PROPERTIES OF PULVERIZED BURNT CLAY AND CALCIUM OXIDE BLENDED CONCRETE.

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ABSTRACT

This paper reports the results of investigation to assess the suitability of pulverized Burnt clay (PBC) and Calcium Oxide (CaO) for blended cement production. Tests were conducted on cement, where pulverized Burnt clay (PBC) was replaced by CaO within the range of 10 to 40%. The physical and chemical properties of PBC and Cao were critically reviewed to evaluate the possible influences on cement properties. The investigation included testing on both fresh and hardened states of cement paste. The standard tests conducted on different PBC / CaO mixtures provided encouraging results, comparable to those for Ordinary Portland cement (OPC), and showed good potential of manufacturing blended pulverized Burnt clay and CaO cement with higher setting time and low heat of hydration using up to 30% replacement.

Key Words: blended cement, calcium oxide, concrete, performance, pulverized burnt clay.

1.0 INTRODUCTION

The search for alternative binders or cement replacement materials had been continued for the last decades. Research had been carried out on the use of volcanic ash (VA), fly ash (FA),blast furnace slag (BFS), silica fume (SF), etc. as cement replacement material (Hossain,2003; Hossain,1999; Al-Ani, & Hughes,1989; Swamy,1986; Berry, and Malhotra,1980; Hooton,2000; Ogunbode,2010). The VA, pumice, and FA are pozzolanic materials, because of their reaction with lime (calcium hydroxide) liberated during the hydration of cement. Amorphous silica present in the pozzolanic materials combines with lime and forms cementitious materials. These materials can also improve the durability of concrete and the rate of gain in strength and can also reduce the rate of liberation of heat, which is beneficial for mass concrete. Over recent years Portland cements containing fly ash and silica fume have gained increasing acceptance while Portland cements containing natural pozzolans like rice husk ash and burnt oil shale are common in regions where these materials are available. Replacement levels of Portland cement in blended cement containing blast furnace slag vary considerably, and contents of well over 50% by mass are common in some regions. Fly ash typically replaces 10–30% of the Portland cement although levels of 50–60% have been advocated (Bilodeau, & Malhotra, 2000). When silica fume is added, it commonly comprises 5–10% of the binder. ASTM Standards exist for the use of natural pozzolans, fly ash, and silica fume and blast furnace slag in concrete (ASTM C 618-00; ASTM C 989-99; ASTM C 1240-01).

Matawal (2005) highlighted that the application or use of various ashes as potential replacement of cement in mortar and concrete production has attracted the attention of researchers in the literary world because of their potentials:

a) To reduce or totally eliminate the classification of ashes as waste materials, polluting environment.

b) For economy, by reducing the quantity and consequently cost of cement applied in concrete works.

The strength of concrete normally improves with age since Pozzolana reacts more slowly than cement and at one year, about the same strength is obtained (Malquori, 1960).

The utilization of lime as an admixture has several advantages such as excellent resistance to water penetration, whilst allows vapour penetration, high ductility to joint and massive masonry, excellent plasticity and hydraulic properties. Thus inherent properties of lime combines very well with Pozzolana such as calcined clay thereby facilitating improved workability improved water retention/reduced bleeding, improved sulphate resistance, improved resistance to alkali aggregate reaction and lower heat of hydration (Margaret 2005).

The practice of modifying lime mortars by the addition of materials containing reactive silicates and aluminates was known to Roman builders, they utilized volcanic deposits from Pozzuoli near Naples, as well as PBC. To this end he suggested two method of production of lime known has the artificial hydraulic lime. This method involved grinding limestone or chalk with clay before firing, to stimulate the intimate mixture found in natural hydraulic limestone. An alternative method, involve the mixing of slaked high calcium lime with clay, drying and re-calcining (burning) the material, which eventually led to the production of Portland cement. At the same time, understanding was growing on the use of Pozzolans for addition of mortars of non –hydraulic or hydraulic lime. Smeaton a civil engineer was instrumental in developing specifications incorporating natural pozzolans with natural hydraulic lime to achieve exceptionally durable mortars for marine, and other engineering works (Tutonico et al, 1994). The continuing search for faster setting and more durable mortar led eventually to the development of modern OPC and, for most of the 20th century, the increasing use of OPC has displaced the use of pure limes, hydraulic lime and pozzolans. The use of PBC in lime mortars in current practice is based on the historic practice and experience, supported by some preliminary scientific investigations, such as the work carried out by English Heritage, London, under the "Smeaton project" published work on the effect of PBC on OPC mortar. (Tutonico et al,1994)

