REVIEW OF SELECTED POZZOLANAS FOR CONCRETE PRODUCTION

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ABSTRACT

In pursuit of producing a sustainable and durable concrete composite, there is need to incorporate some supplementary cementitious materials to modify its conventional properties. Several works have been done on the utilization of agricultural and industrial wastes as pozzolans in concrete. However, there are some naturally occurring materials that also exhibit additional binding tendency that are yet to be explored. Cement being a conventional binder in concreting undergoes hydration reaction producing lime as one of its by-products. This causes expansion thereby predisposing the composite to disintegration and hence, untimely failure. Pozzolans have the tendency of forming additional binding property when in contact with this lime in the presence of water. Lot of research has been carried out on its properties and effects in concrete. However, there have been disparities in the optimum percentage replacement of various pozzolans in concrete. This article focuses on previous findings on the utilization of pozzolans in concrete and its prospects in the construction industry.

Keywords: *Concrete, Cement, Compressive Strength***,** *Pozzolana, Water absorption*

1.0 Introduction

Cement is a finely ground substance having cohesive and adhesive properties of holding fragments to form a compact whole (Neville, 2011). It is an ingredient whose importance cannot be overemphasized because without cement, concrete composite would not stand. There are different types of cement based on the composition and proportion of their raw materials during production, rate of cooling of the clinker amongst others. The selection of the type of cement depends on the nature of the job as there are some meant for specialized jobs. The rate of utilization of concrete in the construction industry is on the increase and consequently, the consumption of cement is on the high side. Cement industries have been one of the contributors of carbon dioxide (CO_2) and other greenhouse gases emission into the environment via the dissociation of carbonates and fuel in the combustion chamber. This affects the ozone layer leading to harsh climatic conditions and in turn have detrimental effect on the living organisms on earth (Morrical, Laker, & Descheneaux, 2011). To minimize the emission of these gases, there is need to reduce the consumption of cement. Consequently, this will reduce the production of cement with consequent reduction in the CO_2 emission. In view of this, the reduced quantity of cement will need to be complemented with some materials that possess supplementary cementitious properties.

Pozzolans are siliceous and aluminous materials in finely divided form having tendency of reacting with calcium hydroxide in the presence of water to produce calcium silicate hydrates. There are many pozzolanic materials in the construction industry which have been broadly classified as natural and artificial. The natural belonging to the family of calcined clay, shales and ashes of volcanoes while the artificial belongs to categories of burnt agricultural and industrial wastes (Husein Malkawi, Shatnawi, & Husein Malkawi, 2017; Rathi & Modhera, 2007). These materials are mostly industrial and agricultural wastes, amongst which are: periwinkle shell ash, rice husk ash, eggshell ash, palm kernel shell ash, coconut shell ash, clamshell ash, ceramic waste, phosphogypsum, sewage sludge, bone ash, surkhi, volcanic ash, shales of opaline, and pumice. Pozzolans occurring naturally, coupled with treated lime (burnt lime), have been in use in mortar and concrete for thousands of years before the advent of modern Portland cement. Some of the earliest use of pozzolan in mortar or concrete occurred in the Greek and Roman civilization, superstructures such as the Olympus arena, aqueducts scattered in Greece and Italy are examples (Morrical et al., 2011). Pozzolans are used worldwide as materials for the partial replacement of cement in concrete and mortar and in the production of blended cement. The merits attached to pozzolans in concreting are enormous and not limited to the following: high resistance to chemically induced attack, enhanced workability, high reduction of bleeding, greater water impermeability, and low evolution of heat of hydration. However, the delay in strength development and problem of shrinkage are some of the disadvantages of pozzolans in concrete and mortar (Joel, 2010). The reaction of pozzolans is enhanced when its most significant compounds of alumina, ferric and siliceous oxides come in contact lime and water. The lime is made available from hydration of cement and alumina and silica oxides being constituents of the pozzolan. During the process of hydration, the lime dissociates releasing OH- ions as shown in Equation 1, and consequently increasing the pH thus making the medium basic in nature and hence, enhancing the reactivity of the pozzolans thereby forming silicates and aluminate hydrates as presented in Equations 2 and 3 respectively (Chen & Lin, 2009; Dermatas & Meng, 2003; Guney, Sari, Cetin, & Tuncan, 2007; Nalbantoğlu, 2004; Yong & Ouhadi, 2007).

$$\mathbf{Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-} \qquad \text{Equation1}$$

$$\mathbf{Ca^{2+} + 2OH^- + SiO_2 \rightarrow CSH} \qquad \text{Equation 2}$$

$$\mathbf{Ca^{2+} + 2OH^- + Al_2O_3 \rightarrow CAH} \qquad \text{Equation 3}$$

The silicate and aluminate hydrates are majorly in charge of the mechanical properties of the cement composites. The pozzolanic reaction is dependent on the presence of alumina and silicate oxides and cases where these oxides are not in abundance, the need to mix with the binder becomes very necessary. Furthermore, the need to incorporate stabilizing material containing significant amount of calcium, silica and aluminum oxides (Degirmenci, Okucu, & Turabi, 2007; Wild, Kinuthia, Jones, & Higgins, 1998).In cases where the abundance of these oxides is enormous, it is not necessary for them to be incorporated as a binding agent. The improved mechanical capacities achieved in each case depend on the amount, reactivity and concentration of the oxides, the size and shape of the particles and also on the curing conditions (Göktepe, Sezer, Sezer, & Ramyar, 2008; Misra, Biswas, & Upadhyaya, 2005; Yarbaşı, Kalkan, & Akbulut, 2007).

