Exploratory Study on Agro-Waste Ashes Combination with Industrial Waste as Alternative Binders in Concrete

[1]B. J. Olawuyi, [2]O. Joshua, [1]I. O. Hassan, [1]M. O. Enejiyon and C. [1]I. Egwuda
[1]Department of Building, Federal University of Technology, Minna, Nigeria
[2]Department of Building, Covenant University, Ota, Ogun State, Nigeria
Corresponding email: babatundeolawuyi@yahoo.com

Abstract

Portland cement (PC), being the world's most commonly used binder in mortar/concrete applications, is adjudged a non-environmental-friendly material due to its green house (carbon dioxide–CO_2) gas emission mainly during its production. Previous studies on the search for alternative binders had centred on the utilisation of natural Pozzolan or ashes from agricultural wastes (agro-wastes) as partial replacement of PC in mortar or concrete construction while reports on total replacement are scarce in literature. Incinerated ashes from agro-wastes at controlled temperatures have been found to be pozzolanic with the major components being amorphous silica which combines with lime in the presence of water to give cementitious properties. This paper reports on the exploratory study on agro-waste ashes namely Rice Husk Ash and Sorghum Husk Ash (RHA and SHA) which are silica sources, in combination with industrial waste materials typically calcium carbide waste (CCW) – a CaO source), as alternative binder for total PC replacement in mortar/concrete construction. Pastes from the different combination ratio of RHA/CCW and SHA/CCW were studied for setting times, degree of hydration and strength development. The study revealed the RHA and SHA have high silica content (SiO_2--93% and 84% respectively) while CCW is primarily contains CaO (66% content). The agro-industrial binders (RHA/CCW and SHA/CCW) showed good binding properties at a slow hydration rate. Mortar samples from 60/40 RHA/CCW and 70/30 SHA/CCW combinations gave best performance with 28-day compressive strength of 5.3N/mm^2 and 7.5N/mm^2 respectively and correspondingly representing 25% and 35% of CEM I strength.

Keywords: *Rice husk ash (RHA), sorghum husk ash (SHA), calcium carbide waste (CCW), Pozzolan, agro-industrial binder.*

1.0 INTRODUCTION

Concrete, the largest manufactured product used by human society (Mehta and Monteiro, 2014) depends greatly on Portland Cement (PC) for strength development and other desired properties. The manufacturing process of PC is known to contribute around 5% of global CO_2 emission resulting from clinker production and the fossil fuel used for pyro-processing (Rubenstein, 2012). Clinker production involve heating calcium carbonate ($CaCO_3$) in the kiln at temperatures above 900°C which results in the production of lime (CaO) and CO_2 as shown in equation 1.

$$CaC0_3 \xrightarrow{heat\ (>900^0 0C)} CaO + CO_2 \qquad (1)$$

The quick lime CaO is further made to react with materials containing silica (SiO_2), alumina (Al_2O_3) and iron (Fe_2O_3) at higher temperatures of about 1450°C. The product is then removed from the kiln, allowed to cool, ground to fine powder and mixed with about 5% gypsum content for controlled setting (Neville, 2012; Mehta and Monteiro, 2014). The major components of PC are CaO, SiO_2, Al_2O_3 and Fe_2O_3 with the strength determinant being the SiO_2 in combination with CaO to form hydrated lime, $Ca(OH)_2$, in the presence of water; and this results in the formation of CaO-SiO_2-H_2O – Calcium Silicate Hydrate (C-S-H) which is the final product for strength development, as cement hydration progresses after contact with water.

Research and development of alternative binders to Portland Cement (PC) is continuously in the forefront in recent years due to the increased awareness on climate change challenge attributable to global warming. Stratospheric ozone depletion and climate change resulting from emission of greenhouse gases (GHG) due to human and industrial activities with chlorofluorocarbons (CFC) and non-CFC gases such as carbon (IV) oxide (CO_2) adjudged the primary gas emitted (Waterloo News, May, 2013; US National Climate Assessment (NCA), 2014; US Environmental Protection Agency, 2016). This, coupled with the constant excavation and depletion of non-renewable limestone ($CaCO_3$) natural resource, has resulted in intense research for alternative materials, with focus on re-use and recycling of the abundant agricultural and industrial waste materials that often cause environmental challenges.

Previous studies on potential alternative binders were focussed on the utilisation of natural Pozzolans such as volcanic ash (Hossain 2003 & 2005; Hassan, 2006; Olawuyi, 2011) or ashes from agricultural wastes (agro-wastes) such as rice husk ash [RHA] (Okpala, 1987; Chaowat, 2001; Abalaka & Okoli, 2013), corn-cob ash [CCA] (Raheem, 2010), sawdust ash [SDA] (Elinwa & Mahmood, 2002), millet husk ash [MHA] (Jimoh et al, 2013) and palm kernel nut ash [PKNA] (Joshua et al, 2015) amongst others, as partial replacement for PC in mortar or concrete. Attempts on total cement replacement in concrete brought about studies into geo-polymer concrete which involved alkali activation of Pozzolanic materials with the use of chemical-based hydroxide [NaOH] at elevated or ambient temperatures (Ul. Haqet. al, 2014; Turner and Collins, 2013). Some studies on total cement replacement with Pozzolan in combination with alternative CaO source (calcium carbide waste [CCW]) included the works of Rattanashotinunt et. al (2013) on baggase ash combined with CCW; and Makaratat et. al. (2010) on fly ash (FA) in combination with CCW. Also Joshua et al (2016) worked on the combination of pulverized calcined clay (PCC) with CCW, both sourced within Nigeria and reported hydration reaction with a 28-day strength of 11MPa without any treatment on the CCW.

Incinerated ashes from agro-wastes at controlled temperatures have been found to be pozzolanic with major components being amorphous silica which combines with lime in the presence of water to give cementitious properties. Pozzolan by definition is siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (ACI Terminology of Concrete, 2013 in ACI Manual of Concrete, 2016; Neville, 2012).

