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

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Abstract
Portland cement (PC) been the world 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 production. Previous studies on the search for alternative binders had centred on 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 temperature have been found to be pozzolanic with major components been amorphous silica which combines with lime in the presence of water to give cementitious properties. This paper report on exploratory study on agro-waste ashes (RHA and SHA – silica sources) in combination with industrial waste materials (calcium carbide waste (CCW) – a CaO source) as alternative binder for total PC replacement in mortar/concrete construction. Pastes from the different combination ratio RHA/CCW and SHA/CCW were studied for setting times, degree of hydration and strength development. The study revealed the RHA and SHA samples to be of high SiO_2 (93% and 84%) while CCW is majorly CaO (66% content). The agro-dustrial 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 give best performance having 28day compressive strength of 5.3 N/mm^2 [MPa] and 7.5 N/mm^2 [MPa] representing 25% and 35% of CEM I strength.
Keywords: Rice husk ash (RHA), sorghum husk ash (SHA), calcium carbide waste (CCW), Pozzolan, agro-dustrial binder.

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 however noted 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 of above 900 ^oC resulting in lime (CaO) and CO_2 as shown in equation 1 below.

$$CaCO_3 \xrightarrow{heat\ (>900\ oC)} CaO + CO_2 \qquad (1)$$

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 ^oC. This is then removed from the kiln, allowed to cool, ground to fine powder and mixed with about 5% gypsum content for a controlled setting (Neville, 2012; Mehta and Monteiro, 2014). The major components of PC is stated as CaO, SiO_2, Al_2O_3 and Fe_2O_3 with strength determinant being the SiO_2 in combination with CaO which forms hydrated lime – $Ca(OH)_2$ in the presence of water resulting in 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 water contact.

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 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 constant excavation and depletion of lime stone ($CaCO_3$) from their natural sources has resulted in research for alternative materials with focus on re-use and recycling of the abundant agricultural and industrial waste materials.

Previous studies on the search for alternative binders centred on utilisation of natural Pozzolan 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 PC replacement in mortar or concrete.

Attempt on total cement replacement in concrete brought about studies into geo-polymer concrete which involve alkali activation of Pozzolanic materials with the use of chemical based hydroxide [NaOH] at elevated temperatures or ambient temperature (Ul. Haq et. al, 2014; Turner and Collins, 2013). Some studies on total cement replacement with Pozzolan in combination with alternative CaO source (calcium carbide waste [CCW]) include the works of Rattanashotinunt et. al. (2013) – baggase ash combined with CCW; Makaratat et. al. (2010) - combining fly ash (FA) and CCW. Joshua et al (2016), combining pulverized calcined clay (PCC) with CCW, both sourced within Nigeria and reported observed hydration reaction with a 28 day strength of 11 MPa without any treatment on the CCW.

Incinerated ashes from agro-wastes at controlled temperature have been found to be pozzolanic with major components been 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)

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

and 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, hence 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 the present study. The CaO source in this study is an industrial waste material (calcium carbide waste (CCW)).

Calcium carbide waste (CCW) is by-product of acetylene gas generated from calcium carbide used in the production of Polyvinyl Chloride (PVC) and in welding steels 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 and rice and sorghum, both being popular which serve as major staple food in the country, Nigeria. The drive towards food security and sustainability by the Nigeria Government with rice and other cereals grains like sorghum, maize and millet being the central focus and Niger State known as a major contributor to rice and cereals production in Nigeria is an indication that the husk of the crops will ever be in abundant supply, utilization of these agricultural and industrial waste material in concrete and mortar construction should be seen as a welcome development. A research into suitability of these materials as total PC replacement promises to offer contribution towards improving knowledge in concrete technology and development of our nation, Nigeria.

RESEARCH SIGNIFICANCE

The quest for developing alternative binders cannot be over emphasized in the face of the dramatically changing economic realities, carbon blue print and the need for sustainable eco-system. The challenge therefore is not only to source alternative cementitious materials but a great deal of research is required so as to solve major and significant processing and reactivity issues with a view of establishing good performance in strength and durability of mortar/concrete made from such binders. To justify the use of these potentially more carbon dioxide-efficient technologies on a large scale and to have global impact, there is the need to develop adequate performance data that will warrant changes to construction codes and standards.

EXPERIMENTAL PROCEDURE

Materials

The materials used for this study are Rice husk and Sorghum husk (Agro-wastes) for production of RHA and SHA respectively as sources of SiO_2, CCW (an Industrial waste from automobile oxy-acetylene welding) as CaO source at varied combinations (70/30, 60/40, 50/50, 40/60 and 30/70 of RHA/CCW or SHA/CCW respectively) which formed the alternative binder; CEM I 42.5N (Dangote 3X) from Obajana factory of Dangote Cement Company served as the binder for the control mortar mix. 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), while potable water available at the Building Laboratory of the Federal University of Technology, Minna was used for mixing.