2.0 Pozzolans

As earlier discussed, pozzolans are either by-products of agricultural and industrial wastes or naturally occurring clay materials. The significance of these materials in concrete technology cannot be overemphasized.

2.1 Sewage sludge ash (SSA)

Sludge is a by-product of the treatment process of wastewater. From the perspective of Sludge Production Factor (SFD), approximately 5.3 million m^3 of sewage sludge is produced annually and by 2035, the production rate will increase to about 10 million m^3 (Krishta David & Karan Nair, 2018). Sludge is disposed by ocean dumping, spreading on reclaimed land and land filling. However, these methods of disposing sludge pose environmental hazards such as air, land, and water pollution. Alternatively, a means of minimizing these problems is by using the SSA to replace cement and aggregate in concrete (Krishta David & Karan Nair, 2018; Naamane, Rais, Taleb, Mtarfi, & Sfaira, 2016; Yusuf, Noor, Din, & Abba, 2012). Based on studies by Cheeseman & Virdi (2005), David & Karan Nair (2018) and Naamane *et al.* (2016), SSA is best calcined at a temperature of 1000^{o}C and above. Lower temperature results in slow and low strength development of concrete due to lower percentage of CaO, SiO_2 and Al_2O_3.

2.1.1 Properties of SSA

SSA is mainly composed of calcium with high amounts of aluminium, magnesium, sulphate, zinc, sodium, iron, phosphorus, silica, and potassium. Other components of SSA are anhydrite, calcite, portlandite, quartz and witlokite (Garcés *et al.*, 2008; Naamane, Rais, Lachquar, & Taleb, 2014; National Bureau of Statistics, 2020). The chemical composition of SSA is shown in Table 1 while its micro structural configurations and mineral constituent arrangement are presented with the scanning electron microscope and XRD micrographs in Figure 1.

Table 1: Chemical composition of SSA

Author	Oxides composition (%)											
	SiO_2	Al_2O_3	Fe_2O_3	CaO	P_2O_5	SO_3	Na_2O	K_2O	TiO_2	MgO	MnO	LoI
(Merino, Arévalo, & Romero, 2007)	25.40	7.64	20.00	21.05	14.02	-	0.48	0.78	0.29	1.63	0.03	8.35
(Coutand, Cyr, & Clastres, 2006)	34.2	12.6	4.7	20.6	14.8	2.8	1.0	1.7	0.9	1.9	0.06	5.5
(Wang, Chion, Chen, & Wang, 2005)	43.6	16.6	10.4	5.61	12.1	0.24	0.82	2.34	-	1.40	-	-
(Park, Moon, & Heo, 2003)	39.52	17.17	11.91	7.16	7.55	1.97	1.23	2.72	0.81	2.13	-	7.31

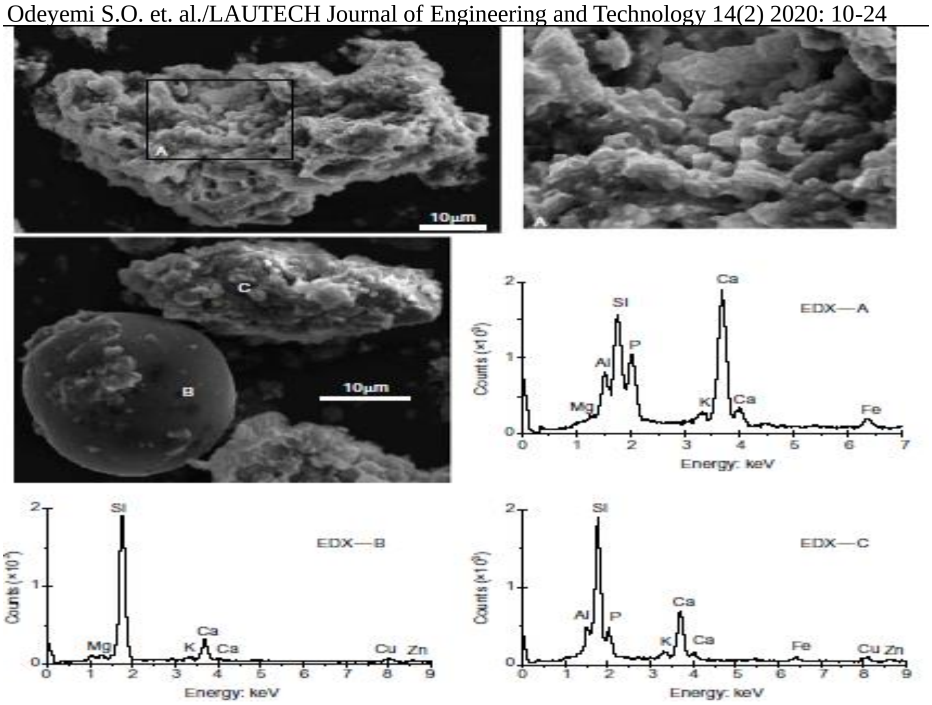

Figure 1: SEM Micrograph and XRD of SSA (Source: Coutand *et al.* (2006))

