A Review of Some Agricultural Wastes in Nigeria for Sustainability in the Production of Structural Concrete

C. Fapohunda*, A. Kilani, B. Adigo, L. Ajayi, B. Famodimu, O. Oladipupo, A. Jeje

Department of Civil Engineering, Federal University Oye-Ekiti, Nigeria.

ABSTRACT: A review of agricultural wastes available in Nigeria that is suitable for use in concrete industry, in order to attain sustainability in structural concrete production and practice, is presented in this paper. The wastes reviewed are: Cassava Peel Ash (CPA), Empty Palm Oil Fruit Brunch Ash (EPO-FBA), Rice Husk Ash (RHA), and Saw Dust Ash (SDA). Others were Palm Kernel Shell Ash (PKSA), Groundnut Husk Ash (GHA), Corncob Ash (CA), and Egg Shell Powder (ESP). The study revealed that some agricultural wastes that have potential for use as supplementary cementing material (SCM) for cement in the production of structural concrete abounds in Nigeria. It was also revealed that the necessity of standardization of procedures for testing of such wastes so that structural performance index can be compared. In addition, there is also the need for the development of classification methods similar to that of fly ash, so that their use can be enhanced. Using these waste materials in concrete will lead to sustainability in concrete production, reduction in the use of natural non-renewable resources, innovativeness in the use of wastes, and the development of small-scale industries.

KEYWORDS: Agricultural waste, Compressive strength, Pozzolans, Structure, Sustainability.

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I. INTRODUCTION

Structural Engineering, a creative process of finding a safe, durable and economic solution to infrastructural problems, has in recent times, widens its scope to include environmental issues (Fapohunda, 2019 and Brito and Kurda, 2021). This is because its practice, which involves usage of non-renewable natural resources on a very huge scale, has a very large environmental footprint (Bauma, 2019). Concrete, the most widely used structural material is produced using cement, sand, gravel and water. The production of cement not only requires massive use of limestone, a non-renewable natural resource, but also results in the release of CO_2 and other greenhouse gases (GHGs) into the atmosphere (Naik and Moriconi, 2008). According to Mehta (2002) and Sudendro (2014), the contribution of cement industry to global emission of greenhouse gases is between 8 to 10%. It is also the third most energy-intensive industry (Shafigh *et al.,* 2014). The gravel components of the concrete are obtained from quarry operations involving the blasting of rock deposits, while sand deposits and river beds serve as the source of sand.

These natural resources are non-renewable, and so, the use of these materials for the production of structural concrete raises serious sustainability issues in the sense of meeting the present needs in the way that undermines the ability of future generations to meet their own needs. Structural engineers around the world are confronting these problems through innovative use of industrial and agricultural wastes materials, making them fit for use, mostly as partial replacement of one of the concrete components (Ochsendorf, 2005, Sunhenro, 2014, and Fapohunda, 2019). It is the view of Mehta (2002 & 2009) that major reduction in the CO_2 emission associated with cement production can be achieved by lowering the clinker content of the final product through maximization of the proportion of mineral admixtures in cement, and increase in the use of blended cements in general construction. It has further been shown that if just 30% of cement used globally was replaced with Supplementary Cementing Materials (SCMs), the rise in CO_2 emissions from cement production could be reversed (Ecosmart, 2008).

Although, Nigeria may not boast of many industrial wastes like silica fume, ground granulated blast furnace slag, fly ash, etc., agricultural wastes abound from which materials for structural concrete can be obtained. These agricultural wastes are presently improperly disposed of, resulting in environmental pollution and nuisance. A polluted environment is hazardous to human's health. Researchers from all the nations of the world have investigated many of these wastes for structural potentials with promising results. Thus, the aim of this research is to review research works on some of the agricultural wastes available in Nigeria in relation to their fitness for use as Supplementing Cementing Materials (SCM) for cement in the production of structural concrete. The reviewed agricultural wastes in the present work are: Cassava Peel Ash (CPA), Empty Palm Oil Fruit Brunch Ash (EPO-FBA), Rice Husk Ash (RHA) and Saw Dust Ash (SDA). Others mentioned are: Corncob Ash (CA), Egg Shell Powder (ESP), Groundnut Husk Ash (GHA), and Palm Kernel Shell Ash (PKSA)

*Corresponding author: christopher.fapohunda@fuoye.edu.ng

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II. AGRICULTURAL WASTES FOR THE PRODUCTION OF STRUCTURAL CONCRETE

A. Cassava Peel Ash (CPA)

Cassava Peel Ash (CPA) is obtained by calcination of cassava peel, which is a by-product of cassava processing, either for domestic consumption or industrial uses. For the ash to be pozzolanic, Ikponmwosa and Olonade (2017) suggested the calcination of the cassava peel at 700^0C for 90 minutes, so that the combined silica, alumina and ferric oxide in the ash are more than 70 per cent. Adesanya et al. (2008) reported that cassava peel constitutes between 20-35% of the weight of tuber, especially in the case of hand peeling. He further reported that about 6.8 million tons of cassava peel is generated annually, which a projection to reach 12 million tons by the year 2020. Although some of these wastes are being used as livestock feeds, for briquettes, etc., the majority of the waste are not used, and are disposed of indiscriminately. Indiscriminate disposal of cassava peels due to gross underutilization as well as lack of appropriate technology to recycle them is a major challenge, which results in environmental problem.