The concept of pozzolanic reaction according to Mehta and Monteiro (2014) is based on the fact that Portland cement react using Tricalcium Silicate (C_3S) with water (H) to give Calcium Silicate-Hydrate (C-S-H) and Calcium Hydroxide (CH)

$$C_3S + H \rightarrow C-S-H + CH \quad (2)$$

The Portland-Pozzolan cement reaction follows as

$$Pozzolan + CH + H \rightarrow C-S-H \quad (3)$$

Where C = CaO, S = SiO_2 and H = $(OH)^-$

The reaction in Equation 2 is known to be fast and lime producing while the reaction in Equation 3 is rather slow or latent, depending on the properties of the pozzolanic material. The pozzolanic reaction in (Equation 3) is basically lime-consuming and does not necessarily require presence of cement but an active source of lime. Thus the thought for alternative source of lime to enhance pozzolanic reaction with an agricultural waste ash as Silica source (rice husk ash (RHA) or sorghum husk ash (SHA) is the focus of this study. The CaO source in this study is an industrial waste material, calcium carbide waste (CCW).

Calcium carbide waste (CCW) is the by-product of acetylene gas generated from calcium carbide used in the production of Polyvinyl Chloride (PVC) and in welding of steel especially in the auto industry. CCW in Nigeria is reported to be 70-80% calcium hydroxide ($Ca(OH)_2$) with the impurities in it listed as copper, lead, iron, manganese, nickel and zinc (Chukwudebelu *et al.*, 2013). RHA and SHA are both ashes gotten from open-air burning of the husk of rice and sorghum that are major staple food in Nigeria. The continuous drive towards food security and sustainability by the Nigerian Government seen in the strategic massive production of rice and other cereals grains like sorghum, maize and millet, etc. in different parts of the country is a pointer to the continuous availability of the husks of these crops as wastes that can be harnessed not only to clean the environment but primarily to harness them for useful application in the construction industry. The utilization of these agricultural and industrial waste materials in concrete and mortar construction should be seen as a welcome development. Consequently, this research into the suitability of these materials as total replacement for Portland cement in construction promises to offer contribution towards improving knowledge in concrete technology and development. This is underscored by the fact that the quest for developing alternative binders is critical in the face of the dramatically changing economic realities, the need for quality and durable sustainable construction materials and technology, carbon blue print and the need for sustainable eco-system.

2.0 EXPERIMENTAL PROCEDURE

2.1 Materials

The materials used for this study are Rice husk and Sorghum husk, both agro-wastes derived from the milling of rice and sorghum. These were used in the production of RHA and SHA respectively as sources of SiO_2. The Rice husk and Sorghum husks were collected from a local rice mill at Garatu Village (near Minna), Bosso Local Government Area in Niger State, Nigeria. The husks were burnt in open air with a locally fabricated incinerator presented earlier in Abalaka (2013). This was ground to finer particles in a local mill at Gida-Mongoro Village of Minna and sieved with a 75 μm sieve; and the particles passing was used as the RHA and SHA for the study.

Calcium carbide waste (CCW), an industrial waste from automobile oxy-acetylene welding, was used as the CaO source at varied combinations (70/30, 60/40, 50/50, 40/60 and 30/70 of RHA/CCW and SHA/CCW respectively).these were used as the alternative binder. For the control mortar mix, CEM I 42.5N (Dangote 3X) from Obajana factory of Dangote Cement Company was used as the binder. The CCW was obtained from a local automobile Welder's (i.e. "Panel-beater" using oxy-acetylene gas) workshop in Minna as sludge. It was sun-dried and sieved with 75 µm sieve and the particles passing used as the CCW sample in this study.

The fine aggregate used is the simulated reference sand (size range 1.18 mm [Sieve No. 16] to 75 µm [Sieve No. 200]) sieved out from the available natural sand in consonance with BS EN 196-1:2016 reference sand prescription for strength test on cement (binder). The potable water available at the Building Laboratory of the Federal University of Technology, Minna was used for mixing.

2.2 Methods

The study involved the determination of the physical and chemical properties of the constituent materials for mortar samples for proper characterisation. Also determined were the properties of the fresh binder pastes and mortar before an examination of the strength properties and degree of hydration of the hardened mortar samples.

Mortar samples of 1:3 (c/s) and 0.5 water/cement (w/c) ratio specified by BS EN 196-1:2016 containing the control PC) and alternative binders (RHA/CCW and SHA/CCW in varied proportions) as indicated in Section 2.1 were prepared and tested for strength and degree of hydration at varied curing ages of 3, 7, 14 and 28 days.

2.2.1 Physical and chemical Properties

Particle size distribution of the available natural sand was conducted using the dry-sieve approach in accordance to BS EN 933-1:1995 for proper classification of the available natural sand. The reference sand used for mortar production in the strength determination test specified in the standard (BS EN 196-1:2016) was then extracted using an arrangement of sieve sizes 1.18mm and 75µm. The particles passing the 1.18mm sieve but retained on the 75µm sieve was used for the mortar mixture for the strength test. The 1.18 mm sieve was adopted as the upper limit value for the simulated reference sand instead of the 1.6 mm sieve specified by BS EN 196-1:2016 because of non-availability of the 1.6 mm sieve in the laboratory. The particle size distribution of both the natural and the simulated reference sand are presented in Fig 2.

The specific gravity of all the materials used in this study were determined in accordance with the provisions of BS EN 1097: 2003; while fineness test on cement (CEM I 42.5N) and the varied combinations of RHA/CCW and SHA/CCW were determined via the wet-sieving method as prescribed by BS EN 196-6:2005 using a 53µm sieve.