2.1.2 Effect of SSA in concrete:

Krishta David and Karan Nair (2018) recommended 10% replacement of SSA with cement and 25% replacement of SSA with fine aggregate as the optimum replacement in concrete. This replacement gave a compressive strength which is 6.76% higher than the control specimen which has no SSA. However, the inclusion of SSA in cement mortar gave a compressive strength lower than the control sample which contains no SSA (Coutand et al., 2006). Despite this, the ratio of the test to control experiment was found to be higher than minimum values recommended by the European standard for pozzolanas.

2.2 Corn Cob Ash (CCA)

Corn cob is the agricultural waste product obtained from maize or corn, which is the most important cereal crop in sub-Saharan Africa (Adesanya & Raheem, 2009). It is the semi-hard thick cylindrical central core of maize which bears the grains. Previous research efforts on the use of corn cob ash (CCA) as a pozzolan (Adesanya, 1996) involved the mixing of the CCA with Ordinary Portland Cement at the point of need. Nigeria was the largest producer of maize in Africa with over 33 million tonnes in the year 2018 followed by South Africa, Egypt, and Ethiopia (IITA, 2020).

2.2.1 Properties of Corn Cob Ash

Olafusi, Kupolati, Sadiku, Snyman, & Ndambuki (2018) revealed the colour of CCA to be greyish purple with an average particle size of 75 µm and specific gravity of 3.49. The calcination of 120.33 kg of corncobs generated 1.48 kg of CCA; which implies an ash to solid ratio of 0.012. Table 2 shows the chemical composition of CCA and Figure 2 shows the SEM imagery of CCA

Table 2: Chemical composition of CCA

Author	Oxides compositions (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
(Kamau, Ahmed, Hirst, & Kangwa, 2016)	38.8	7.9	7.4	1.8	2.1	0.59	0.9	23.5
(Raheem, Oyebisi, Akintayo, & Oyeniran, 2010)	66.53	7.41	4.25	10.30	1.82	1.12	0.37	4.10

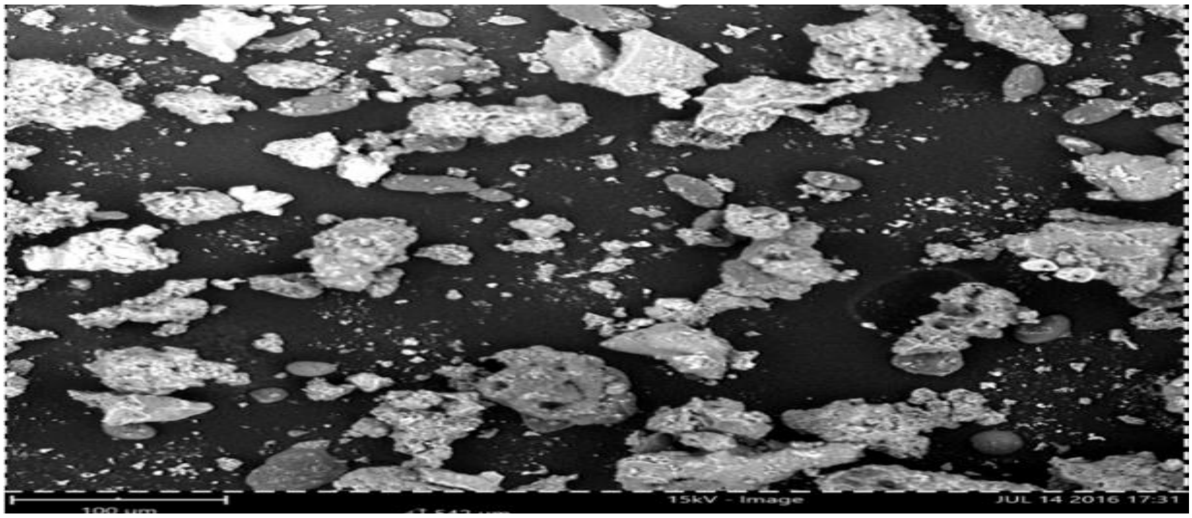

Figure 2: SEM Micrograph of CCA (Source: Olafusi *et al.* (2018))