1) Physical and chemical properties

The specific gravity of CPA, according to Amartey *et al.* (2017) is 2.32 as against 3.04 for ordinary Portland cement (OPC) that it is meant to replace. What this means is that more CPA is needed for a unit weight replacement of cement with CPA. The chemical properties of CPA are shown in Table 1.

Table 1: Chemical properties of CPA.

Material	**Oxide (%)**								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	LOI
Cement	20.80	3.10	2.50	64.50	1.70	0.23	0.85	2.50	3.40
CPA	36.79	7.57	2.23	8.20	2.90	1.37	18.74	1.52	15.10

Source: (Ikponmwosa and Olonade, 2017).

It can be observed that the dominant oxide in CPA is the silicates (SiO_2) which is the major contributor to the binding properties of cement during hydration processes in the presence of water. According to Neville (2011), the silicates are the main cementitious compounds and the behavior of cement during hydration is similar to the behavior of the silicates.

2) Fresh state properties

The results of investigation conducted by Salau *et al.* (2012) showed that the water required to achieve standard consistency in cement-CPA paste increased with CPA content. Further, Salau *et al.* (2012) also found out that the slump values decreased with increase in amount of CPA for thesame water-binder ratio. This indicates that more water is required to maintain the same consistency as the CPA content increases.

3) Hardened state properties

Salau *et al.* (2012) concluded that using CPA as replacement of cement up to 25% by weight will result in densities range between 2414 and 2473 kg/m^3 indicating that they can be categorized as normal concrete with density of 2400 kg/m^3 (Table 2). They also showed that up to 15% replacement levels, the compressive strength of concrete specimens with CPA is comparable to specimens without CPA (Table 2). The strength activation index (SAI) specimens at replacement levels up to 15% developed compressive strength (CS) that is more than that of 75% of the control as per ASTM C 618-08 (2005).

Table 2: Density, compressive strength and strength activation index of specimens with CPA.

% CPA	**Density (kg/m^3)**					**Curing Ages (Days)**									
	Curing ages (Days)					**7**		**28**		**56**		**90**		**120**	
	7	**28**	**56**	**90**	**120**	**CS**	**SAI**	**CS**	**SAI**	**CS**	**SAI**	**CS**	**SAI**	**CS**	**SAI**
0	2414	2414	2427	2483	2469	16.6	100	18.7	100	20.3	100	21.9	100	22.3	100
5	2456	2405	2423	2421	2468	11.9	72	15.6	83	18.6	91	21.0	96	22.2	99
10	2427	2452	2473	2417	2427	11.4	68	15.3	82	17.9	88	19.8	90	21.2	95
15	2420	2456	2441	2441	2436	10.6	84	14.7	79	17.2	85	18.7	85	19.4	87
20	2425	2437	2431	2439	2431	9.6	58	12.8	68	14.3	70	16.3	74	16.6	74
25	2438	2428	2421	2466	2425	9.2	56	12.5	67	13.9	69	15.6	71	16.2	72

Source: (Salau *et al.* (2012)

Improvement in the compressive strength development was observed at later ages. This is characteristic of pozzolans. Further, they observed that the tensile strength followed the compressive strength pattern.

4) Durability properties

According to Ikponmwosa and Olonade (2017), Cassava peel ash reduces shrinkage of concrete, provided that the CPA content is kept below 15%. However, the works of Olonade *et al.* (2014), showed that concrete with CPA will not perform well in sulphuric acid environment because of decrease in the compressive strength witnessed in their investigation.

B. Empty Palm Oil Fruit Bunch Ash (EPO-FBA)

The palm oil industry generates many wastes: the empty palm oil fruit bunch is one of them. This is the residue remaining, after the mesocarp and kernel of the palm fruit oil are removed (Figure 1).

a) A Single empty fruit bunch.

b) Drying of heap of empty fruit bunch.

Figure 1: Empty Palm Oil Fruit Bunch (Fapohunda and Oluwasegunota, 2019).