The addition of PBC to OPC mortar mixes has been used for many years in Germany, Holland and Belgium, where it has been used for docks and harbors, inland water ways drainage systems, Railway Bridge and other structures. The American Society for Testing Material (ASTM) standard C618 – 78 describe that the Lime – PBC mortars are used in many parts of Europe such as the bridge of fabrious which is a Roman monument. According to Matawal (2005) the PBC content are widely used in the same mix proportions as OPC for mortar in general building construction, for dams and for reinforced concrete in sea water for which the lime – PBC mortar are too slow in hardening. PBC with or without air entrainment is particularly suitable for use in mortar and in mass concrete structures (such as dams and bridge piers) where low heat of hydration is desired; Hydraulic structures of all kinds where water tightness is important; structures subjected to attack from ground water, sea water or dilute industrial wastes; and under water construction where the concrete is deposited by Tromie or bucket (Talero, 1990).

According to Neville and Brooks (1997), it was only in 1824 that the modern cement, known as Ordinary Portland cement (OPC) was patented by Joseph Aspdin a Leeds builder. OPC is the name given to cement obtained by intimately mixing together of calcareous and argillaceous or other silica, alumina and iron oxide – bearing materials, burning them at a clinkering temperature, and grinding the resulting clinker, as presented in Table 1. The raw materials used in the manufacture of OPC consist mainly of lime, silica, alumina and iron oxide, as presented in Table 1.

Shetty, (1999) observed critically and link the development of pozzolanic properties in PBC on burning with the temperature at which loss of water of hydration occurs. Lime with high calcium content often called 'fat; or 'white' limes are desirable for most industries, although the construction industry can use limes containing impurities. For instance, limestone containing a proportion of clay is often seen as an advantage in building as they produce hydraulic lime which will set under water and will produce stronger mortars. (Margaret 2005).

2.0 MATERIALS AND METHOD

The material used for this research includes Pulverized Burnt Clay (PBC), lime (Cao), coarse aggregate and fine aggregate. The pulverized burnt clay used for the research was obtained from urban shelter brick factory along Suleja road while the lime was purchased from a chemical and reagent sales store at Keteren-Gwari, Minna Niger State. The Brick was then pulverized by the use of mortar and pestle, the resulting powder was further grounded by the use of grinding machine. It was then taken to the Laboratory where it was sieved in to fine powder by the use of 75μm sieve. The fine and coarse aggregate used was soured within the environment of federal polytechnic Bida. Chemical and physical properties of PBC are compared with those of OPC and Class N fly ash in Table 1. The Portland cement has a specific gravity of 3.15 and Blaine fineness of 320 m^2/g. Chemical analysis as per ASTM C 114-00 indicated that the main oxide component of PBC is silica (about 54.74%) and the main oxide component of OPC is calcium oxide (about 64.1%). The Blaine fineness and oven dry bulk density of PBC are 290 m^2/kg and 1594 kg/m^3, respectively (Table 1). PBC satisfy most of the criteria of Class N fly ash as per ASTM C 618-00. The particle size distributions as per ASTM C 136-01 for aggregates, the bulk density and water absorption of aggregates are presented in Table 2. Portable drinking water was used in the concrete mixes. The mix proportions of PBC and CaO mixtures derived from extensive preliminary investigation on trial mixes are presented in Table 4. PBC and CaO mixtures were prepared based on the same quantity by weight of OPC designed to provide a minimum 28-day compressive strength of 25N/mm^2.PBC and CaO was introduced as total cement replacement and were proportioned; 90%-10%, 80%-20%, 70%-30 and 60%-40% by mass. Control mixes incorporating OPC were also prepared for comparison purposes. The numeric in mix designations represents the percentage of PBC and CaO by mass in Table 4. Comprehensive series of tests on fresh, mechanical, and micro-structural properties of PBC/CaO concrete such as slump, setting time, consistency, compacting factor, air content, compressive strength, and density were carried out. The slump values of fresh PBC/CaO were determined as per ASTM C 143-00, while the air contents were determined by pressure meter as per ASTM C 231-97. The water-to-binder ratio (W/B) was kept constant at 0.64 for all the mixtures. No air entraining admixtures was used. Compressive strength test was performed on 150×150×150-mm cubes at an age of 7,14,21,28 and 56 days as per ASTM C-39. Three specimens were tested for each test at each age and mean values were reported. The specimens were removed from the moulds after 24 h of casting and then placed in a water tank at 23±2 °C. After the respective days of water curing, they were transferred while maintaining the relative humidity to testing point.