2.2.2 Effect of CCA on concrete

Ikponmwosa, Salau, & Kaigama (2015) researched the features of concrete made with laterite, sharp sand, cement, and CCA at 0, 10, 20, 30, and 40% replacement levels from cement weight. The setting times and water demand of concrete was observed to increase with increase in the quantity of CCA replacement and consequently reduction in the workability and density. The incorporation of 40% of the ash was found to reduce the density of concrete by 8%. This reduction was attributed to the low specific weight of CCA as compared to that of Ordinary Portland cement. Olafusi and Olutoge (2012) concluded that concrete of grade as high as 35 was obtained when cement was replaced with CCA in varying percentages of 0, 10, and 20% respectively. The results of compressive strength showed there was delay in the development of strength at early stages of curing. This finding agrees with the work of Adesanya and Raheem (2009) where super plasticizer was used to improve the workability of low water-cement ratio CCA composite.

2.3 Fly Ash (FA)

According to Feng and Clark (2011), Fly ash is described as a substance obtained when pulverized coal is being burnt in the course of electric power generation. It has gained application in concrete technology as a material complementing the binding properties of cement and has been used in the batching of over 50 % of ready-mix concrete.

2.3.1 Properties of Fly Ash

Memphis (1996) opined that FA is primarily silicate glass containing silica, alumina, iron, and calcium. Minor constituents are magnesium, sulfur, sodium, potassium, and carbon. Crystalline compounds are present in small amounts. The colour of FA is greyish with its specific gravity falling between 1.9 - 2.8. The chemical composition of FA is shown in Table 3 while Figure 3 shows the SEM imagery.

Table 3: Chemical Compositions of Fly Ash

Author	Oxides compositions (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
(Dermatas & Meng, 2003)	34.2	19.3	5.64	25.8	5.07	2.2	2.04	0.52
(Memphis, 1996)	35	18	6	21	-	4.1	5.8	0.7

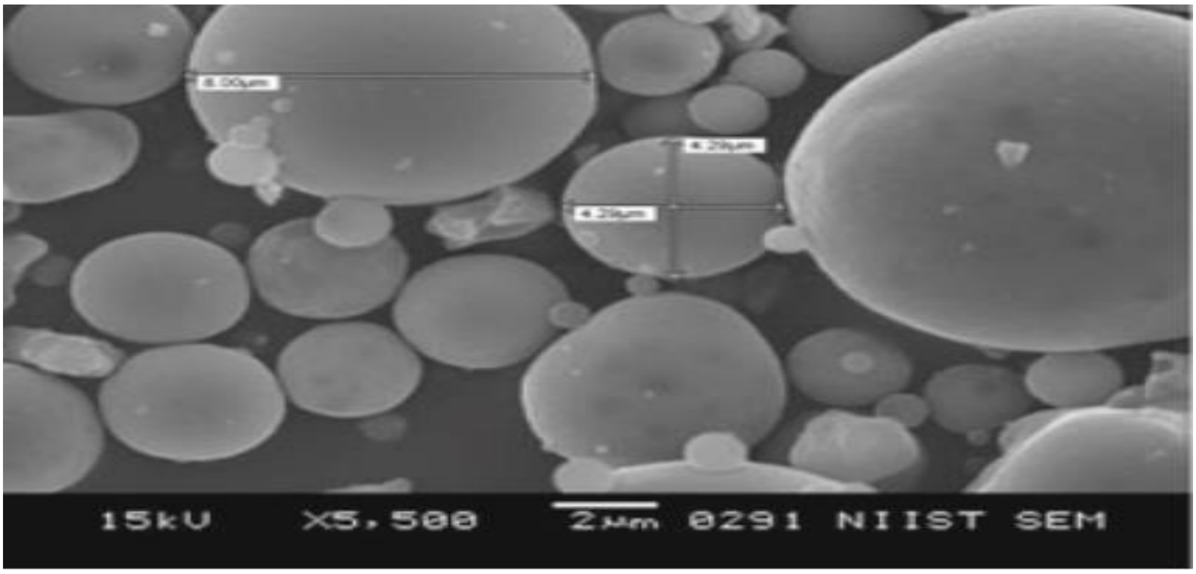

Figure 3: SEM Image of Fly Ash (Source: Venkateswara Rao & Srinivasa Rao (2020))

2.3.2 Effects of FA in Concrete

According to Thomas (2007), the optimum composition of fly ash differs not only with the intending application, but also with composition and proportions of all the materials used in the concrete mixture (especially the fly ash), the conditions during placing (especially temperature), construction practices (for example finishing and curing). It could be recommended that the level of replacement of Fly ash in concrete could be as high as 50% in as much as early-age strength development could be achieved with adequate curing medium provided. Venkateswara Rao & Srinivasa Rao (2020) concluded in their study that replacement of cement with 30% fly ash in regular works can be recommended and where strength is of minor importance cement can be replaced with either 40% fly ash or 50% fly ash based on the strength requirements.