X-Ray Fluorescence (XRF) analysis for the determination of the oxide composition was conducted on the cementitious materials (CEM I 42.5, RHA, SHA and CCW) at Ewekoro Works Department of Lafarge Cement using XRF Analyser connected to a computer system for data acquisition.

2.2.2 Setting time and soundness of cement and the agro-industrial binders

The initial and final setting times and the Le Chatelier soundness tests for the binders (CEM I 42.5N and the various proportion combinations of RHA/CCW and SHA/CCW) were determined using neat pastes of standard consistency in accordance with BS EN 196-3:2011. This involved determining the water content of the paste which will produce the desired standard consistency (Neville, 2012). Vicat apparatus Model No EL 38-2010 by ELE was used for measurement of the consistency, and both the initial and final setting times following the procedures as outlined in the standard (BS EN 196-3:2011). The soundness test was also carried out on the respective binders using a Le Chatelier apparatus Model No EL 38–3400 by ELE.

2.2.3 Determination of strength and degree of hydration of the binders

The determination of strength and degree of hydration of the binders was conducted using 50mm mortar cubes. This involved weighing out the appropriate constituent materials and ensuring that the agro-wastes ash (RHA or SHA as appropriate) was thoroughly mixed with the industrial waste materials (CCW) in an head-pan before being poured on the measured quantity of the simulated reference sand already spread into the steel mixing platform. The sand and binder were then mixed thoroughly before the weighed mixing water was added; and mixing continued until a uniform mix was achieved before casting into the 50mm cube moulds. The control mortar sample with the PC i.e. CEM I 42.5N was similarly prepared and cast in cube moulds. The samples were left covered with jute bags and cured by water sprinkling until 72 hours before demoulding; and water curing by immersion made to continue until testing age.

The procedure for the strength test and degree of hydration determination adopt followed a similar approach reported by Hasholt et al. (2010) as cited in Olawuyi (2016). The highlight of the procedure is as follows:

a) The mortar cubes were cast and crushed at the different curing ages of 3, 7, 14, and 28 days (immediately after demoulding) in the Digital Universal Testing Machine (DUTM–20) to assess the strength development.
b) The remains of the sample in (a) above was then milled properly using the 150mm x 150mm Θ cylindrical moulds and 25mm Θ bar as mortar and pestle. The milled sample was then vacuum-dried for 1 hour to stop further hydration.
c) A known weight of the vacuum-dried sample, about 20g particle passing 75μm standard sieve [Sieve #200] was measured and oven-dried for 24hours at 105°C, and weighed again to determine the evaporable water, i.e. the capillary water + gel water
d) This sample was then placed in the furnace [Model No SNOL 8,2 /1100–1LZ] set to 900°C. One hour after attaining furnace temperature of 900°C, the furnace was switched off, allowed to cool and the sample weighed. This was to determine the amount chemically bound water, i.e. the non-evaporable water.

All calculations were then based on ignited weight basis to give the following:

Loss on ignition (LOI) of the binders (CEM I 52.5 N, RHA, SHA and CCW) and hydrated mortar pastes were calculated:

LOI (%) = 100 x (as received weight – ignited weight)/as received weight (4)

w_n (i.e. non-evaporable water) content of the hydrated mortar pastes was determined to evaluate

the degree of hydration as provided for in literature (Lam et al., 2000; Neville, 2012). This is the difference in mass measurement of the crushed paste at 900°C and 105°C.

The degree of hydration (α) is calculated on the basis that 1g of anhydrous cement produces 0.23g of w_n; hence the w_n is calculated by using the following formula

$$w_n\% = \frac{100\ x\ (dried\ weight\ of\ paste \quad ignited\ weight\ of\ paste)}{(Ignited\ weigth\ of\ paste \quad loss\ on\ ignition\ of\ cement)} \qquad (5)$$

The degree of hydration (α) is given by:

$$\alpha = 100\ x\ \frac{w_n}{0.23} \qquad (6)$$

The degree of hydration in the agro-industrial binders at the various combinations of RHA/CCW and SHA/CCW were however calculated with consideration for the LOI of the SCM and the proportion made to adjust for their $w_n\%$ as appropriate.

3.0 RESULTS AND DISCUSSION

3.1 Characterisation of the Constituent Materials

Figure 1 presents the particle size distribution (PSD) of the available natural sand and the simulated reference sand used for the experiment. The PSD revealed the simulated reference sand to have a C_u and C_c values of 2.06 and 0.86 respectively and a Fineness Modulus (FM) of 2.56 indicating a fine sand classification of Shetty (2004).

Table 1 presents the PSD of the CEN reference sand for determination of strength of cement as compared to the simulated reference sand used. It was observed that the simulated reference sand was compliant to three of the six size requirements of the CEN reference sand as prescribed in BS EN 196-1:2016.

The simulated reference sand was used for the study despite the shortcomings of not meeting the other three requirements since the study is basically a comparative study on strength development of the alternative binder developed and the CEM I, but not product validation and certification of the cement. The strength of the mortar samples from CEM I used in this study serve purely as a reference to which the strength of the alternative agro-industrial waste binder was compared.