Table 1: Chemical and physical properties of cementing materials

Oxide compounds	PBC Mass %	Volcanic Ash Mass %	ASTM C 618 requirement) for fly ash (Class N) Mass %	Portland Cement(PC) ASTM Type I Mass %
Chemical composition				
Calcium oxide (CaO)	0.10	1.00	–	64.1
Silica (SiO_2)	54.74	68.20	–	21.4
Alumina (Al_2O_3)	19.66	11.20	–	5.7
Iron oxide (Fe_2O_3)	8.92	1.8	–	3.5
$SiO_2+Al_2O_3+Fe_2O_3$	83.32	81.2	Minimum=70	94.7
Sulphur trioxide (SO^3)	0.71	0.01	Maximum= 4	2.1
Magnesia (MgO)	1.07	0.20	–	2.1
Sodium oxide (Na_2O)	0.26	0.20	–	0.5
Potassium oxide (K_2O)	1.50	3.40	–	0.6
Equivalent alkali (P_2O_5)	2.04	2.44	–	0.89
Free lime (CaO)	–	–	–	0.6
Loss on ignition	2.60	–	Maximum=10	1.1
Physical properties				
Fineness, m^2/kg	290	–	–	320
Retained on 45 µm sieve, %	12	–	Maximum=34	–
Density, kg/m^3	1594	–	–	3150

Table 2: Properties of aggregates and PBC

Grain size distribution of aggregates			*Physical properties of aggregates and PBC*			
Sieve size (mm)	Fine % passing	Coarse % passing		Bulk density (kg/m3) Oven dry	SSD	Water Absorption (%)
20	100	100	Coarse	1473	1550	5.0
12.7	100	7.5	Fine	1566	1610	2.7
9.5	100	0.8				
4.75	100	0.0				
2.36	97.2		PBC	1594	1758	9.3
1.18	82.5					
0.6	46.5					
0.3	9.0					
0.15	1.5					
0.075	0.2					

SSD: Saturated surface dry

Table 3: Mix proportion of PBC/CaO mixtures

Mix Designation	PBC (%)	CaO (%)	W/B	Water (W) kg/m3	PBC kg/m3	CaO kg/m3	Aggregates kg/m3 Fine	Coarse
PC- 0	90	10	0.64	170	239.4	26.6	722	1402
PC-10	90	10	0.64	170	239.4	26.6	722	1402
PC-20	80	20	0.64	170	212.8	53.2	722	1402
PC-30	70	30	0.64	170	186.2	79.8	722	1402
PC-40	60	40	0.64	170	159.6	106.4	722	1402

Numerics in mix designation represent percentage of CaO; B: Binder.

Table 4: Slump, air content, density and compressive strength of PBC/CaO Concrete.