2.4 Rice Husk Ash (RHA)

Rice husk ash is obtained from the burning of rice husk, a by-product from rice milling operation. In Nigeria, rice husk is produced in most northern and central states where rice is grown. Some of the states are Niger, Kaduna, Kano, Benue, Nasarawa, Kogi, Kwara (Joel, 2010).

2.4. 1 Properties of RHA

RHA is a pozzolanic material, with a specific gravity of 2.13 (Joel, 2010). Ghosal (2015) pointed out that RHA has the properties of lightweight aggregates. That the water cement ratio needed by rice husk ash concrete is slightly higher than that of normal aggregates. He posited that it is possible to use rice husk ash as partial substitute for cement to produce light weight concrete. Ai-khalaf & Yousift (1984) classified RHA as an artificial pozzolana of siliceous material, the material conforming to the chemical and physical requirements of class N pozzolan (ASTM C-618, 2001). The elemental oxide composition of RHA as obtained by some researchers is shown in Table 4.

Table 4: Chemical Composition of RHA

Author	Oxides compositions (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O
(Oyejobi, Raji, Aina, & Siva, 2015)	92.54	0.31	0.15	1.19	0.15	0.26	0.17	1.38
(Joel, 2010)	67.30	4.90	0.95	1.36	1.81	2.8	-	-
(Basha, Hashim, Mahmud, & Muntohar, 2005)	71.16	16.15	4.98	-	0.25	-	-	1.46

2.4.2 Effects of Rice husk Ash on Concrete

The strength variation of OPC-RHA composites suggest that with good quality control of the concreting process, about 5% to 30% OPC replacement with RHA could perform satisfactorily when used for reinforced concrete works and 35% to 50% for minor works in concrete. Furthermore, in cases where light low bearing structures is of the subject matter, replacement of RHA in the range of 5%-20% could be recommended (Ettu, Ajoku, Nwachukwu, Awodiji, & Eziefula, 2013).

2.5 Coconut Shell Ash (CSA)

Coconut shell being a part of natural fillers is obtained in the tropical regions. The application of CSA has been very relevant in the production of quality and sustainable concrete composites. The material possesses no binding tendency itself but could exhibit cementitious features when it comes in contact with lime obtained from hydration of cement thus forming additional silicates (C_2S and C_3S) responsible for strength development and durability tendency (Desai, 2017).

2.5.1 Properties of Coconut Shell Ash

The application of CSA as replacement for conventional binder in concrete production could reduce the consumption of cement and consequently, reduce the cost of production as well as produce an ecofriendly composite that will mitigate against the dumping of agricultural wastes into the landfills thereby minimizing environmental pollution (Oyedepo, Olanitori, & Akande, 2015). Rao, Swaroop, Rao, & Bharath (2015) pegged the water absorption of coconut shells at 8% and specific gravity at saturated surface dry condition of the material as 1.33. The elemental oxide composition of CSA is shown in Table 5.

Table 5: Chemical composition of CSA

Author	Oxides compositions (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	ZnO	Na_2O	K_2O
(Joshua et al., 2018)	66.32	8.79	5.35	6.25	0.87	-	-	3.26
(Bhartiya & Dubey, 2018)	37.97	24.12	15.48	4.98	1.89	-	0.95	0.83
(Madakson, Yawas, & Apasi, 2012)	45.05	15.6	12.4	0.57	16.2	0.3	0.45	0.52

2.5.2 Effects of Coconut Shell Ash on Concrete

Parthasarathi *et al.* (2017) observed that compressive strength, split tensile strength and flexural strength are on higher side for 15% of CSA replacement by weight. Oyedepo *et al*. (2015) concluded that at 28 days of curing, the 10% replacement gave the optimum compressive strength of 20.58 N/mm^2 as against the 20 % replacement with a compressive strength value of 17.26 N/mm^2. The strength values of the duo replacement could be recommended for the production of light and heavy weight concrete. Thus, the researchers concluded that the use of CSA as a partial replacement for cement in concrete, at lower volume of replacement, will enhance the reduction of cement usage in concretes, thereby reducing the production cost and the environmental pollution caused by the dumping of the agricultural waste.

2.6 Bone Ash (BA)

Opeyemi & Makinde (2012) defined bone ash as a complex chemical made from calcium, phosphate, and hydroxyl ions, but which may also contain small amount of cationic, magnesium and strontium replacing calcium, bicarbonate, fluoride and the hydroxyl anions. Bone is a strong, hard, fibrous material in mammalian body (endoskeleton) which gives shape and supports to the body.

2.6.1 Properties of Bone Ash (BA)

There is abundance of the whitish cow bone ash in Nigeria which makes it a prime product. The chemical composition of BA is shown in Table 6; the average specific gravity of bone ash is 1.85 (Olutaiwo, Yekini, & Ezegbunem, 2018).