Its presence presently constitutes environmental nuisance, as no effective disposal method has been found (Fapohunda and Oluwasegunota, 2019). Thus, making it fit for usage in concrete production, will help in the protection of the environment by conserving the natural resources for cement, and also enable the civil/structural engineer affirm its commitment to sustainable practices in structural concrete. The Empty Palm Oil Fruit Brunch Ash (EPO-FBA), is the residue of burning empty palm oil fruit bunches through incineration process to 700^0C within 90 minutes or open burning system (Coelho *et al.*, 2019).

1) Physical and Chemical Properties of EPO-FBA

In the result of fineness test carried on samples of EPO-FBA and Ordinary Portland Cement (OPC) by Fapohunda and Oluwasegunota (2019), percentage residue remained on the 90 μm sieve was found to be 9% for ordinary Portland cement (OPC) while that of EPO – FBA is 31%. This indicated that EPO-FBA used is more coarse when compared with the OPC. The characterization as determined by Fapohunda and Oluwasegunota (2019) is presented in Table 3.

Table 3: Oxides Composition of Empty Palm Oil Fruit Bunch Ash (EPO-FBA).

Oxides	EPO-FBA	OPC
CaO (%)	19.01	64.37
SiO_2 (%)	6.42	20.68
Fe_2O_3 (%)	6.64	3.62
MgO (%)	4.10	1.81
Al_2O_3 (%)	12.70	5.41
SO_3 (%)	1.42	1.03
Na_2O (%)	7.25	0.51
K_2O (%)	1.86	0.47
LOI (%)	40.60	0.39

Source: (Fapohunda and Oluwasegunota, 2019)

From Table 3, it can be seen that the combined total of $SiO_2+Al_2O_3+Fe_2O_3$, which is, 32.07%, is not up to the value of above 50% that could permit classification into the categories of fly ash as per ASTM C 618 (2005). Also, the loss of ignition (LOI) present in the EPO-FBA is far greater than the LOI present in the cement. Neville (2011) was of the opinion that higher loss on ignition is advantageous since hydrated lime, which it reflected, is innocuous However, the chemical composition is similar to bauxite waste (found in Ghana) and natural cement (found in UK) recorded as pozzolans by Day (1990), as well as limestone powder (LSP) in the work of Le *et al*. (2014). This is because, hydrated free lime is innocuous, and for a given free lime content of cement, a greater loss on ignition is really advantageous (Neville (2011).

2) Fresh state properties

Findings by Fapohunda and Oluwasegunota (2019) showed that water content that will produce the desired consistency (expressed as a percentage by weight of the dry cement, usually between 26 and 33%) of paste containing EPO-FBA increased with increase in the EPO-FBA content. These results indicated that more water will be required to obtain a consistent mix, when used in concrete. Unless high water cement-ratio is used, mix containing EPO-FBA may lead to harsh mix and hydration process may stop prematurely leading to reduced strength. The initial and final setting times of paste with and without EPO-FBA were also found to be within the limits set of 60 minutes prescribed by BS EN 197-1 (2000) for cement with strength 42.5MPa. In addition, the slump values of concrete with EPO-FBA decrease to as low as 20 mm with increase in percent replacement of cement with EPO-FBA (Fapohunda and Shittu, 2017). The numerical slump value of 20 mm translates to concrete with low workability (Neville, 2011). Gambhir (2013) suggested that concrete with low workability, in the manner displayed by concrete specimens with EPO-FBA, can be employed in lightly reinforced structural concrete sections of slabs, beams, walls, column, strip footings with substructure walls, hand placed pavement and for mass concrete.

3) Hardened state properties

Fapohunda and Oluwasegunota (2019) showed that the developed densities of the concrete specimens with EPO-FBA are between 2406 and 2510 kg/m^3.This suggests concrete containing EPO-FBA can be used for normal structural concrete applications. Using the performance criterium through Strength Activation Index (SAI), specimens with EPO-FBA up to 10% developed compressive strengths comparable to the control (ASTM C 618-08, 2005) at the 28-day curing (Table 4).

Table 4: Potential of EPO-FBA as pozzolanic potentials of the samples.

Mix Designation	Compressive Strength, CS (N/mm^2) and Strength Activation Index, SAI									
	Curing Age (days)									
	7		14		28		60		90	
	CS	SAI (%)	CS	SAI (%)	CS	SAI (%)	CS	SAI (%)	CS	SAI
M_0	24.84	100.00	25.34	100.00	29.78	100.00	33.61	100.00	35.28	100.00
M_5	24.96	100.48	24.82	97.95	26.42	88.72	34.12	101.52	34.11	96.68
M_{10}	19.82	79.79	22.71	89.62	24.38	81.87	30.75	91.49	32.90	93.25
M_{15}	15.82	63.69	18.85	74.39	22.24	74.68	27.51	81.85	30.84	87.42

Source: (Fapohunda and Oluwasegunota, 2019)

At higher curing ages of 60 and 90 days, all the specimens developed strength greater that 75% of the control. It can however be concluded that, on the basis of the SAI, the optimum use of EPO-FBA is at 10% replacement level.