The Rice husk and Sorghum husk were both 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 used as the RHA and SHA for the experiment. The CCW on the other hand 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.

Methods

The study involved physical and chemical properties of the constituent materials for the mortar samples for proper characterisation of the materials used. Also determined were the fresh properties of the 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 as control and for the alternative binders of varied proportion combinations of RHA/CCW and

SHA/CCW respectively as stated in Section 3.1 above were prepared and tested for strength and degree of hydration at varied curing ages (3, 7, 14 and 28 days).

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 required for mortar production in strength determination test specified in the standard (BS EN 196-1:2016) was then extracted using an arrangement of sieve size 1.18 mm and 75 µm. The particles passing the 1.18 mm sieve but retained on the 75 µm 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. Figure 2 of Section 4.1 present the particle size distribution of both the natural sand and the simulated reference sand.

The physical properties determined for all the materials used for this experiment is the specific gravity test carried out in accordance to BS EN 1097: 2003 while fineness test was also conducted on the CEM I 42.5N and the varied combination of RHA/CCW and SHA/CCW via wet-sieving method as prescribed by BS EN 196-6:2005 using a 53 µm sieve available in the Laboratory.

X-Ray Fluorescence (XRF) analysis for 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.

Setting time and soundness of cement and the agro-dustrial 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 to 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. Section 4.2 thereby presents the results and discussion.

Determination of strength and degree of hydration of the binders

Determination of strength and degree of hydration of the binders was conducted using 50 mm [2 in.] mortar cubes as mentioned in Section 3.2. Production of the mortar samples 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 it is poured on the measured quantity of the simulated reference sand already spread into the steel mixing platform. The sand and binder was then mixed thoroughly before the weighed mixing water was added and mixing continued until a uniform mix was achieved before casting into the 50 mm [2 in.] cubes moulds which had mould-oil already applied. The control mortar sample on the other hand, has the CEM I 42.5N mixed as described above with the simulated reference sand and requisite quantity of mixing water before casting into the cube moulds. Based on observation from the setting times tests as reported in Section 4.2, 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 thereby adopt similar approach reported in Hasholt et al. (2010) as cited in Olawuyi (2016). The procedure is as highlighted below:

i. The mortar cubes were cast and crushed at the different curing ages (immediately after demoulding – 3, 7, 14, and 28 days) in the Digital Universal Testing Machine (DUTM – 20) to assess the strength development.
ii. The remains of the sample in (i) above was then milled properly using the 150 mm [6 in.] x 150 mm Ɵ [6 in.] cylindrical moulds available in the lab and 25 mm [1 in.] diameter bar as mortar and pestle. The milled sample was then vacuum-dried for 1 hour stop further hydration.
iii. A known weight of the vacuum-dried sample, about 20 g from the particle passing 75 µm standard sieve [Sieve #200] was measured and oven dried for 24 hours at 105 ^{o}C [221 ^{o}F] and weighed again (to determine the evaporable water i.e. the capillary water + gel water)
iv. This sample was then placed in the furnace [Model No SNOL 8,2 /1100 – 1LZ] set to 900 ^{o}C [1652 ^{o}F]. At one hour time after the furnace temperature reads 900 ^{o}C [1652 ^{o}F], the furnace was switched off, allowed to cool and the sample weighed (to determination of 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 calculated by

LOI (%) = 100 x (as received weight – ignited weight)/as received weight (1)

w_n (i.e. non-evaporable water) content of the hydrated mortar pastes were 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 ^{o}C [1652 ^{o}F] and 105 ^{o}C [221 ^{o}F], to calculate the degree of hydration (α) 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

$$w_n\% = \frac{100\,x\,(dried\ \ weight\ of\ paste - ignited\ weight\ of\ paste)}{(Ignited\ weigth\ of\ paste - loss\ on\ ignition\ of\ cement)} \qquad (4)$$

The degree of hydration (α) is then:

$$\alpha = 100\,x\,\frac{Wn}{0.23} \qquad (5)$$

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

RESULTS AND DISCUSSION

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).