Table 6: Chemical Composition of Bone Ash

Author	Oxides compositions (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	MnO	P_2O_5	CuO
(Olutaiwo *et al*., 2018)	2.28	2.97	0.43	76.43	1.21	0.086	5.56	0.28

2.6.2 Effect of bone ash on concrete

The research conducted by Olutaiwo *et al*. (2018) concluded that concrete containing Bone Ash (BA) up to 20% replacement for cement, satisfies the minimum structural requirement for construction. Opeyemi & Makinde (2012) showed that there was reduction in density of the concrete at 10% and subsequent increase in the range of 10% - 20% replacement.

2.7 Palm Oil Fuel Ash (POFA)

Palm Oil Fuel Ash (POFA) is one of the numerous by-products from palm kernel production whose applications have not been fully utilized in the construction industries. Palm kernel is produced in all the regions in Nigeria except the northern part where the growth of the palm is not well favoured. The metric tonne of oil palm annually is slightly above 900 metric tons with about 2.2 % rate of growth (Opeyemi & Makinde, 2012). Palm kernel shell is a by-product of palm fruit produced in large volume annually and disposed into landfills as waste. PKS come in various sizes such as 0-5mm for small sizes, 5-10mm for medium sizes and 10-15mm for large sizes (Odeyemi, Abdulwahab, Abdulsalam, & Anifowose, 2019).

2.7.1 Properties of POFA

POFA contains a large amount of SiO_2 which gives it the pozzolanic property. From researches conducted by Singh & Siddique (2014) and Siddique, Aggarwal, & Aggarwal (2012) POFA contains high SiO_2 (>60%), low Al_2O_3 (<8%) and high P_2O_3 (3.78%-4.6%). In addition, the Fe_2O_3, CaO and MgO content of POFA is higher than that of GGBFS, and calcined kaolin as well as that of fly ash in class F. These relative abundance of the latter compositions enhance the cementitious characteristics of POFA thereby making it similar to ordinary Portland cement coupled with its pozzolanic tendency exhibited as a result of the presence of other oxides (Oyejobi *et al*., 2015). The elemental oxide composition of POFA is shown in Table 7. The specific gravity of POFA is 2.12 (Oyejobi *et al.*, 2015). The colour of POFA is grey and it is readily available in Nigeria (Oyejobi, D .O. Raji, S.A. Jimoh, 2019). Figure 4 shows the SEM image of POFA.

Table 7: Chemical Composition of POFA

Author	Oxides compositions (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	$S0_3$	P_2O_5	K_2O
(Oyejobi *et al*., 2015)	53.52	11.4	12.68	4.62	3.28	-	0.18	3.08
(Jamo, Abdu, & Pahat, 2015)	66.91	6.4	5.72	5.56	3.13	0.33	3.72	5.20
(Sata, Jaturapitakkul, & Rattanashotinunt, 2010)	42.5	0.9	2.4	11.0	7.1	2.2	5.7	7.0

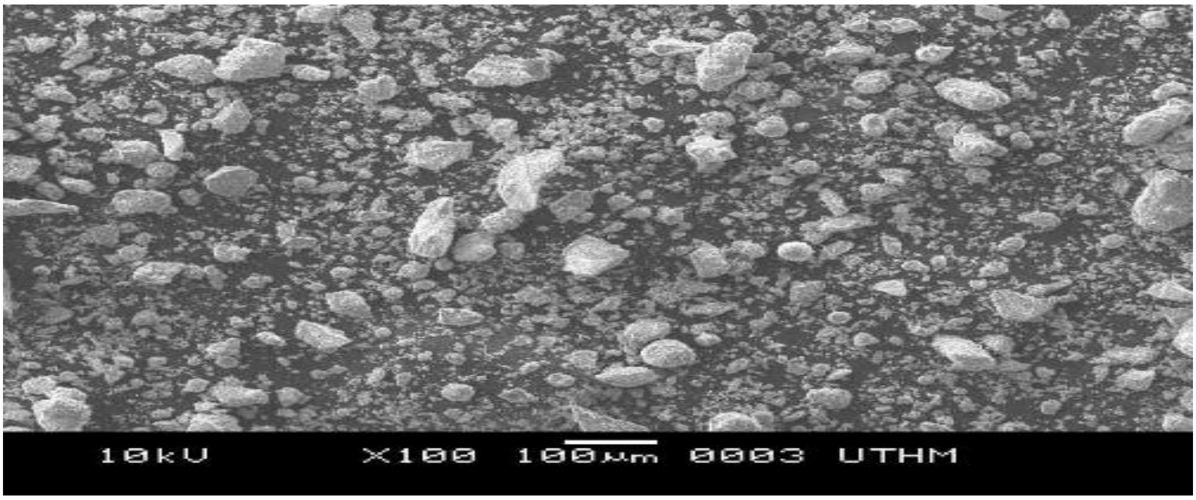

Figure 4: Scanning Electron Micrograph of POFA (Source: Jamo *et al*. (2015))

2.7 2 Effects of POFA on concrete

Munir *et al*. (2015) concluded that POFA can replace cement up to 50% based on the weight of cement. Their finding indicates a potential use of POFA in foamed concrete production for non-structural building material. Although, there was a fall in the compressive strength of concrete by 30 to 40 % when the percentage replacement of POFA increased to 50 %, the addition of 20% POFA gave the acceptable strength of foamed concrete for non-structural purposes. The decrease of compressive strength is insignificant in term of economic value by cement replacement.