4) Durability properties

The results of the investigation by Babatola (2018) to assess the durability properties showed a water absorption capacity of less than 10%. This is an indication that concrete with EPO-FBA will be durable. According to Nevile (2011), a good concrete should have a water absorption capacity of less than 10%.

C. Rice Husk Ash (RHA)

Rice Husk Ash is obtained from calcination of Rice Husk, which is the by-product of rice milling operations, in rice-producing countries of the world. Approximately 1000 million tons of rice is annually produced in the world, which usually leaves about 400 million tons of rice husks as a waste material (IRRI, 2005). According to FINELIB (2019), Nigeria is the largest producer of rice in West Africa. FINELIB (2019) stated that rice is cultivated in states like Benue, Borno, Cross River, Enugu, Kaduna, Kano, Taraba, Niger, Kwara and Kebbi. Rice husk ash (RHA) can be produced either through open field burning (usually below 450^{0}C) or under incineration conditions in which temperature (in excess of 700^{0}C) and duration are controlled. However, open field calcination is not encouraged because of pollution problems and it also produces poor quality rice husk ash. It has been found out that the RHA produced from open burning has relatively high carbon content (above 4%) which adversely affect concrete performance and also results in a structure of highly crystalline form that is of low reactivity (Hwang and Chandra, 2016). The RHA in the amorphous form of silica, which has the potential to be used for structural concrete, is produced through controlled incineration conditions (temperature and duration).

1) Physical properties of RHA

Some physical properties of Rice Husk Ash that are of structural relevance are the specific gravity, mean particle size, and its Blaine fineness. Investigations conducted by Chatveera and Lertwattanaruk (2009); Marthong (2012), and Karim *et al.* (2013) showed that the specific gravity of RHA varies between 2.05 – 2.53. These values are relatively lower than the specific gravity of the ordinary Portland cement which is between 3.10 and 3.14 (Ganesan *et al*., 2008; Tangchirapat *et al.*, 2009) that it is meant to partially replace. What this means is that, for a unit weight replaced by cement, higher volume of RHA will be required. The consequence of this is that, the concrete produced will have a relatively lower density than the concrete without RHA. Lower density will result as the percent replacement increases (Obilade, 2014). In order for RHA to be used as a binder, majority of research studies conducted concluded that the material has to be ground into a very high specific surface area of up to 100 m^2/g before use (Ganesan *et al*., 2008 and Nguyen *et al*., 2011). The investigation conducted by Antiohos *et al.* (2014) revealed that highest pozzolanic activities were achieved when the more reactive RHA was ground to7000 cm^2/g. Also, for RHA to be pozzolanic, its particle size should be between 5.6 – 8 mm (Nguyen *et al*, 2011). The works of Bouzoubaa and Fournier (2001) revealed that median particle size of about 8mm is required to achieve pozzolanic activity index of 100 percent.

2) Oxides composition and pozzolanic properties

The oxides composition of Rice Husk Ash (RHA) as obtained by various researchers (Joel 2010; Oyekan and Kamiyo 2011, Le *et al*., 2014 and Swaminathen and Ravi (2016)) showed a very high silica content – above 70%. This is an indication of how reactive RHA is, since silica is the compound that has been found to be responsible for the strength in concrete (Nair *et al.*, 2008). This is particularly good, for the high silica in RHA enables it to contribute to the strength development process if used in concrete production. Also, the sum of SiO_2+Al_2O_3 + Fe_2O_3 exceeds 70% for all the RHA specimens used by these researchers. This demonstrated that the RHA are in the same category with the Class F fly ash (ASTM C618-05, 2005) with high pozzolanic characteristics.

3) Fresh state properties

The fresh properties that are of significant in concrete production are, consistence, workability, and setting times. Consistence of concrete is the degree of wetness or otherwise which indicates whether a concrete is workable or not through the whole process of transportation, placement, finishing without segregation. Results of investigations conducted by Calica (2008), Kartini *et al*. (2010) and Marthong (2012) showed that paste containing RHA requires more water to achieve the standard consistence when compared to the samples without RHA. Water demand, according to Rashid (2016) increased with increase in cement replacement with RHA, and that it could be as high as 100%. Also, the results of investigation conducted by Kartini *et al.,* 2010 and Khassaf *et al.,* 2014 on the effect of RHA on the workability of concrete showed a progressive reduction in workability as the percent replacement of cement with RHA increases unless water-reducing admixtures are used. There seems no agreement yet among researchers concerning the effect of RHA on the setting times of paste. The results of the investigation conducted by Oyetola and Abdullahi (2004), Dabai *et al.* (2009), Marthong (2012) showed both initial and final setting times increasing with increase in RHA irrespective of the grade of the ordinary Portland cement used. The work of Rashid *et al.* (2010) and Chanu and Devi (2013) however revealed different results. They found out that initial setting times increased up to 15% cement replacement and RHA. The obvious disagreement between these results was probably due to the fact that Rashid *et al.* (2010) used open burning method to obtain the RHA used, in which the burning temperature was less than 450^{0}C within the time frame of 72 hours. This temperature will only produce crystalline RHA as has been previously discussed. It is possible that the setting times characteristics of crystalline RHA are different from that of amorphous RHA, and that this difference is yet to be well-understood.