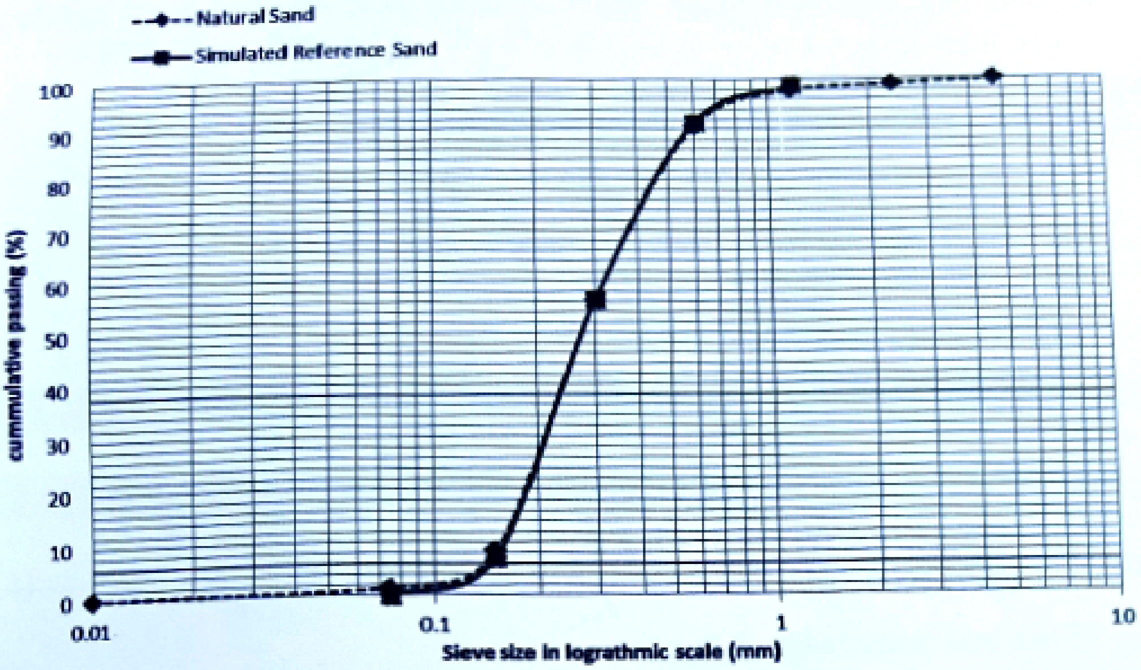

Fig. 1: Particle Size Distribution of Fine Aggregate

The specific gravity for the constituent materials is presented in Table 2. The result shows the values fit well with earlier reports in literature (Neville, 2012)

Table 5: Particle Size Distribution of Fine Aggregate

Sieve opening (mm)	CEN Reference Sand (%)	Simulated Reference Sand (%)	Remark
2.00	0	0	√
1.60	7 ± 5	0	
1.00	33 ± 5	3	
0.50	67 ± 5	16	
0.16	87 ± 5	92	√
0.08	99 ± 1	99	√

Table 6: Specific Gravity of Constituent Materials (kg/m^3)

Cement	RHA	SHA	CCW	Sand
3.15	2.30	2.32	2.29	2.58

The oxide composition of the various cementitious materials obtained through XRF conducted at Lafarge Cement in Ewekoro is as presented in Table 3. The RHA and SHA samples are mainly silica having 94% and 83% SiO_2 contents respectively. The Table reveal the agro-waste ashes as Class N Pozzolan with total SiO_2+Al_2O_3+Fe_2O_3 above 70%, SO_3 below 4% and loss on ignition (LOI) of less than 10%. The CCW was observed to contain 66% CaO, a similar value to the CaO content (64%) of the CEM I sample. The CCW was however contain lower SiO_2 and Al_2O_3 when compared to the PC sample. The LOI of CCW was above the specified 10% maximum, an indication that some heat treatment might be required for more effective performance of the material.

Table 7: XRF Analysis for Oxide Composition of Cementitious Materials

Samples	LOI	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	Mn_2O_3	Cr_2O_3	AR	SR	$SiO_2+Al_2O_3+Fe_2O_3$
RHA	0.0	93.6	1.1	0.9	1.3	1.2	0.1	1.7	0.2	0.1	0.0	0.0	0.0	1.2	49.3	95.[illegible]
SHA	5.6	83.0	2.9	2.7	1.3	0.8	0.0	0.2	2.8	0.2	0.5	0.0	0.0	1.1	14.7	88.[illegible]
CCW	26.4	3.6	1.6	1.3	65.8	0.2	0.0	0.1	1.0	0.1	0.0	0.0	0.0	1.2	1.2	6.[illegible]
CEM I	0.0	21.5	5.2	1.2	64.0	2.9	4.5	0.6	0.0	0.1	0.2	0.0	0.0	4.5	3.4	27.[illegible]

3.2 Setting Times and Soundness of Binders

Table 4 presents the result of the consistency and soundness test conducted on the binder combinations and the control (CEM I). The result show that the water demand of the agro-industrial binders was about three times of the CEM I demand. The RHA/CCW and SHA/CCW binders reflect a higher water demand trend for similar penetration values. The higher the ash (i.e. RHA or SHA) content, the higher the water demands. The water demand trend is similar for the two agro-waste binders and this was accounted for in the mortar production process for strength test of the binders.

The soundness test presented in Table 4 revealed that all the binder combinations conform to the 10mm maximum expansion specified by BS EN 197-1:2011. Figures 2 and 3 present the plot of the setting times (initial and final) for the RHA/CCW and SHA/CCW binder combinations respectively.

Table 8: Fresh Properties of Binders

Specimen	Consistency				Soundness Expansion (mm)[0.04 in]	
	Water Demand (%)	Penetration (mm)[0.04 in]	Water Demand	Penetration (mm)[0.04 in]	RHA/CCW	SHA/CCW
CEM I	32.0	5.5	36.8	5.0	1.0	0.0
70/30	96.0	6.0	96.8	7.0	2.5	0.0
60/40	87.2	6.0	92.8	5.0	1.0	0.5
50/50	84.0	6.0	87.2	5.0	1.0	0.5
40/60	81.2	6.0	82.8	7.0	1.5	1.0
30/70	76.8	6.0	81.2	7.0	1.0	1.0