2.8 Silica Fume (SF)

Silica fume, which is also described as micro silica or condensed silica fume is a by-product of the reduction of high-purity quartz in the presence of coal in an electric arc furnace during the manufacturing of silicon. Silica fume rises as an oxidized vapor from the 2000°C (3630°F) furnaces, when it cools it condenses and it is collected in huge cloth bags and the condensed silica fume is then processed to remove impurities and to control particle size (Memphis, 1996).

2.8.1 Properties of Silica Fume

The specific density of silica fume is recorded at 2.20 (Srivastava, Agarwal, Atul, Kumar, & Mehta, 2013). The bulk density (uncompacted unit weight) of silica fume varies from 130 to 430 kg/m^3 (Memphis, 1996). Table 8 shows the chemical composition of Silica Fume. Figure 5 shows the SEM image of silica Fume.

Table 8: Chemical Composition of Silica Fume

Author	Oxides compositions (%)							
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	SO_3	K_2O
(Srivastava, Kumar, Agarwal, & Mehta, 2014)	85	1.2	1.46	0.2-0.8	0.2-0.8	0.5-1.0	-	3.08
(Memphis, 1996)	90	0.4	0.4	1.6	-	0.4	0.4	2.2
(Zain, Safiuddin, & Mahmud, 2000)	97.1	0.4	0.3	0.3	0.0	-	0.2	-

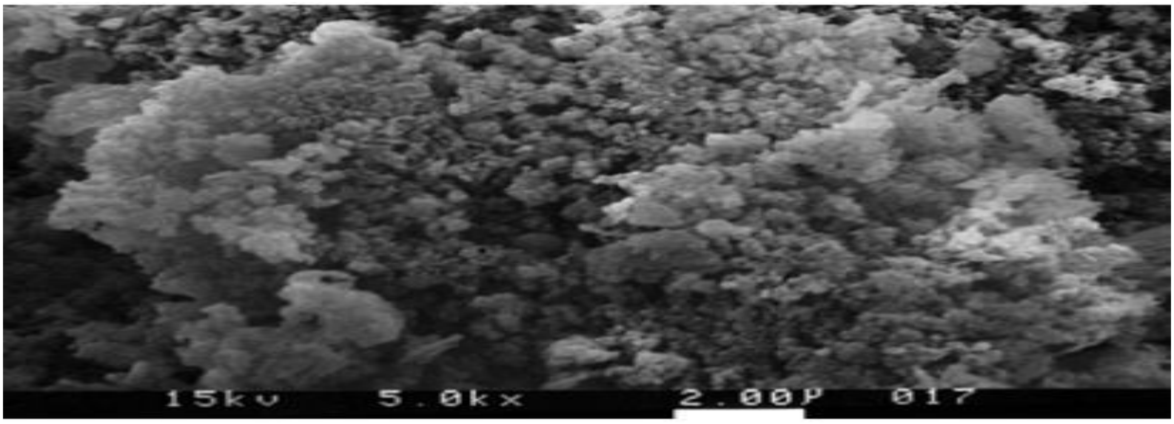

Figure 5: Scanning Electron Micrograph image of Silica Fume (Source: Memphis (1996))

2.8.2 Effect of Silica Fume on Concrete

Srivastava *et al.* (2014) opined that the optimum replacement level of cement by silica fume is found to be 5% by weight. Furthermore, there was enhancementin the development of compressive strength of concrete infused with silica fume at 7 and 28 days of curing. The incorporation of SF in concrete enhanced the workability even at very high level of replacement, though with compromise in the compressive strength.

2.9 Ceramic Waste Powder (CWP)

Ceramic products are very essential construction materials used in most buildings for aesthetic purpose. Some common manufactured ceramics include wall tiles, floor tiles, sanitary wares, household ceramics and technical ceramics. They are mostly produced using natural materials containing high content of clay minerals. However, its wastes disposal has been a major threat to the environment as it is a non-biodegradable material thereby piled up in landfill, hence, constituting environmental pollution.

2.9.1 Properties of Ceramic Waste Powder

Images from SEM micrograph of ground CWP material as shown in Figure 6 indicates that it consisted of irregular and angular particles which are similar to cement particles in shape (El-Dieb & Kanaan, 2018). The chemical composition of the CWP by X-ray florescence (XRF) is presented in Table 9. El-Dieb & Kanaan (2018) illustrated that CWP mainly consisted of silica (SiO_2) and alumina (Al_2O_3). These higher percentages of silicate and aluminate in the CWP material could indicate some pozzolanic reactivity. Ceramic waste has a specific gravity of 2.72 (Pereira-De-Oliveira *et al*., 2012).