Mix ID (N/mm^2)	Slump (mm)	Air content (%)	28-day density kg/m3	Compressive strength	
				28-day	56-day
PC-10	26	2.6	2155	16	19
PC-20	24	2.8	2252	17	20
PC-30	22	3.0	2299	22	25
PC-45	10	3.2	2236	14	17

Table 5: Workability, consistency, setting time and partial compacting factor of PBC/CaO mixtures.

Mix Designation	Slump mm	Consistency %	Setting - Time		Compacting factor
			Initial	Final	
PC-10	26	31	200	290	0.87
PC-20	24	32	227	332	0.86
PC-30	22	33	245	362	0.86
PC-40	10	35	270	410	0.80

Numerics in mix designation represent percentage of CaO.

3.0 RESULTS AND DISCUSSIONS

The air contents and slump values of non-air entrained PBC/CaO concretes are presented in Table 4. Air content ranged between 2.6% and 3.2%. Generally air content of the PBC/CaO concretes increased with the increase of CaO content. All the mixtures were produced at a slump that ranged between 10 and 26 mm. The compressive strengths of PBC/CaO concretes are presented in Table 4. Generally compressive strength increased with the increase of CaO content and with the increase of age until after 30% replacement of PBC with CaO. However, the finely divided silica (59%) in PBC can combine with calcium hydroxide in the presence of water to form stable compounds like calcium silicates, which have cementitious properties (ASTM C 612-97). Such pozzolanic action of PBC can contribute to the enhancement of strength and long-term durability of PBC/CaO concretes. A PBC/CaO concrete having a 28-day compressive strength of 16N/mm2, 17 N/mm2, 22N/mm2 and 14 N/mm2 can be developed using 10, 20, 30 and 40% of CaO respectively to replace PBC. Table 5 shows that 31% of water by weight of PBC and CaO is required to obtain standard consistency at 10% partial replacement, 32% is required for 20% partial replacement, 33% is required for 30% replacement and 35% of water by weight of PBC and CaO is required at 40% replacement respectively. The result shows that the quantity of water required to obtain a standard consistency increase as the percentage of partial replacement of CaO increases from 10% - 40%. Tables 3 and 5 shows that at fixed water binder ratio, the Slump decreases from 26mm to 10mm as the partial replacement increase from 10% – 40% respectively. Furthermore, the compacting factor also decreases as the percentage partial replacement increases. From the test carried out, Table 4 and Figure 1 shows that the results of the compressive strength increases with hydration period of 7, 14, 21,28 and 56 days for all the percentage replacement. Result in Table 4 shows an increase in compressive strength of all the tested samples, for the various percentage replacements as the curing period increases, except at 40% partial replacement of Pulverized burnt clay (PBC) with calcium oxide which shows a decrease in the compressive strength when compared to other replacement levels. The maximum strength obtained was 22 N/mm^2 at 30% replacement of PBC with Calcium oxide for 28 days hydration, this was found to be less than the targeted strength of 25 N/mm2 calculated for OPC.

