as binary in concrete to aid the consumption of Ca $(OH)_2$ by pozzolanic reaction. This action refines the paste-aggregate interface, minimizes chemical interaction between the fibres and the matrices, hence improve the durability of the composite. Most often, these additives in form of pozzolanas are expensive and contribute to CO_2 emission, especially artificial pozzolanas. Fly ash is a waste product generated by thermal power plant, and calcined waste crushed clay bricks also a waste product of brick factory. The ternary blend of these waste products which otherwise would have been destined for landfills, with OPC has not attracted much research attention. It is therefore necessary to investigate the ternary blend of fly ash and calcined waste crushed clay bricks in hardened cement paste and concrete. Successful outcome of the study of the effects of ternary blend of fly ash and

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calcined waste crushed clay bricks on the properties of cement paste and concrete could offer potential for the development of low-cost construction materials.

The objective of this paper is to determine the Ca $(OH)_2$ content for various binary and ternary blends of Fa and CWCCB of hardened cement paste, using the Energy Dispersive X-Ray Fluorescent Spectrometry (ED-XRFS) and evaluate the compressive strength of concrete.

2. MATERIALS AND METHODS

2.1 Materials

The "BUA" brand 43 grade OPC conforming to BS 12 (1996) and ASTM – C 150, (1994) was used for this study. Fly ash was procured from a waste dump at the thermal electric power plant in Oji River, Enugu State, Nigeria. Calcined waste crushed clay bricks burned at 850°C was procured from a brick manufacturing industry located in Minna, Niger State, Nigeria. The calcined waste crushed clay bricks were ground with the aid of porcelain ball mill for 90minutes. River sand was used as the fine aggregate (FA), while 19mm crushed granite was used as the coarse aggregate (CA). The physical and chemical properties of OPC, Fa and CWCCB are shown in Table 1.

2.2 Preparation of Specimens

For all the replacement ratios of binders adopted in this investigation, except for the control specimens, OPC content was fixed at 50% of binders, while the Fa and CWCCB varied from 15%Fa + 35%CWCCB (15Fa + 35CWCCB) to a maximum of 30%Fa + 20%CWCCB and vice versa. The blending ratios and quantities of materials for the preparation of the paste and concrete specimens per cubic meter are given in Tables 2 and 3 respectively.

The materials for the paste and concrete as shown in Tables 2 and 3 were hand mixed to the various replacement ratios with water (W), giving a water/binder ratio (w/b) of 0.4 for paste and 0.6 for concrete. The pastes, for the purposes of determining the Ca $(OH)_2$ content, were cast and compacted using tamping rod in 70.7mm cube moulds. The concrete cubes, for the purposes of evaluating the compressive strength, were cast and compacted with a tamping rod, in 150mm cube moulds in accordance with the requirements of B.S 1881: Part 116 (1983). The samples were de-moulded after 24 hours and cured by immersion in a water tank kept at 20°C for 7, 28 and 90 days.

Table 1 Physical and Chemical Properties of Materials

Properties	OPC	Fa	CWCCB
Physical Properties			
Blain specific surface area (m^2/kg)	340	200-600	-
% retained on mesh 325 (45µm)	22.0	8.4	35.0
Specific gravity	3.15	2.25	2.26
Bulk density (kg/m^3)	1440		
Loose bulk density (kg/m^3)	-	1306	1157
Compacted bulk density (kg/m^3)	-	1414	1371
Chemical Properties	***wt%***	***wt%***	***wt%***
CaO	61.65	0.93	2.30
SiO_2	19.92	57.10	60.80
Al_2O_3	4.26	24.00	19.00
Fe_2O_3	2.88	19.14	11.97
MgO	3.10	0.46	0.04
SO_3	2.80	2.30	-
K_2O	0.88	1.23	3.38
TiO_2	0.21	3.83	1.15
Na_2O	0.13	0.18	Traces
Ignition lose	2.98	2.71	-

Table 2 Mortar Mix Proportions

Percentage Replacement	OPC (kg.)	Fa (kg.)	CWCCB (kg.)	FA (kg.)	W (kg.)	w/b
0 (Control)	540	-	-	1618	216	0.4
0Fa + 50CWCCB	270	-	270	1618	216	0.4
15Fa + 35CWCCB	270	81	189	1618	216	0.4
20Fa + 30CWCCB	270	108	162	1618	216	0.4
25Fa + 25CWCCB	270	135	135	1618	216	0.4
50Fa + 0CWCCB	270	270	-	1618	216	0.4
35Fa + 15CWCCB	270	189	81	1618	216	0.4
30Fa + 20CWCCB	270	162	108	1618	216	0.4

Table 3 Concrete Mix Proportions

Percentage Replacement	OPC (kg.)	Fa (kg.)	CWCCB (kg.)	FA (kg.)	CA (kg.)	W (kg.)	w/b
0 (Control)	344	-	-	776	1529	207	0.6
0Fa + 50CWCCB	172	-	172	776	1529	207	0.6
15Fa + 35CWCCB	172	52	120	776	1529	207	0.6
20Fa + 30CWCCB	172	69	103	776	1529	207	0.6
25Fa + 25CWCCB	172	86	86	776	1529	207	0.6
50Fa + 0CWCCB	172	172	-	776	1529	207	0.6
35Fa + 15CWCCB	172	120	52	776	1529	207	0.6
30Fa + 20CWCCB	172	103	69	776	1529	207	0.6

3. EXPERIMENTAL

3.1 Measurement of Calcium Hydroxide Content in Paste

For each of the curing ages of 7, 28 and 90 days, the samples were crushed, ground and sieved in a 75µm sieve. Part of the sieved sample was used to determine the Ca $(OH)_2$ content analysed by ED-XRFS.