4) Hardened state properties

The hardened state properties of concrete with RHA that researchers have come up with are: density, compressive strength, tensile strength, and modulus of elasticity. Results of investigations conducted by Adenuga *et al.* (2010) showed that the density of concrete specimens containing RHA decreased with increase in the content of RHA at all water-binder ratio. They also found out that the densities fell in the normal weight category of between 2200–2550 kg/m^3 as per ACI Committee 213 (2003) and Falade *et al.* (2011). This information is necessary to ensure effective application of RHA in concrete.

The results of some of these researchers showed that factors such as water-cement ratio and curing duration affect the compressive strength of concrete incorporating RHA. Chindaprasirta *et al.* (2009), and Babaiefar (2007) suggested that at the water cement ratios of 0.30, 0.32, and 0.34 compressive strength increased (relative to the control) with RHA up to 20% at the curing ranges between 7, 28 and 90 days. The works of Shatat (2014) and Mahmud *et al.,* 2016) showed that concrete incorporating RHA developed later compressive strength that is higher than specimens without RHA (Figure 2). Investigations conducted by Le *et al.* (2014) and Foong *et al.* (2015) showed that the 28-day splitting tensile strength increased with increase in RHA contentup to 15% by as much as 17.65% and 28% respectively but decreased afterward to

about 5.88% ofthe control specimens at 20% replacement level of cement with RHA. However, the splitting tensile strength is about 10% of the compressive strength. Investigations conducted by Le *et al.* (2014) and Foong *et al*. (2015) showed that the 28-day splitting tensile strength increased with increase in RHA content up to 15% by as much as 17.65% and 28% respectively.

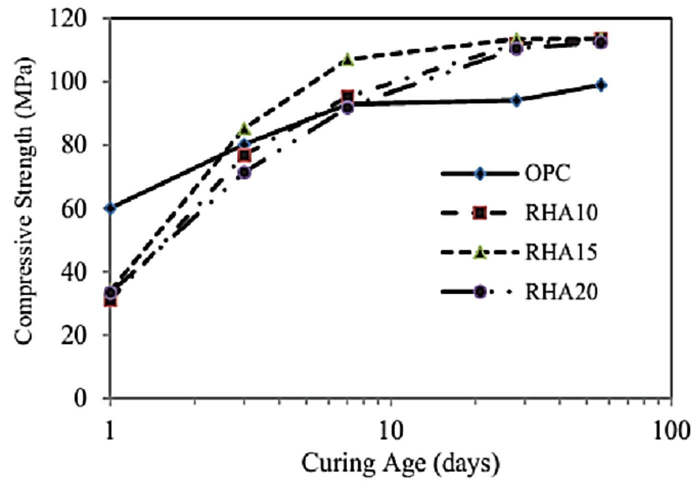

Figure 2: Effect of RHA on the compressive strength of concrete (Mahmud *et al.*, 2016).

In addition, Foong *et al*. (2015, found out that it decreased afterward to about 5.88% of the control specimens at 20% replacement level of cement with RHA. However, the splitting tensile strength is about 10% of the compressive strength. There is also evidence that inclusion of RHA affect the modulus of rupture of concrete. Talsania *et al.* (2015) recorded an increase of up to 20% in the modulus of rupture when RHA was used in concrete. In a similar investigation, Foong *et al.* (2015) showed that the presence of RHA in concrete increased the Young's modulus by as much 25%. In order to predict the Young Modulus of elasticity of concrete with RHA, Foong *et al*. (2015) further suggested Eq. (1).

$$E = 5(\frac{\rho}{2400})^2 f_{cu}{}^{0.333} \qquad (1)$$

where E = Young modulus of elasticity (GPa), ρ = density of concrete (kg/m^3) and f_{cu} = compressive (cube) strength (MPa).