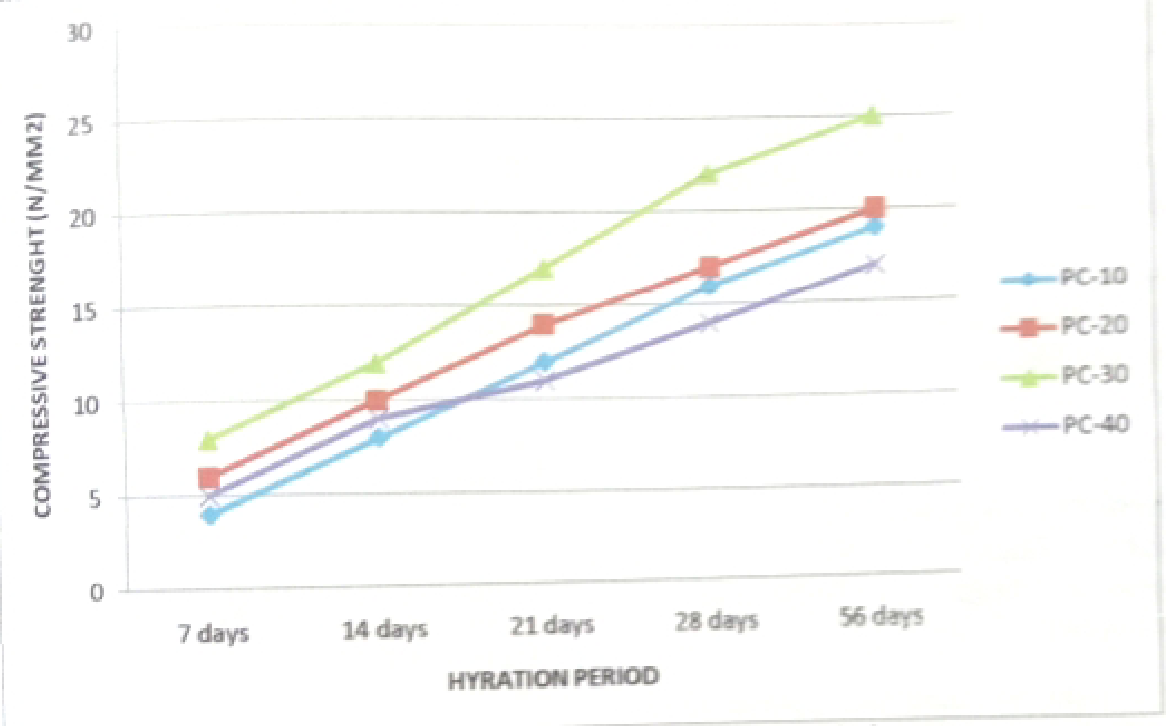

Figure 1: Variation of Compressive Strength with Hydration Period

CONCLUSIONS

Development of concrete with reasonable compressive strength at curing ages above 28 days can be achieved by replacing partially or totally OPC with PBC/CaO at different percentages (10 to 40% by mass) of PBC as cement replacement having a constant water-to-binder ratio (W/B) of 0.64 is reported. The fresh and hardened properties of PBC/CaO concrete were assessed. This paper demonstrates that PBC/CaO can be used as a cement replacement material to manufacture concrete having satisfactory strength and durability Characteristics at higher curing ages. The following conclusions were drawn from the study:

1. Pulverized Burnt Clay (PBC) contains very low percentage of lime (CaO) which is about 0.10%. This was found to be lower than 60-66% specified for ordinary Portland cement (ASTM C114-00)
2. PBC contains very high percentage of silica (SiO); 54.78% which is higher when compared with that of cement (OPC) which is between 17% to 25% as provided by ASTM C114-00.
3. The initial setting time at 10% replacement was 200min and 270min at 40% replacement, this was found to be higher when compared with that of cement (OPC) but falls within the limit recommended by BS12(1978) and AS/NZS 2350.11.1997

4. The final setting time at 10% replacement was 290min and 410min at 40% replacement, this was found to be lower when compared with that of cement (OPC) but falls within the limit recommended by BS12(1978) and ASTM C191-92

5. The specific gravity of PBC was 2.17 which is less than 3.15 specified for OPC as specify

6. The bulk density of PBC was 1593kg/m3 which is higher compared with 1440kg/m3 for cement (Neville 1995)

7. The workability parameters (Slump and compacting factor) decreases from 26mm and 0.087 to 10mm and 0.80 as the percentage replacement increases from 10 to 40

REFERENCES

Al-Ani, M. and Hughes, B. (1989). "Pulverized-fuel ash and its uses in concrete", Mag.Concr. Res. 41 (147) 55–63.

AS/NZS 2350.11:(1997). Methods of testing Portland and blended cements- Compressive strength of Portland and blended cement.