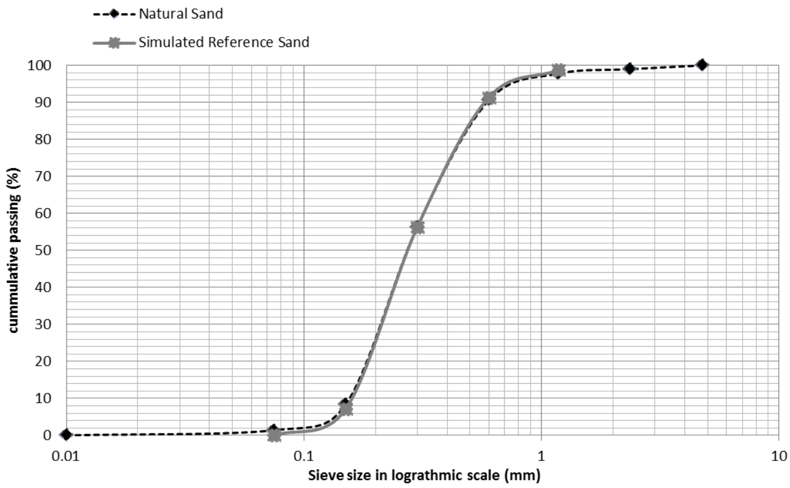

Figure 1: Particle Size Distribution of Fine Aggregate

Table 1 however present 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.

Table 1: 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	√

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-dustrial waste binder was compared.

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

Table 2: 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 majorly 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 note to be of lower SiO_2 and Al_2O_3 when compared to the PC sample. The LOI of CCW was noted to be above the specified 10% maximum, an indication that some heat treatment might be required for more effective performance of the material.

Table 3: Result of 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	95.5
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	88.6
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	6.5
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	27.8

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-dustrial binders was about three multiple 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.

Table 4: Fresh Properties of Binders

Specimen	Consistency				Soundness Expansion (mm)[0.04 in]	
	RHA/CCW		SHA/CCW			
	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

The soundness test presented in Table 4 revealed that all the binder combinations conform to the 10 mm 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.