5) Durability properties

Importance of durability issues in structural design cannot be overemphasized, especially in limit state design, where the structure must not reach a state where it becomes unserviceable. The results of various researchers showed that RHA-concrete microstructure is impervious to agent of degradation like, sulphate attacks (Sakr, 2006), chloride ingress (Chopra *et al.*, 2015); as well as good shrinkage properties (Khassaf *et al.*, 2014). Its use in concrete also inhibit alkali-silicate reaction (Hasparyk *et al.,* 2000) as well as lower water absorption and sorptivity (Da Silva *et al.,* 2008).

D. Sawdust Ash (SDA)

Sawdust Ash (SDA) is produced when saw dust, which is a waste material from the sawmill industry, is thermally decomposed. According to Raheem *et al.* (2012) and Adamu *et al.* (2017), timber sawmills are located virtually in all major towns in Nigeria where sawdust is generated as waste daily.

1) Physical and chemical properties

The reported specific properties of SDA from structural perspectives include specific gravity, ranging from 2.05 to 2.60 and density ranging from 720 – 830 kg/m^3 (Udoeyo *et al.*, 2006 and Ettu *et al.*, 2013). When these values are compared with the ordinary Portland cement values - 3.12 specific gravity and 1550 kg/m^3 density – it is obvious that, for a unit weight of cement replaced with SDA, a larger volume will result and consequently lighter concrete (from weight-volume relations). Microstructural studies conducted by Naik and Kraus (2003) revealed that SEM micrographs showed wood ash as a heterogeneous mixture of particles of varying sizes that are generally angular in shapes (Figure 3).

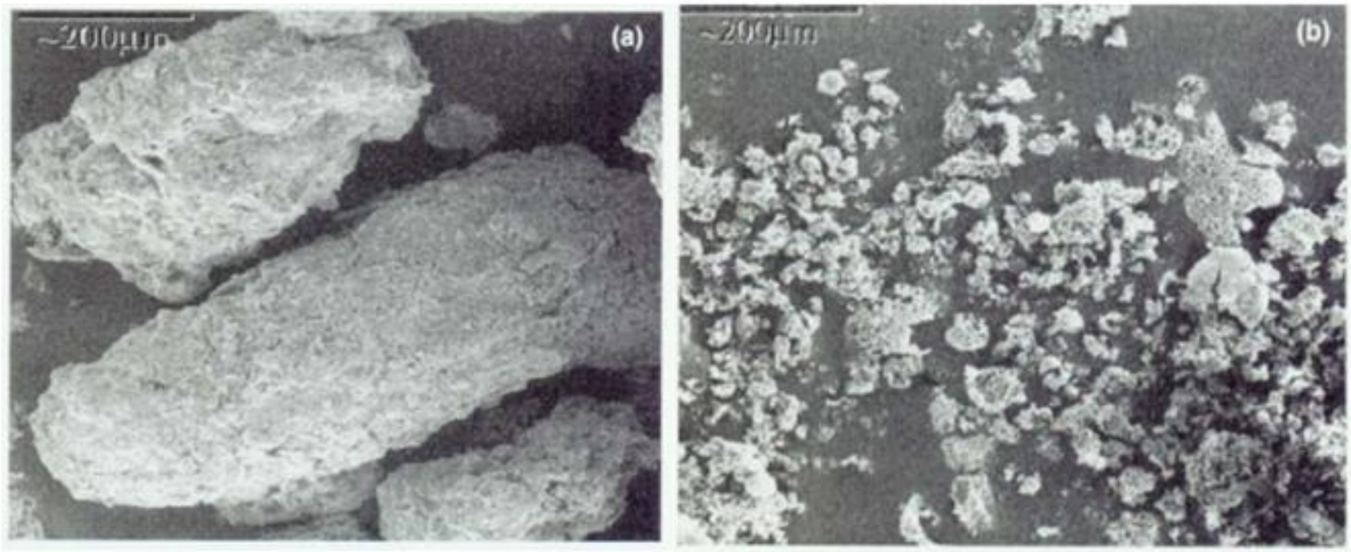

Figure 3: SEM micrographs of the structure of SDA.

Some of the wood ash particles were found to be porous (that is, in cellular form) agglomerated particles. These cellular particles are mostly unburnt or partially burnt wood chips, knots or bark particles. Further investigations by Naik and Kraus (2003), using X-ray diffraction (XRD) for the mineralogical analysis of wood ash, revealed that both amorphous (non-crystalline) and non-amorphous (crystalline) phases were present in the wood ash examined. The composition of oxides in sawdust ash, from the findings of Raheem *et al.* (2012) is presented Table 5.

Table 5: Oxides composition of SDA.