ASTM C 114-00, Standard test method for chemical analysis of hydraulic Cement, Annual Book of ASTM Standards, Philadelphia, USA.

ASTM C 1240-01, Standard specification for use of silica fume as a mineral admixture in hydraulic-cement concrete, mortar and grout, Annual Book of ASTM Standards, Philadelphia, USA.

ASTM C 136-01, Standard test method for sieve analysis of fine and coarse aggregate, Annual Book of ASTM Standards, Philadelphia, USA.

ASTM C 143-00, Standard test method for slump of hydraulic cement concrete, Annual Book of ASTM Standard Philadelphia, USA.

ASTM C 231-97, Test method for air conten for freshly mixed concrete by pressure method, Annual Book of ASTM Standards, Philadelphia, USA.

ASTM C 39-01: Standard test method for compressive strength of cylindrical concrete specimens, Annual Book of ASTM Standards, Philadelphia, USA.

ASTM C 612-97:1997. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Concrete.

ASTM C 618-00, Standard specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete, Annual Book of ASTM Standards, Philadelphia, USA.

ASTM C 989-99, Standard specification for ground granulated blast furnace slag for use in concrete and mortars, Annual Book of ASTM Standards, Philadelphia, USA.

Berry, E.E. and Malhotra, V.M. (1980). "Fly ash for use in concrete-a critical review", J. of ACI 77 (8) 59–73.

Bilodeau, A. and Malhotra, V.M. (2000). "High volume fly ash system: concrete solution for sustainable development", ACI Mater. J. 99 (1) 41–48. *Design,* Surrey University Press, Great Britain. 3 (1).

Hassan I.O. (2006). "Strength properties of concrete containing volcanic ash as partial replacement of ordinary Portland cement", Unpublished Msc Thesis, University of Jos. Nigeria.

Hooton, R.D. (2000). Canadian use of ground granulated blast-furnace slag as a supplementary cementing material for enhanced performance of concrete, Canadian J. Civ. Eng. 27. 754-760.

Hossain, K.M.A. (1999), Properties of volcanic ash and pumice concrete, IABSE.

Hossain, K.M.A. (2003), "Blended cement using volcanic ash and pumice", *Cem.Concr. Res.* 33 (10), 1601–1605.

Hossain, K.M.A. (2005). "Performance of volcanic ash based precast and in-situ blended cement concretes in marine environment", *ASCE J. Mater. Civ. Eng.* 17 (6), 694–702.

Malquori, G. (1960), "Portland Pozzolan Cement", Chemistry of Cement, *Proc. Of Fourth International Symposium, Washington*, 7(1) 983-1005.

Margaret T. (2005). "Properties of Lime Mortar", Structures Magazine, p25-29.

Matawal, D.S. (2005) ."Application of Ashes as Pozzolana in Mortar and Concrete Production", *1st National Academy Conference,* 31st August -2nd September, ATBU Bauchi.

Neville, A.M and Brooks J.J (1997). *Concrete Technology*, 2nd Edition, London, Longman Publishers.

Neville, A.M. (1995). Properties of Concrete, Fourth edition Longman Group Limited, Harlow, England, Rep. 80 145–150.

Ogunbode E. B. (2010). Performance characteristic of Fly ash/OPC Laterized Concrete, M.Sc. Thesis, Department of Building, University of Jos.

Shetty, M.S. (1999). Concrete Technology Theory and Practice . Ram Nagar, New Delhi, S. chand and company Ltd

Swamy, R.N. (1986). "Cement Replacement Materials", *Concrete Technology and Design,* Surrey University Press, Great Britain. 3 (1).

Talero, R. (1990). "Qualitative Analysis of Natural Pozzolanas, Fly Ashes, and Blast Furnace Slags by XRD", *Journal of Materials in Civil Engineering,* 2(2), 106-117.

Tutonico, J.M., McCaig, I., Burns, C., and Ashurst, J. (1994). *The Smeaton Project AC1: Phase 1 Report*, English Heritage, London.