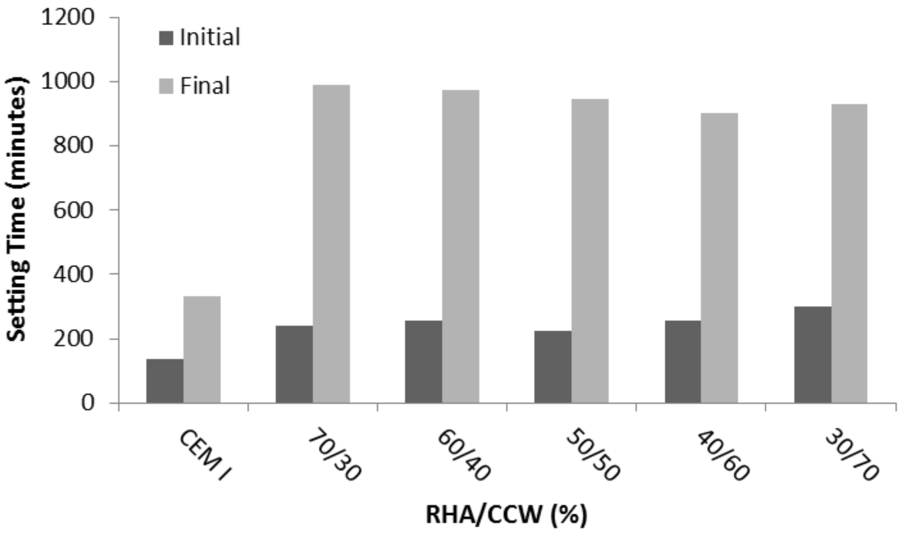

Figure 2: Setting times (initial and final) of the RHA/CCW Binder

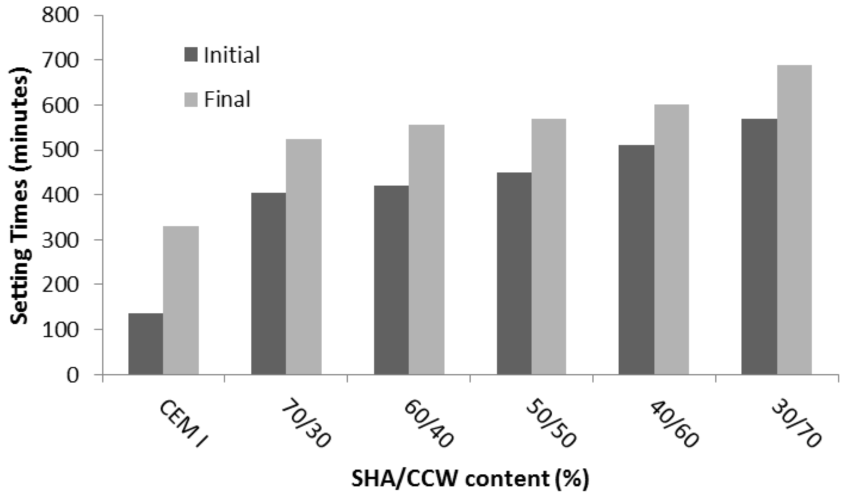

Figure 3: Setting times (initial and final) of the SHA/CCW Binder

The results revealed that the initial setting times of RHA/CCW binder combinations are one and a half to twice multiple 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 multiple of the final setting time for CEM I. This affirms literature postulation that Pozzolan 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.

Degree of Hydration and Strength of Agro-dustrial Waste Binders

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

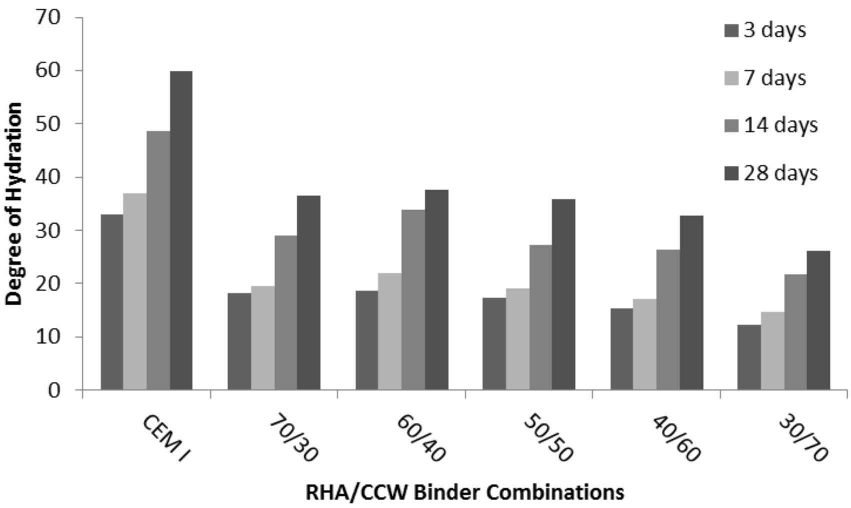

Figure 4: Degree of Hydration of Hardened RHA/CCW Mortar

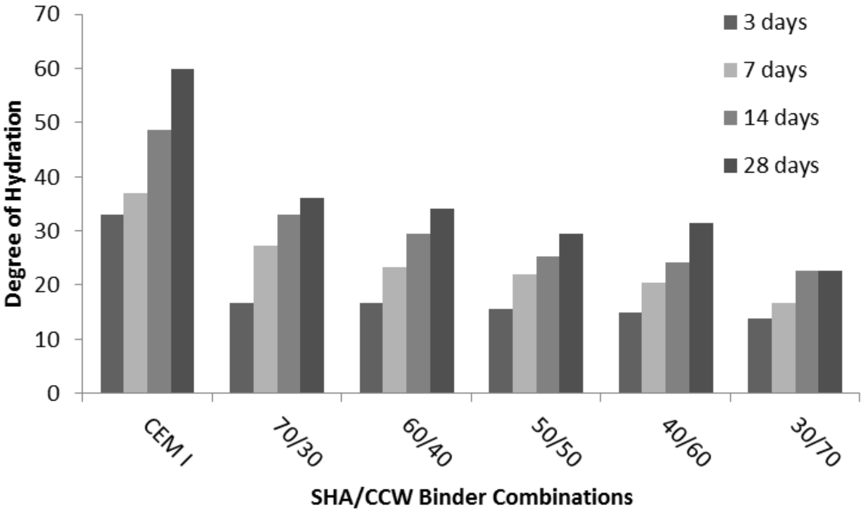

Figure 5: Degree of Hydration of Hardened SHA/CCW Mortar

The result revealed 60/40 RHA/CCW and 70/30 SHA/CCW combinations as the best of the agro-based binders with 36% and 38% levels of degree of hydration respectively by the 28 day curing age. This amount to RH_{28} values of 0.6 and 0.63 respectively with reference to the 28 days value of CEM I. Hydration was observed to improve as the curing age increased and the binders are expected to show good long term age strength development.

Table 5: Degree of Hydration and RH_{28} Factor of the Agro-dustrial 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) was observed to follow 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 5.3 N/mm2 [MPa] – 25% of CEM I strength and 7.5 N/mm_2 [MPa] – 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-dustrial 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 in this experiment. The agro-dustrial binder when improved upon possibly in further studies through the use of water reducers, keeping the water/binder ratio to be same as for control or engaging set accelerating mixtures/procedures.