Oxide	Percentage composition (%)			
	Sample 1	**Sample 2**	**Sample 3**	**Sample 4**
SiO_2	65.42	66.05	65.79	65.75
Al_2O_3	5.69	5.12	4.88	5.23
Fe_2O_3	2.16	2.09	2.01	2.09
CaO	9.82	9.65	9.39	9.62
MgO	4.23	4.11	3.03	4.09
SO_3	1.09	1.20	0.98	1.09
K_2O	2.38	2.22	2.68	2.43
Na_2O	0.04	0.08	0.07	0.06
LOI	4.89	4.05	3.95	4.30
LSF	1.09	1.98	2.07	1.71
SR	10.53	11.03	10.45	10.67
AR	11.35	12.88	12.73	12.32
$SiO_2 + Al_2O_3 + Fe_2O_3$	73.27	73.26	72.78	73.07

LOI = Loss on Ignition, LSF = Lime saturated factor, SR = Silica ratio, AR = Aluminum ratio

Source: (Raheem *et al.*, 2012)

It can be seen that the sum of SiO_2+Al_2O_3 + Fe_2O_3 exceeds 70%. This is an indication that sawdust ash is in the group with Class F fly ash (ASTM C618-05, 2005), whose characteristics is high pozzolanicity.

2) Fresh state properties

Findings from various investigations by Elinwa and Ejeh (2004) and Abdullahi (2006) established that the inclusion of SDA as a partial cement replacement material in blended cement. resulted in a higher water requirement in order to achieve a standard level of cement paste consistency. The higher water demand of OPC-SDA paste relative to OPC is mainly due to a higher specific surface area of porous wood waste ash particles in comparison to OPC particles. The setting characteristics of paste containing SDA is shown in Figure 4.

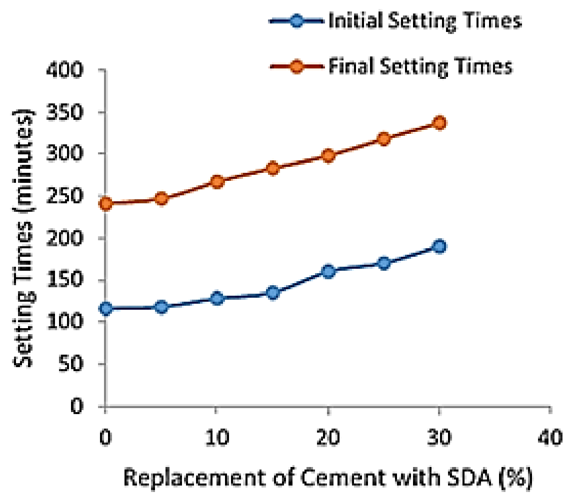

Figure 4: Initial and final setting times of paste with SDA (Elinwa & Ejeh, 2004.).

It is observed in Figure 4 that both the initial and final setting times increased with increase in percent replacement of cement with SDA. This means that SDA acts as retarder. Also, the research conducted by Udoeyo *et al.* (2006) showed that concrete with SDA becomes less workable, turning into harsh mixes with increased content of SDA, and thus require higher water content to maintain its workability (Figure 5) (Elinwa and Mahmood (2002) and Udoeyo *et al.* (2006). Thus, using SDA will require appropriate dosage of super plasticizer in order maintain required workability.

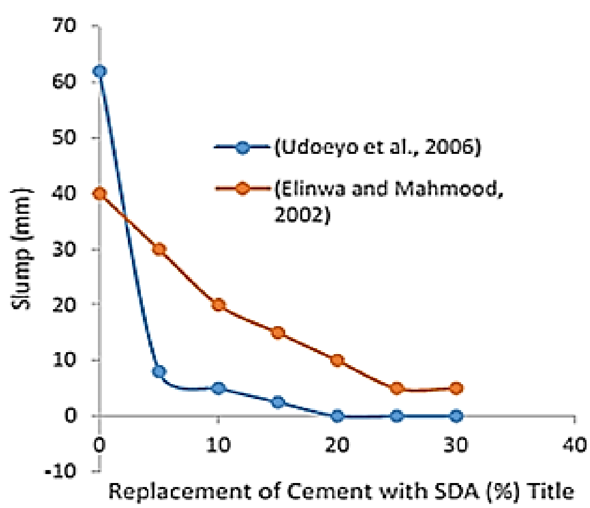

Figure 5: The slump characteristics of concrete with SDA.

3) Hardened state properties

The developed densities of specimens with SDA, from investigations conducted by researchers (Cheah and Ramli, 2012 and Ettu *et al.*, 2013) were found to be in the range of range of 2220 and 2316 kg/m^3.for replacement values up to 40%. These findings showed that SDA will develop densities that can be used for conventional normal weight applications. The compressive strength, on the other hand decreased in relation to the control with increase in the percent replacement of cement with SDA (Udoeyo *et al.*, 2006 and Raheem *et al.*, 2012). However, the numerical values of compressive strength obtained from cube tests by researchers, as presented by Fapohunda *et al.* (2018) in Table 6, suggested that SDA can be incorporated into the concrete mixes to develop the required strength specified by various international standards. However, at the curing ages of 90 days, the results of Ghorpade (2012) showed improved compressive strength over the control samples at replacement levels up to 30%.