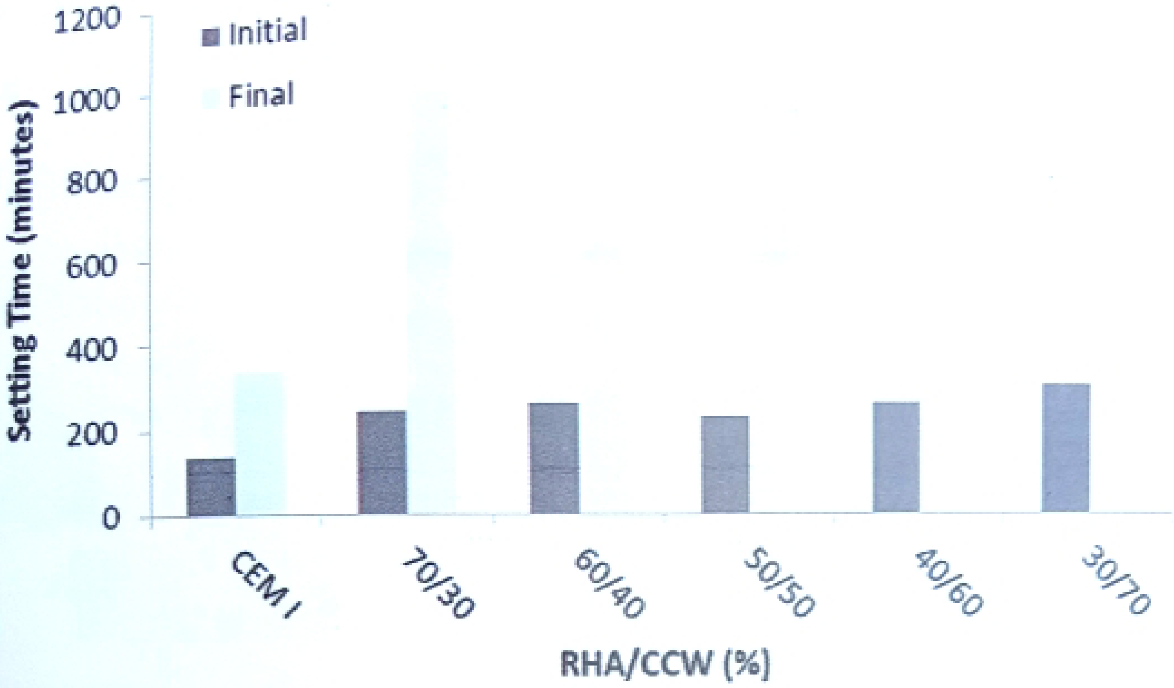

Figure 2: Setting times (initial and final) of the RHA/CCW Binder

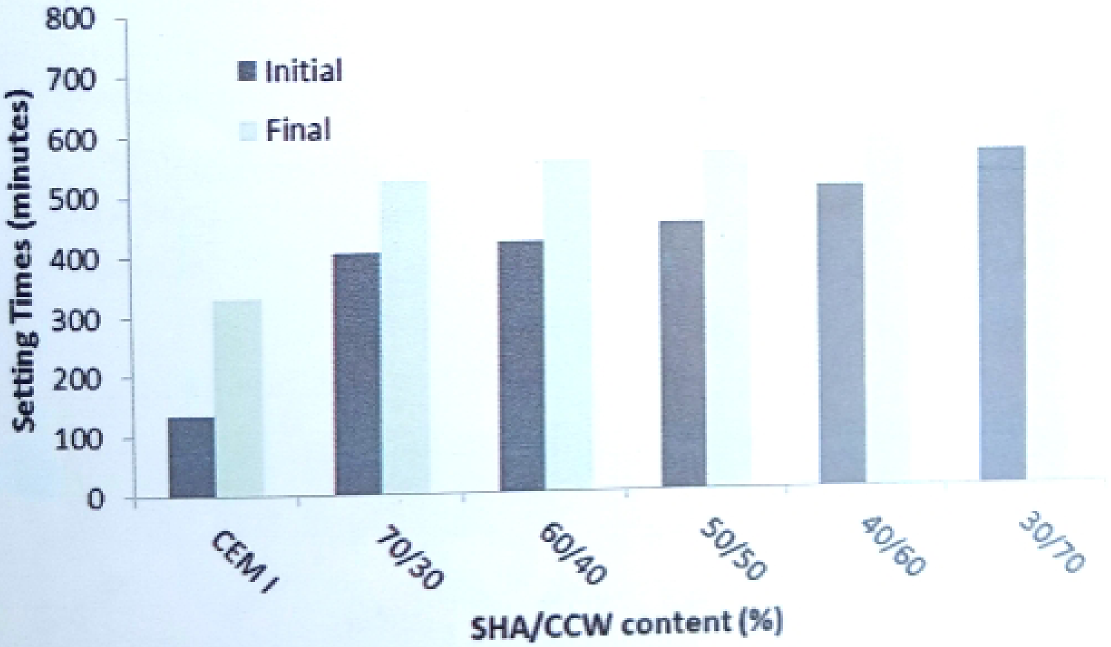

Figure 3: Setting times (initial and final) of the SHA/CCW Binder

The results revealed that the initial setting times of RHA/CCW binder combinations are one and a half to twice that of the CEM I but lower than the values for the SHA/CCW binders. The final setting times of both RHA/CCW and SHA/CCW binders were however of similar values and about three times of the final setting time for CEM I. This affirms literature postulation that Pozzolans are of latent setting in nature and improvement on the binders can be geared towards accelerating the setting times which is believed will enhance their strength development trends.

3.2.1 Degree of Hydration and Strength of Agro-industrial Waste Binders

The plot of degree of hydration of the binders are presented in Figures 4 (RHA/CCW) a[nd 5] (SHA/CCW) while the rate of hydration (RH_{28}) with reference to the 28 day value for the co[ntrol] sample (CEM I) is further shown in Table 5.