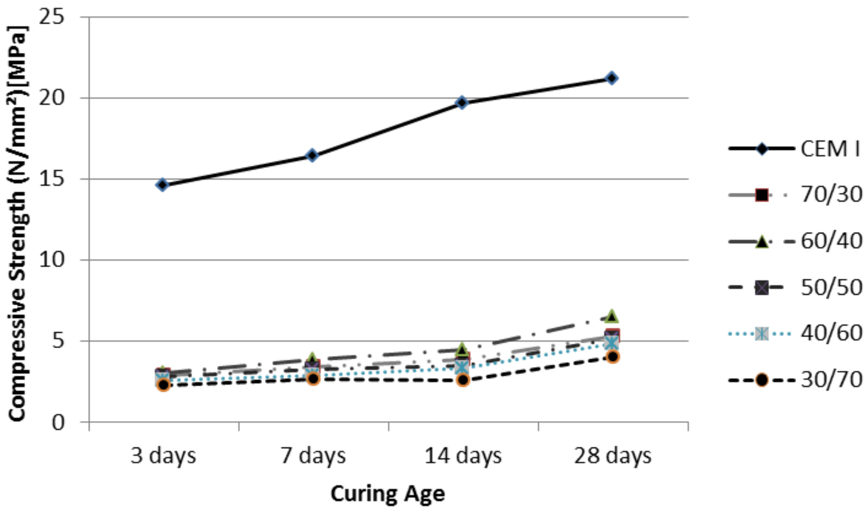

Figure 6: Compressive Strength of RHA/CCW Binder Mortar

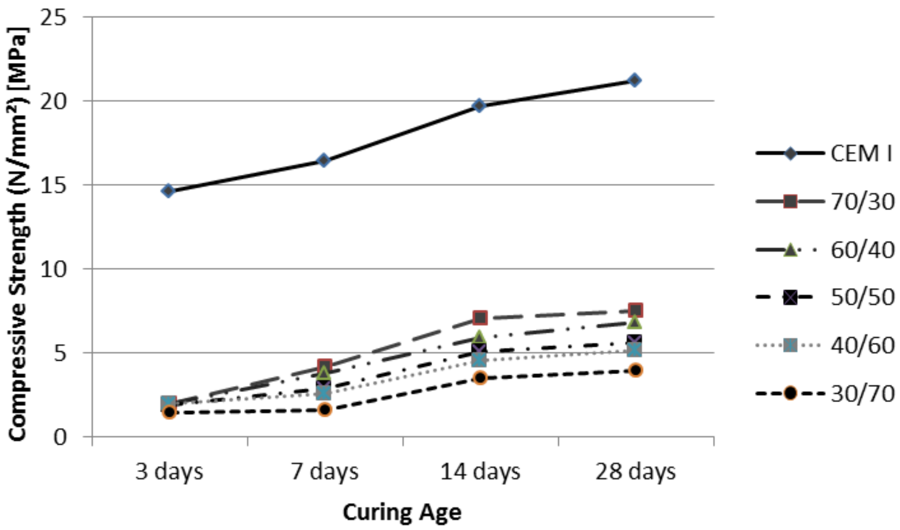

Figure 7: Compressive Strength of SHA/CCW Mortar

CONCLUSION AND RECOMMENDATIONS

The result from the study show the alternative binders from the agricultural (RHA and SHA) in combination with CCW another waste material from industrial activity possess binding properties. The chemical analysis shows RHA and SHA as Class N Pozzolan of high SiO_2 content (94% and 83% respectively) while CCW is a good CaO source of similar percentage concentration (65%) as the CEM I used for the study. Further studies targeted at set-acceleration and improved early strength development of the binder combinations holds a promise towards the desired breakthrough in production of suitable alternative binder from these agricultural and industrial waste materials. The following are thereby recommended based on the findings of this study.

i. Further studies on the RHA/CCW and SHA/CCW should focus on set-acceleration and early strength development through the use of water reducing admixtures and set accelerators as admixtures.
ii. Investigation into influence of temperatures slightly above the ambient temperature (i.e. 40 – 90 ^oC) on the initial and final setting of the agro-dustrial binders should be carried out.
iii. Future studies on product of hydration should be conducted using scanning electron microscopy and X-ray diffraction analysis.
iv. RHA/CCW (70/30) and SHA/CCW (60/40) in 1:3 binder/sand mortar at 0.5 W/B with water-reducing admixture can be adopted for use in masonry works.

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