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Effect of potassium hydroxide and lime on the strength and durability of cassava peel ash blended cement mortar

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ABSTRACT

This research work investigates the effect of addition of potassium hydroxide (KOH), an alkali, and lime on the properties of cassava peel ash (CPA) blended cement mortar. Four binder combinations were used, viz; ordinary Portland cement (OPC, control), OPC-CPA blend, OPC-CPA-Lime blend and OPC-CPA-Lime-KOH blend respectively at 10% replacement of OPC with CPA. Properties investigated include strength and durability, measured using sorptivity, water absorption and apparent porosity for mortar specimen cured at 7, 14 and 28 days respectively for each of the binder combinations. The result shows that the OPC-CPA-Lime mortars showed better compressive strength, sorptivity, apparent porosity and water absorption performance than the other mixes. The performance of CPA-Lime blended cement mortar at 10% replacement of OPC with CPA and 4% replacement of CPA with lime compared favorably with OPC mortars in terms of strength and durability and is thus recommended for use in mortars.

Keywords: Mortar, Lime, Cassava peel ash, Compressive strength, Durability, Sorptivity, Apparent porosity.

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1. INTRODUCTION

Cement or some form of binding agent is a vital element in almost all types of construction and in recent years the cement market has been dominated by one product, ordinary Portland cement (OPC), which is an expensive and sometimes scarce commodity. The economic implication of this scarcity is the limiting of construction of affordable housing in much of the Third World. Alternative cements provide an excellent technical option to OPC at a much lower cost and have the potential to make a significant contribution towards the provision of low-cost building materials and consequently, affordable shelter. These secondary cementitious materials, such as pozzolana, have been used successfully in concrete and mortar, with positive results (Bahadure and Naik, 2013). These reactions can be slow from the start and hence the use of activators to enhance the pozzolanic reaction (Abdulla et al., 2012).

Hydration reaction of OPC with water produces calcium-silicate-hydrate, C-S-H (responsible for strength development) and calcium hydroxide (CH) which can be harmful to concrete. The $Ca(OH)_2$ product can be reduced and the production of C-S-H which contributes to the strength can be further increased with the addition of pozzolanic materials. This is due to the reaction between the pozzolana and the $Ca(OH)_2$ formed (Abdullah et al., 2012). It has been reported that the use of chemical activators namely sulfate activation and alkali activation may be utilized to accelerate the reactivity of fly ash (a typican pozzolana) (Lee et al., 2003). Cassava peels are available in large quantity in Nigeria and disposed for no benefit in return. Olonade (2015) in his research evaluating the pozzolanic properties of Cassava Peel Ash (CPA), concluded that CPA possesses pozzolanic potential.

Martinez-Ramirez and Palomo (2001) defined alkali activation as a chemical process where the amorphous structure is transformed into a skeletal structure that exhibits cementitious properties. Polymeric gel with variable composition is formed in the media of high alkalinity. The gel is produced when the solution of high alkalinity reacts with the starting materials. The main behavior of the products formed via these conditions is having great mechanical properties at the early period of hydration. Ma et al. (1995) as cited by Abdullah et al. (2012), found that an additional material is required to enhance the hydration process of the lime-pozzolana system. They reported that when the lime is mixed together with fly ash, the mechanical strength obtained at the early age is reduced.

Different techniques have been used to activate the pozzolanic reactivity and thus to enhance the mechanical strength of cement paste and concrete. These techniques include calcinations of natural pozzolan, prolonged grinding, elevated temperature curing and the addition of chemical activators. However, in previous published work, it has been found that the strength of lime-pozzolan cement pastes increased significantly when proper chemical activators are added. This technique was also found to be more efficient than grinding or subjected to elevated curing conditions.

The present research investigates the effect of lime and KOH (an alkali activator) on the compressive strength and durability performance of CPA blended cement mortars.

2. MATERIALS AND METHOD

The methodology for this research work was divided into three parts. In the first part, cassava peels were obtained from a cassava processing plant at Aliade, in Benue State, dried and burnt in the open air to reduce its carbon content after which it was calcined in a muffle furnace at the department of physics, university of agriculture makurdi laboratory at a temperature of 600°C for 2 hours, and sieved through a 300 µm sieve to increase the fineness. The CPA was divided into three parts and mixed with cement at 10% replacement of OPC with CPA. The cement used was a grade 42.5 OPC produced by Dangote Cement Industries Plc, Gboko plant, while the lime and KOH were obtained locally from a retail shop in Makurdi. Four binder mixes were prepared, namely; OPC, OPC-CPA blend, OPC-CPA-Lime blend and OPC-CPA-Lime-KOH blend respectively at 10% replacement of OPC with CPA; 4% replacement of CPA with lime and 2% replacement of CPA with KOH respectively.