Table 6: The numerical values of compressive strength of concrete specimens with SDA.

Authors	Mix	W/c ratio	Max 28-day f_c (N/mm^2)	Dosage (%)	Group (Table 1)
Chowdhury *et al.* (2015)	NA	0.40 0.50	31.70 – 35.30 29.00 – 33.30	5 – 20 5 – 20	CaO
Marthong (2013)	NA	NA	32.50	Up to 10	SiO_2
Ogork and Ayuba (2014)	1: 2: 4	0.55	20.00	Up to 10	CaO
Raheem *et al.* (2012)	1: 2: 4	0.60	15.00	Up to 10	SiO_2
Subbaramaiah (2016)	1: 1.84: 2.89	0.50	24.00 – 39. 74	Up to 40	NA
Ettu *et al.* (2013)	1: 2: 4	0.60	20.90	Up to 10	SiO_2
Abhishek and Kumbar (2017)	1: 1.61: 2.78	0.45	25.00 – 36.00	Up to 15	CaO
Adamu *et al.* (2017)	1: 2: 4	0.55	22.00 0 28.00	Up to 15	SiO_2

Source: (Fapohunda *et al*., 2018)

Both the splitting tensile strength and the modulus of rupture decreased, in relation to the control, with increase in the percent cement replacement with SDA up to 28 days curing age (*Udoeyo et al.*, 2006 and Rajamma *et al.*, 2009). The developed tensile strength is between 9 – 10 % of the compressive strength. There is however reason to believe that, beyond 28 days, the compressive strengths are higher than the control specimens (Naik *et al.*, 2002).

4) Durability properties

Results of investigations suggested that concrete with SDA has good durability properties. For example, Udoeyo *et al.* (2006) obtained water absorption values of less than 10% for replacement up to 30%. Neville (2011) considered concrete with absorption capacity less than 10% to be a good concrete. Similarly, Cheah and Ramli (2012) found out that specimens with SDA up to 15% developed shrinkage properties. Ramos *et al.* (2013) concluded that alkali-aggregate reaction is mitigated for replacement values up to 20%. Cheah and Ramli (2012) observed reduced depth of carbonation (which is a measure of resistance to carbonation) in their investigation, suggesting ability to prevent carbonation. Reduced depth means improved carbonation resistance and vice versa. Wang *et al.* (2008) also showed that concrete containing SDA up to 25% exhibited improved chloride resistance. The results of Elinwa and Ejeh (2004) however suggested vulnerability of concrete with SDA in acidic environment

III. IMPLICATIONS OF AGRICULTURAL WASTE IN CONCRETE PRODUCTION IN NIGERIA

Relevant structural characteristics of some agricultural wastes have been presented in this review. Others that have been found to have pozzolanic potentials for structural use are: palm kernel shell ash – PKSA (Olutoge *et al.*, 2012), groundnut husk ash – GHA (Ketkukah and Ndububa, 2006), corncob ash – CA (Adesanya *et al.*, 2008), and egg shell powder – ESP (Yerramala, 2014). The optimum values vary between 10 to 30%. However, there is the need for standardization of procedures for testing, knowing that the wastes perform differently. It is also necessary to classify these wastes in the way the American classified fly ash (ASTM C 618, 2005), silica fume (ASTM C 1240, 2015) and granulated blast furnace slag (ASTM C 989, 2018). Standardization and classification will enhance the usage of these waste in structural concrete, and thus ensure following benefits:

i. Reduction in the Nigeria contribution to the total global emission of greenhouse gas
ii. Reduction in the consumption of non-renewable raw materials used in cement manufacture, thus helping to conserve the nation's natural resources.
iii. Help remove unwanted waste, resulting in a cleaner environment
iv. Development of small-scale industries around these wastes in the rural areas. This will provide employment opportunities for rural dwellers, improve GDP and reduce rural-urban migration.
v. Downward review of the price of cement will be occasioned by the total sum of these wastes, when they are available in the market as substitute to cement.

IV. CONCLUSION

A review of some agricultural wastes that are found in Nigeria for possible use in the production of structural concrete is presented. From this review, it can be concluded that, in Nigeria abounds many wastes of agricultural origin that can be made fit for use as partial replacement of cement in the production of structural concrete. But standardization of tests and procedures of investigations as well as performance-based classification are not yet in place to enhance its usage. There are also some properties that are yet to be investigated such as: flexural responses, crack development, propagation and patterns, and shear behaviors of concrete with these agricultural wastes. All these are necessary for the complete structural response of these wastes to be captured. These are thus recommended for investigation.

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