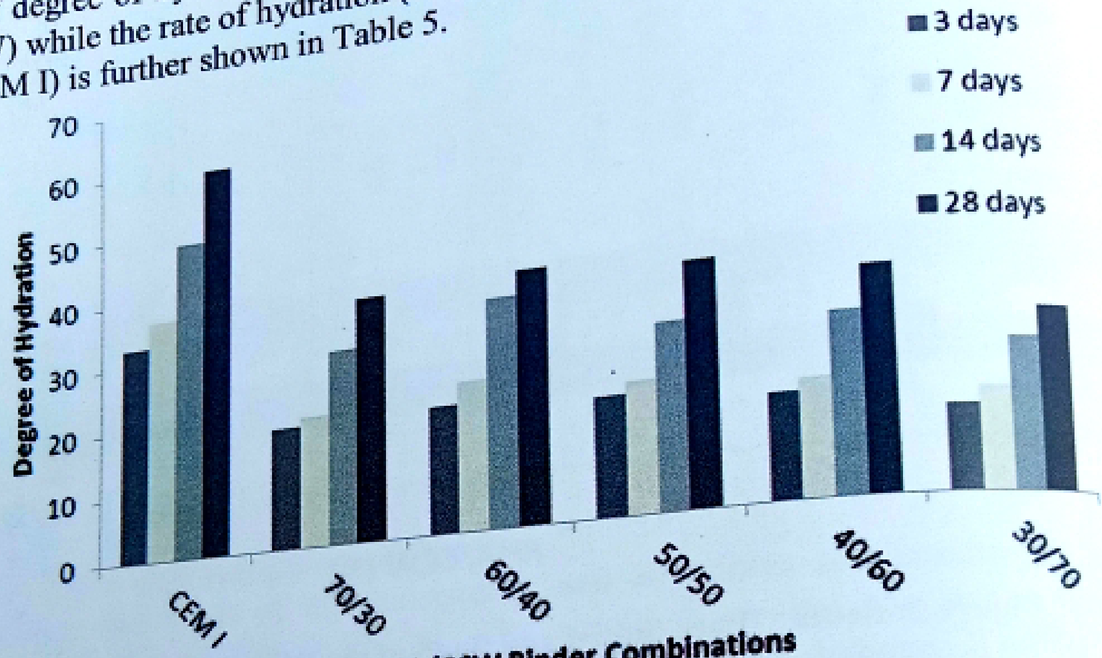

Figure 4: Degree of Hydration of Hardened RHA/CCW Mortar

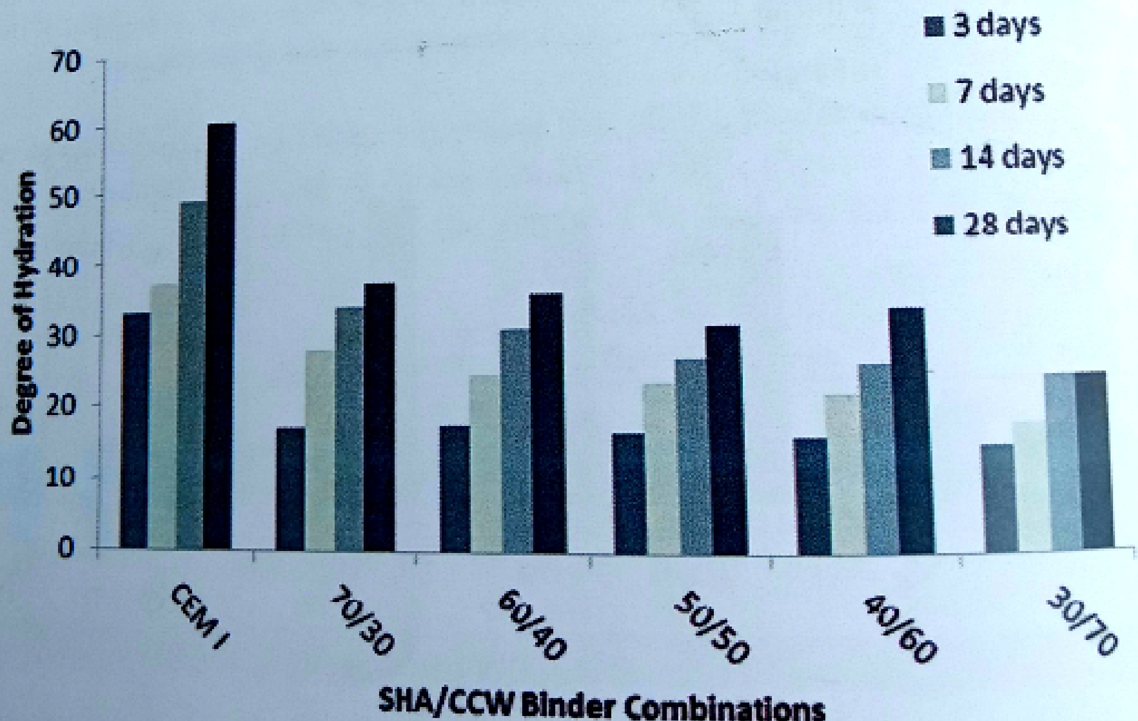

Figure 5: Degree of Hydration of Hardened SHA/CCW Mortar

The result revealed 60/40 RHA/CCW and 70/30 SHA/CCW combinations as the best o[f] agro-based binders with 38% and 36% levels of degree of hydration respectively at the 28 curing age. This amounts to RH_{28} values of 0.63 and 0.60 respectively with reference to the [28] day value of CEM I. Hydration was observed to improve as the curing age increased; and binders are expected to show good long term age strength development.