The second part of the experimental programme involved carrying out preliminary tests on the materials used for the research (OPC, CPA and fine aggregates). The tests include moisture content, specific gravity, oxide composition, setting times, consistency, fineness and particle size determination. The tests were carried out in line with the provisions of the relevant of BS 12 and BS 812 for cement and aggregates respectively.

The third part of the programme involve casting a total of 144 number 50 mm × 50 mm × 50 mm mortar cubes at a binder-sand ratio of 1:6 and water-binder ratio of 0.5. For each binder combination, 36 cubes were casted, 12 each for 7, 14 and 28 days curing, and for each age, 3 cubes were used for each of compressive strength, sorptivity, water absorption and apparent porosity tests. The sorptivity, water absorption and apparent porosity tests were carried out in line with the methodology presented by Thokchom, et al. (2009); Shah and Pitroda (2013).

3. RESULTS AND DISCUSSION

3.1 Preliminary Investigation

The result of the preliminary tests on the materials used is presented in Table 1and Fig. 1. Fig. 1 shows the result of particle size determination of the fine aggregates carried out using sieve analysis. The oxide composition of OPC and CPA were determined using X-ray florescence analysis (XRF) at the National Geological Institute Kaduna and the result is presented in Table 2.

Table 1. Preliminary tests on materials

S/No	Property tested	Material tested					
		OPC	Sand	CPA	CPA-OPC	OPC-CPA-Lime	OPC-CPA-Lime-KOH
1	Specific gravity	3.05	2.62	2.60	2.94	2.88	2.78
2	Setting times (Mins.): Initial (Final)	90 (195)	-	-	120 (225)	105 (180)	105 (225)
3	Moisture content (%)	-	0.24	-	-	-	-
4	Std. Consistency (%)	30	-	-	41.25	34.75	35
5	Soundness (mm)	1.0	-	-	4.0	3.0	5.0
6	Clay and silt content (%)	-	2.4	-	-	-	-
7	Bulking (%)	-	2.0	-	-	-	-
8	Fineness	0.011	-	-	-	-	-
9	Fineness modulus	-	3.45	-	-	-	-

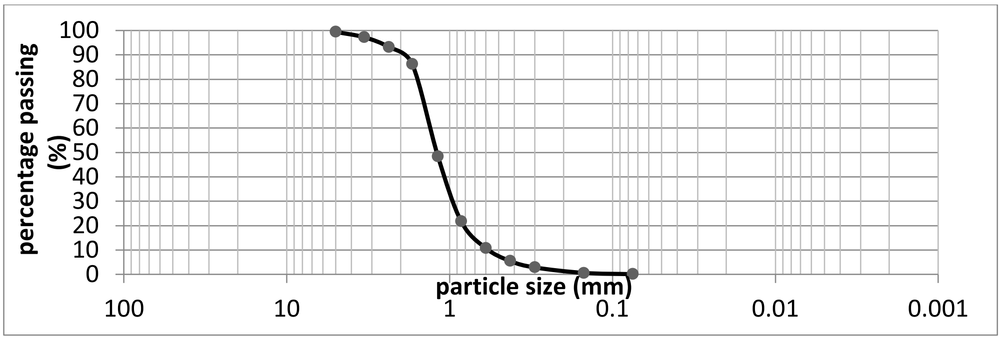

Fig. 1. Particle size distribution of river sand

Table 2. Oxide composition of CPA and OPC

Oxide	CaO	Fe_2O_3	Al_2O_3	SiO_2	MgO	K_2O	Na_2O	SO_3	MnO	LOI
CPA	8.53	1.41	12.80	58.02	5.02	7.67	0.03	2.18	nd	4.18
OPC	65.57	6.83	5.60	16.20	nd	0.48	nd	2.15	0.047	3.12