Table 9: Chemical Composition of Ceramic Waste Powder

Author	Oxides compositions (%)								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	SO_3	K_2O	TiO_2
(El-Dieb & Kanaan, 2018)	68.6	17.0	0.8	1.7	2.5	-	0.12	-	-
(Raval, Patel, & Pitroda, 2015)	63.29	18.29	4.32	4.46	0.72	0.75	0.10	2.18	0.61
(Irassar *et al*., 2014)	64.6	17.0	5.6	2.5	1.5	4.2	-	2.9	0.7

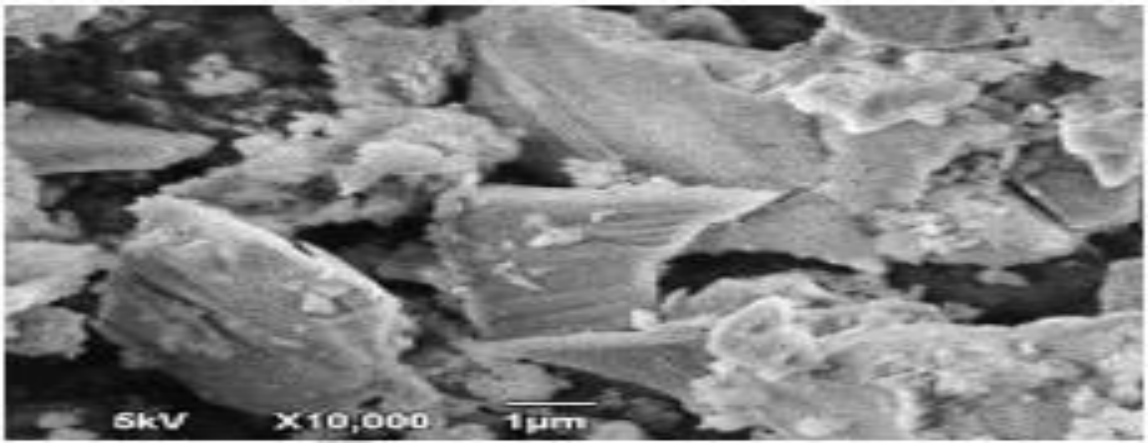

Figure 6: Scanning Electron Micrograph of CWP (Source: El-Dieb & Kanaan (2018))

2.9.2 Effects of CWP on Concrete

The ceramic wastes are suitable for partial replacement of cement in mix up to 20–30% weight without being detrimental on the compressive strength of either concrete or mortar (Lavat, Trezza, & Poggi, 2009). El-Dieb & Kanaan (El-Dieb & Kanaan, 2018) concluded that CWP slowed the compressive strength development especially at early ages but concrete mix with CWP showed good strength development at 90 days of age. Ceramic wastes powder can be classified as a slow reactive pozzolan (Irassar *et al.*, 2014). However, attention needs to be given to the method of milling as the powder could also be roasted prior application. This thermal phase changing approach could enhance its pozzolanic tendency.

2.10 Ground Granulate Blast-furnace Slag (GGBS)

GGBS is a waste product of the steel industry produced from the melting of pig iron in the presence of limestone flux in a blast furnace. The cooling of the molten is very significant in the formation of the slag in that if the cooling is fast using water, little or no crystals will be formed and hence, makes it amorphous in nature. GGBS has pozzolanic behaviour when in contact with minute quantity of lime and its application in the construction and engineering works cannot be overemphasized (Binici, Temiz, & Köse, 2007; Oti, Kinuthia, & Bai, 2009; Wild *et al.*, 1998).

2.10.1 Properties of GGBS

The oxides composition of GGBS is shown in Table 10. The average specific gravity of GGBS is recorded at 2.87 kg/m^3 and Blaine specific surface area was 4250 cm^2/g. The GGBS remaining on 90 µm and 45 µm sieves were 0% and 0.8%, respectively (Oner and Akyuz, 2007).

Table 10: Chemical Composition of GGBS

Author	Oxides compositions (%)								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	SO_3	K_2O	LOI
(Sharma & Sivapullaiah, 2016)	29.2	13.8	5.5	44.9	6.0	0.3	-	1	-
(Oner & Akyuz, 2007)	39.18	10.18	2.02	32.82	8.52	0.19	-	0.67	1.0

2.10.2 Effects of GGBS on Concrete

The compressive strength of GGBS concrete increases as the GGBS content is increased up to an optimum replacement level of 59%, after which the compressive strength decreases (Oner & Akyuz, 2007).

CONCLUSION

The reviewed pozzolans possess cementitious properties and optimum replacement percentage per weight of cement depends on the chemical composition of each pozzolan. Their use in concrete will help in waste management and reduce the cost of concrete production. Research need to be tailored towards determining the rate of roasting the wastes in the furnace. Also, more attention should be given to joint application of two or more pozzolans (ternary blend) in concrete composites as the properties of individual pozzolan would complement the properties of the concrete thus, producing composite with novel features.

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