Table 9: Degree of Hydration and RH_{28} Factor of the Agro-industrial Binders

Binder Type	Specimen	Degree of Hydration				RH_{28} Factor			
		3 days	7 days	14 days	28 days	3 days	7 days	14 days	28 days
Control	CEM I	33.00	37.01	48.72	59.81	0.55	0.62	0.81	1.00
SHA/CCW	70/30	16.74	27.23	33.09	36.07	0.28	0.46	0.55	0.60
	60/40	16.59	23.24	29.44	34.05	0.28	0.39	0.49	0.57
	50/50	15.52	21.95	25.26	29.56	0.26	0.37	0.42	0.49
	40/60	14.86	20.43	24.23	31.39	0.25	0.34	0.41	0.52
	30/70	13.88	16.76	22.55	22.55	0.23	0.28	0.38	0.38
RHA/CCW	70/30	18.15	19.53	29.05	36.57	0.30	0.33	0.49	0.61
	60/40	18.62	21.86	33.82	37.54	0.31	0.37	0.57	0.63
	50/50	17.31	19.00	27.21	35.85	0.29	0.32	0.45	0.60
	40/60	15.25	17.01	26.47	32.67	0.25	0.28	0.44	0.55
	30/70	12.25	14.79	21.75	26.10	0.20	0.25	0.36	0.44

The early age (3 days) hydration values for the agro-industrial binders was observed to be about half that of the PC. The plot of the compressive strength of the binders (Figures 6 and 7) followed similar trend as the inference drawn from the degree of hydration results. RHA/CCW (60/40) and SHA/CCW (70/30) gave 28day compressive strength values of 5.3N/mm^2, which is 25% of CEM I strength and 7.5N/mm^2 representing 35% of CEM I strength respectively. The low strength can be adduced to the additional water used for the binders on basis of the water demand established from the result of the consistency test.

Despite the low strength development of the agro-industrial binders as observed in this study, the samples were noted to bind effectively with the fine aggregates after demoulding at 72 hours (3 days) after casting. The mortar made from the agro-based binders did not dissolve in the immersed water in the curing tank all through the curing ages. The agro-industrial binder could be improved upon possibly in further studies through the use of water reducers, and keeping the water/binder ratio to be same as for control or engaging set accelerating mixtures/procedures.

Figure 6: Compressive Strength of RHA/CCW Binder Mortar

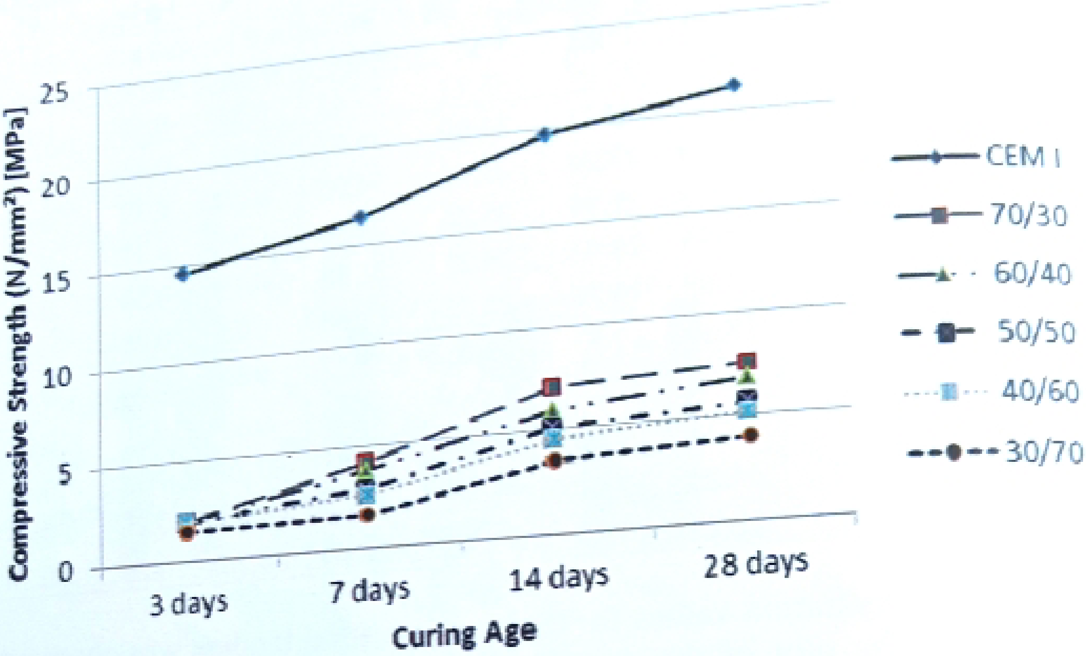

Figure 7: Compressive Strength of SHA/CCW Mortar

4.0 CONCLUSION AND RECOMMENDATIONS

The results from the study show that the agro-based waste alternative binders (RHA and SHA) in combination with an industrial-based waste (CCW) possess binding properties. The chemi analysis shows RHA and SHA classify as Class N Pozzolan of high SiO_2 content (94% and 8 respectively) while CCW is a good CaO source having percentage concentration of 65% sim to the CEM I used for the study. Further studies targeted at set-acceleration and improved ea strength development of the binder combinations holds good promise towards the des breakthrough in the production of suitable alternative binder from these agro-industrial wa materials.

The following are hereby recommended based on the findings of this study:

a) Further studies on the RHA/CCW and SHA/CCW should focus on set-acceleration a early strength development through the use of water reducing admixtures and s accelerators as admixtures.
b) Investigation into the influence of temperatures slightly above the ambient temperature (i 40 – 90°C) on the initial and final setting of the agro-industrial binders should be carri out.
c) Future studies on the product of hydration should be conducted using scanning electr microscopy and X-ray diffraction analysis.
d) RHA/CCW (60/40) and SHA/CCW (70/30) in 1:3 binder/sand mortar at 0.5 W/B wi water-reducing admixture can be adopted for use in masonry works.