nd: not detected

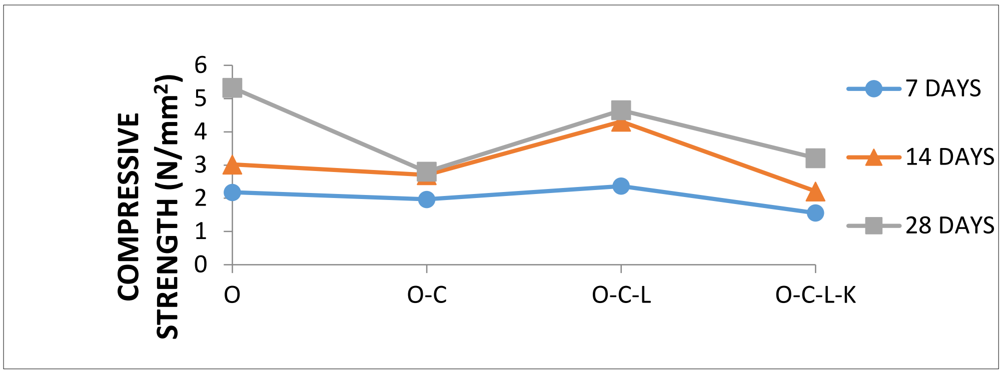

Fig. 2. Variation of compressive strength with binder material

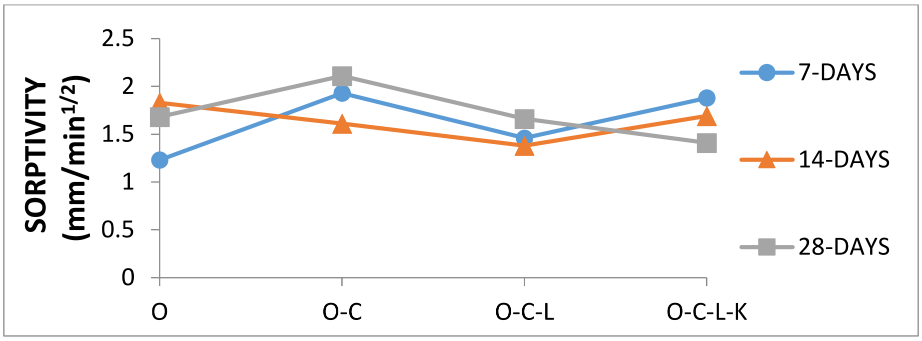

Fig. 3. Variation of sorptivity with binder material

The result of the preliminary investigation presented in Table 1 and Table 2 and Fig. 1 shows that the materials characterized met the relevant provisions of the various codes. The specific gravity of the CPA and CPA blends all fall below the specific gravity of cement. This is expected since the replacement materials are all less dense than the OPC. The fine aggregate is well graded and falls within zone 2 which is suitable for use in concrete and mortar.

3.2 Compressive Strength, Sorptivity, Water Absorption and Apparent Porosity

The result of compressive strength, sorptivity, water absorption and apparent porosity for 7, 14 and 28 days is given in Fig. 2 to Fig. 5 respectively.

3.2.1 Compressive Strength

The result of compressive strength presented in Fig. 2

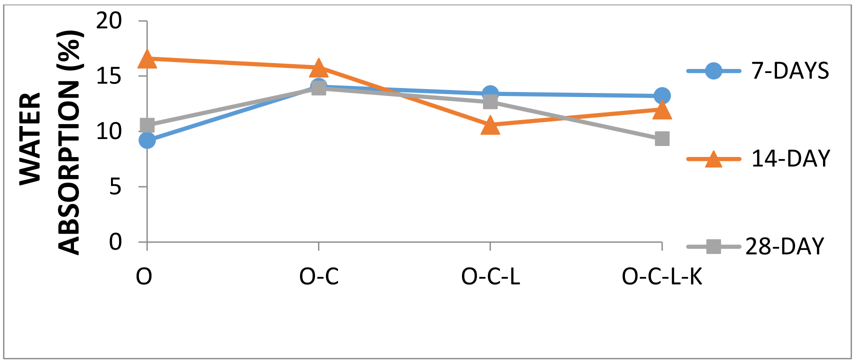

Fig. 4. Variation of water absorption with binder material

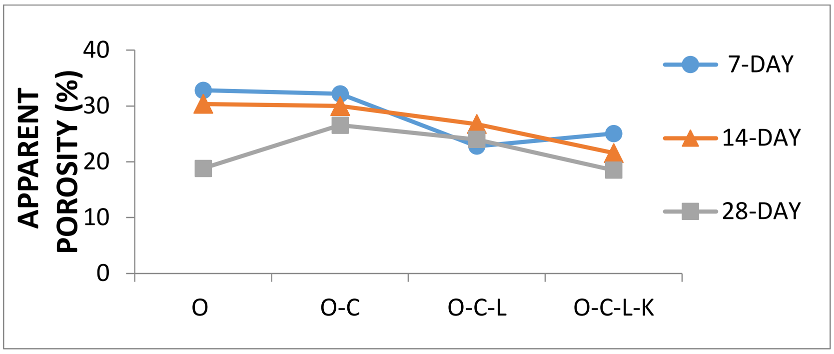

Fig. 5. Variation of apparent porosity with binder material

Legend: O = OPC; O-C = OPC-CPA blend; O-C-L = OPC-PLA-Lime blend and O-C-L-K = OPC-CPA-Lime-KOH blend.