3.2 Compressive Strength Test

All 150mm concrete cube specimens for compressive strength test were tested at the appropriate curing age. The crushing test was conducted on an ELE compression testing machine with capacity of 2000kN, housed in the Department of Building, University of Jos, Nigeria.

4. RESULTS AND DISCUSSION

4.1 Calcium Hydroxide in Paste

Table 4 shows the results of the ED-XRFS analysis on the hardened pastes. It is shown that the Ca $(OH)_2$ content in the OPC paste (control specimens), increased with curing age whereas in the binary and ternary blended pastes, Ca $(OH)_2$ content decreased with curing age. Table 4 also shows that the specimen for a binary blend of Fa (50Fa + 0CWCCB) at 7days curing age resulted in reduction of Ca $(OH)_2$ content to 7.65% compared with 14.70% for OPC control pastes. Pastes with binary blend showed higher Ca $(OH)_2$ reduction compared to OPC control pastes for all curing ages. The binary blend of 50Fa + 0CWCCB showed greater Ca $(OH)_2$ reduction than the binary blend of 0Fa + 50CWCCB indicating greater pozzolanic reactivity of fly ash compared to calcined waste crushed clay bricks. The highest reduction of Ca $(OH)_2$ (3.49%) was found in the binary blend of 50Fa + 0CWCCB at curing age of 90days, whereas the highest reduction of Ca $(OH)_2$ (5.78%) was found in the ternary mixture of 30Fa + 20CWCCB.

4.2 Compressive Strength Of Concrete

The results of the compressive strength of the various blends are shown in Table 5. The results showed that early strength development at 7 days curing age for the binary and ternary blends were low. The early compressive strengths ranged from 6.22N/mm² for ternary blend of 35Fa + 15CWCCB to 10.22N/mm² for ternary blend of 15Fa + 35CWCCB compared with 23.11N/mm² for OPC control specimens. However at 90 days curing age, there was remarkable strength development, ranging from as high as 10.44N/mm² for a ternary blend of 25Fa + 25CWCCB to 21.33N/mm² for a ternary blend of 30Fa + 20CWCCB compared with 28.00N/mm² for OPC control specimens. This result is an indication of slow pozzolanic reactivity of Fa and CWCCB with OPC at early age. The improvement in the compressive strength of the 30Fa + 20CWCCB, blend, could be as a result of the blend containing higher proportion of Fa, which had better pozzolanic reactivity than CWCCB. The compressive strength results were also in conformity with the trend shown in Ca $(OH)_2$ content as indicated in Table 4.

Table 4 Percentage Calcium Hydroxide (Ca $(OH)_2$) Content of Blends at Various Curing Age

Percentage Replacement	Curing Age (Days)		
	7	28	90
0 (Control)	14.7	17.65	20.80
0Fa + 50CWCCB	12.72	9.12	7.20
15Fa + 35CWCCB	11.25	9.99	8.75
20Fa + 30CWCCB	12.86	9.73	6.53
25Fa + 25CWCCB	11.07	10.85	9.77
50Fa + 0CWCCB	7.65	5.27	3.49
35Fa + 15CWCCB	12.67	8.42	5.90
30Fa + 20CWCCB	12.10	9.65	5.76

Table 5 Compressive Strength of Concrete Blends at Various Curing Age

Percentage	Curing Age (Days)

Replacement	7	28	90
0 (Control)	23.11	27.56	28.00
0Fa + 50CWCCB	6.67	8.89	12.69
15Fa + 35CWCCB	10.22	11.56	17.67
20Fa + 30CWCCB	9.33	10.22	16.78
25Fa + 25CWCCB	6.66	8.44	10.44
50Fa + 0CWCCB	6.50	8.00	15.33
35Fa + 15CWCCB	6.22	7.11	12.00
30Fa + 20CWCCB	8.44	11.11	21.33

5. CONCLUSION

The Ca $(OH)_2$ content of OPC control mix increased with curing age from 14.70% at 7 days curing age to 20.80% at 90 days curing age. This is in contrast with the binary and ternary blends, which showed a reduction in the Ca $(OH)_2$ content with increase in curing age. There is low consumption of Ca $(OH)_2$ at early curing age of 7 days compared with 90 days curing age, for binary and ternary pastes. The binary paste blended with fly ash (50Fa + 0CWCCB), showed higher consumption of Ca $(OH)_2$ (3.49%) than with blend of CWCCB, indicating higher pozzolanic reactivity of fly ash. The ternary concrete with a blend of 30Fa + 20CWCCB was found to have the highest compressive strength of 21.33N/mm^2.

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