REFERENCES

Abalaka, A.E. and Okoli, O.G. (2013). "Comparative Effects of Air and water Curing on Concrete containing Optimum Rice Husk Ash Replacement" Journal of Emerging Trends in Engineering and Applied Sciences, 4(1) pp. 60-65

American Concrete Institute (2013). "ACI Terminology of Concrete" in ACI Manual of Concrete, 2016, ACI

British Standard Institution (2016). *Methods of Testing Cement – Strength Test, BS EN 196-1. London, British Standard Institution (BSI)*

British Standard Institution (2011). *Cement- Composition, Specifications and Conformity Criteria for common Cements. BS EN 197-1*, London, BSI

British Standard Institution (2012). *Test for Geometrical Properties of Aggregates – Determination of Particle Size Distribution (Sieving Method), BS EN 933-1*. London, BSI

British Standard Institution (2003). *Test for Mechanical and Physical Properties of Aggregates – Determination of Loose Bulk Density and Voids, BS EN 1097-3. London, BSI.*

Chaowat, N. (2001). *"Properties of Portland Cement Mixed with Rice Husk Ash and Quicklime", Unpublished M.Sc. Thesis, Department of Civil Engineering Education, King Mongkuts Institute of Technology, North Bangkok.*

Chukwudebelu, J. A., Ige, C. C., Taiwo, O. E, & Tojola, O.B. (2013). "Recovery of pure slaked lime from carbide sludge: Case study of Lagos State, Nigeria". African Journal of Environmental Science and Technology, 7(6), Pp 490-495

Elinwa, A.U. & Mahmood, Y.A. (2002). "Ash from Timber Waste as cement replacement Material". Cement and Concrete Composites. 24(2), Apr. Pp 219-222

Hassan, I. O. (2006). "Strength properties of concrete obtained using volcanic ash pozzolan as partial replacement of cement". *Unpublished M.Sc. Thesis*, Department of Building, University of Jos.

Hossain, K. M. A. (2003). "Blended cement using volcanic ash and pumice". Cement and Concrete Research. 33, Pp 1601-1605

Hossain, K. M. A. (2005). "Chloride induced corrosion of reinforcement in volcanic ash and pumice based blended cement". Cement and Concrete Composites. 27, Pp 381-390.

Jimoh, R.A., Banuso, R.O. & Oyeleke, M. (2015). "Exploratory assessment of strength characteristics of millet husk ash (MHA) blended cement laterized concrete". Advances in Applied Science Research. 2013, 4(1):452-457

Joshua, O., Matawal, D.S., Akinwumi, T.D., Ogunro, A.S. & Lawal, R.B. (2016). "Development of Green and Environmentally Friendly Alternative Binder to Cement towards Sustainable Construction". Proceedings of International Construction Summit on Repositioning the Nigerian Construction Industry – Realities and Possibilities, Abuja, Nigeria, 24th – 26th May, Pp 282-294

Joshua, O., Ogunde, A.O., Omuh, I.O., Ayegba, C. & Olusola, K.O. (2015). "Exploring the Pozzolanic Potential of Blend of Palm Kernel Nut Ash (PKNA) with Cement towards a Sustainable Construction". International Conference on African Development Issues (CU-ICADI). Material Technology Track, Pp 135-140

Lam, L., Wong, Y. L., & Poon, C. S. (2000). Degree of hydration and gel/space ratio of high-volume fly ash/cement systems, *Cement and Concrete Research. 30*, 747-756.

Makaratat, N., Jaturapitakkul, C., & Laosamathikul, T. (2010). "Effects of calcium carbide residue–fly ash binder on mechanical properties of concrete". *Journal of Materials in Civil Engineering. 22*(11), 1164-1170

Mehta, P. K., & Monteiro, J. M. (2014). *Concrete microstructure properties and materials* (4th ed.), U.S.A.: McGraw-Hill Education.

Neville, A. M. (2012). *Properties of concrete* (Fifth ed.), England: Pearson Educational Limited.

Okpala, D.C (1987). "Rice husk ash (RHA) as partial replacement of cement" In: Concrete Procedure. NSE AGM.

Olawuyi, B.J. (2011). "Strength Characteristic of Volcanic Ash Blended Cement Laterized Concrete". *Unpublished M.Phil. Thesis*, Obafemi Awolowo University, Ile-Ife, 160 pp

Olawuyi, B.J. (2016). The mechanical behaviour of high-performance concrete with Super absorbent Polymers (SAP). *PhD Thesis*, University of Stellenbosch, 221 pp

Raheem, A. Y. (2006). "An Investigation of Corn Cob Ash Blended Cement for Concrete Production". *Unpublished Ph.D. Thesis*, Department of Building, Obafemi Awolowo University, Ile-Ife.

Rattanashotinunt, C., Thairit, P., Tangchirapat, W., & Jaturapitakkul, C. (2013)."Use of calcium carbide residue and bagasse ash mixtures as a new cementitious material in concrete". *Materials & Design*. *46*, 106-111

Rubenstein, M. (2012). Emission from the Cement Industry. "State of the Planet" a publication of the Earth Institute, University of Columbia accessed online on 6th February, 2017 http://blogs.ei.columbia.edu/2012/05/09/emissions-from-the-cement-industry.

Shetty, M. S. (2004). *Concrete technology - theory and practice*. New Delhi, India: S. Chand and Company Limited.

Turner, L. K., & Collins, F. G. (2013)."Carbon dioxide equivalent (CO_2-e) emissions: a comparison between geopolymer and OPC cement concrete'. *Construction and Building Materials*. *43*, 125-130

UlHaq, E., Padmanabhan, S. K., & Licciulli, A. (2014). Synthesis and characteristics of fly ash and bottom ash based geopolymers–a comparative study. *Ceramics International*. *40*(2), 2965-2971.

United States Environmental Protection Agency (2016); "Causes of Climate Change" in Climate Change Science accessed online on 6th February, 2017. https://www.epa.gov/climate-change-science/causes-climate-change

United States National Climate Assessment (2014). "Climate Change Impacts in the United States". A publication of US Global Research Program accessed online on 6th February, 2017. http://nca2014.globalchange.gov/downloads