shows that OPC-CPA-Lime mortars showed strength behavior similar to that of the OPC mortars, whereas the OPC-CPA-Lime-KOH blended mortars showed the least strength at all ages. This reduction in strength with the addition of the KOH could be due to the high concentration of the KOH which releases K^+ ions that are detrimental to strength gain (Petermann, 2010 citing Khale et al., 2007). According to Neville (1995), hydration of cement carried out in the media of high alkalinity and subjected to curing processes of less than 28 days has negative effect on the strength, which reduces with increasing alkali concentration. Similar findings were reported by Martinez-Ramirez and Palomo (2001). Petermann (2010) cited Kong and Sanjayan (2008) in explaining the chemistry behind this strength reduction, noting that $Ca(OH)_2$ reacts with KOH under favorable humidity conditions to form a gel which eventually morphs into a rigid crystalline structure causing internal expansion and deterioration of the cementitious mass. The resulting gel will have an expansive nature relative to the content of CaO in the final product. The OPC -CPA-Lime mortar showed the highest strength after plain OPC mortar and its ratio of 14 days to 7 days strength (2.37 N/mm^2 and 4.31 N/mm^2) shows the highest rate of early strength development. The early strength gain is due to the pozzolanic reaction between CPA and lime. In a normal concrete or mortar without the lime, the pozzolanic activity only starts after the hydration of cement has started and CH is released into the concrete/ mortar matrix. However, the presence of the lime provides the needed CH for early pozzolanic reaction, hence the production of additional CSH early in the hydration due to the pozzolanic reaction between lime and CPA, hence the high rate of early strength gains in the OPC-CPA-Lime mortar as compared to the OPC-CPA mix. Evidently, there is no extra element to hamper the pozzolanic reaction of the lime and CPA. The plain OPC mortar with the highest 28 day strength recorded also showed the highest rate of strength gain occurring between 14 and 28 days of curing.

3.2.2 Sorptivity

Sorptivity is the ability of a material to absorb and transmit water through it by suction. The principle of this test is that an unsaturated hardened mortar specimen has one surface in contact with water while the others are sealed. It is a function of the viscosity, density and surface tension of the liquid and also the pore structure of the specimen. The ingress of moisture and the transport properties of these materials have become the underlying source for many engineering problems such as corrosion of reinforcing steel, and damage due to freeze-thaw cycling or wetting and drying cycles (Vimal, 2009). Sorptivity is increasingly being used as a measure of concrete and mortar resistance to exposure in aggressive environments, thus making it a measure of concrete or mortar durability. Mortar specimens with higher sorptivity values lose more strength than those with lesser corresponding values (Thokchom et al., 2009). In the present work, plain mortar showed better sorptivity performance (least value of sorptivity), followed by mortar containing CPA and lime. This could be due to the filling of the pore spaces by the products of hydration. The sorptivity of mortar containing KOH is highest followed by lime mortar. This could be due to deterioration as a result of the presence of KOH. More so, the reaction between KOH and CH produces crystalline products thereby leaving the concrete exposed. The sorptivity values show no particular trend with age. The variability in sorptivity could be due to differences in compaction since sorptivity testing was shown to be sensitive to compaction as prolonged ramming decreased porosity (Vimal, 2009 citing Hall and Raymond Yau, 1987).

3.2.3 Water Absorption

Water absorption test, like permeability test; measure the response of mortar to pressure. In the present work, mortars activated with KOH showed a consistent improvement in water absorption with age, absorbing the highest and lowest amounts of water at 7 and 28 days respectively. This is in agreement with work done by Thokchom et al. (2009) who observed that specimens containing lesser alkali (Na_2O) were found to possess higher water absorption and lost more strength than those with lesser values after 24 weeks of exposure in sulfuric acid.

3.2.4 Apparent Porosity

The porosities of plain OPC, OPC-CPA and activated CPA blended mortars decreased with curing age while the porosity of OPC-CPA-Lime mix increased at 14 days and dropped at 28 days of curing. Remarkably, the activated CPA mortar showed better porosity performance with age.

4. CONCLUSIONS

The following conclusions can be drawn from this research work:

1. The addition of 4% lime increased the strength performance of CPA blended cement mortars
2. The use of alkali activator (KOH) improved the durability performance of CPA blended mortars measured in terms of water absorption and apparent porosity.
3. Cement mortar incorporating 10% CPA, 4% lime and using 2% KOH as alkali activator improves the performance of mortar.
4. The percentage of the alkali activator should be varied in future research to ascertain the effect on the properties of mortar and concrete.
5. Different activators should be used under the same conditions to ascertain which performs better in concrete applications.

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