A Review of Pozzolana in Nigeria: Current State and Exploratory Assessment for Commercialization in Construction

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Abstract

Many researches have been conducted on pozzolanic materials in Nigeria, mainly from agricultural and industrial wastes, and calcination of natural deposit material as clay. Many conclusions on these researches indicate they can improve the quality of concrete produced with them, resulting in the production of sustainable concrete. They possess the potential for more affordable construction and reduce the ill reputation concrete has garnered over the years due to its growing carbon footprint. The utilization of these wastes in concrete also reduces the pressure on landfills, an environmentally friendly process. The outcome of these researches has remained on shelves and have not been harnessed to develop a footprint for its commercial application in construction. This review seeks to address this problem. Of the agricultural wastes studied, pozzolans from rice husk, palm oil wastes can be harnessed locally for processing and local utilization in locations unique to their generation source. Wastes from coconut shells and sugar cane are not viable in their current quantity to explore commercially. The waste from corn-cob and clay processed to pozzolana in concrete applications is commercially viable to meet the Nigerian demand. However, the cement manufacturing companies in Nigeria need to adopt these wastes to produce the cheaper corresponding blended cement alongside their regular cement. The Nigerian populace needs to be educated on the benefits of utilizing these pozzolans for ease of patronage.
Keywords: Pozzolans, Agro-Wastes, Industrial-Wastes, Nigeria, and Calcined-Clay

1.0 Introduction

The hallmark of development of a place or a nation is evident in the quality and size of infrastructure(s) provided. These infrastructures are mostly construction-related that involved concrete, like, roads, residential/office buildings, school and other public infrastructure. The aforementioned could be why concrete is the most consumed human-made material globally, as concluded by Naik (2008). Portland cement (PC), which is the main constituent of concrete, is also a material that contributes over seven percent (7%) of the total greenhouse gas emissions globally (Al Muhit, et. al., 2013). It is of little wonder, Vidal (2019) termed concrete as the most harmful material on earth as it is tipping the world into a climate catastrophe.
These have increased in research to significantly reduce the quantity of PC needed in concrete to produce greener and sustainable concrete to avert the catastrophe as much as possible. A material with the potential to replace PC is pozzolans. According to Mehta and Monteiro (2014), a pozzolanic material is a siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form and in the

presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

Pozzolans could occur naturally, like in volcanic ash. Pozzolans could be derived from incinerating agricultural and industrial wastes supposedly meant for landfills, like coconut shell ash (CSA), Palm Kernel Nut Waste Ash (PKNWA), corn cub ash (CCA), rice husk ash (RHA), millet husk ash (MHA), sugar cane bagasse ash (SCBA), granulated blast furnace slag (GBFS) and unrecyclable waste glass (UWG) amongst others (Joshua *et al.*, 2018a; Joshua *et al.*, 2017; Olawuyi *et al.*, 2017). Pozzolans could also be derived by simply calcinating naturally occurring materials like clay and others currently being researched are laterite and montmorillonite clay. The utilization of some pozzolans has even been standardized in some standards as in ASTM C618-15 and BS EN 197-1:2011.

There are significant studies on pozzolanic materials sourced in Nigeria online, but no major thing is being done to explore them for onsite application(s). This review intends to explore the commercial viability of these studies.

This review intends to identify and establish the agro and industrial wastes with proven pozzolanic indices, assess their possible available quantity for viability and applicability for commercial production. This review also intends to establish the sources and commercial viability of naturally occurring materials that would simply be calcinated to pozzolans like clay types and sources.

A study that has made the most commercial viability attempt is one done by the Nigeria Building and Road Research Institute (NBRRI). They went as far as developing a pilot pozzolana plant that is currently exploring calcined clay being sold in fifty kilograms (50kg) bags branded as 'NBRRI Pozzolana' that is available in the market at limited quantities for research and guided application purposes.

2.0 Methods

For the purpose of this review, research conducted on pozzolan and pozzolanic materials that are unique to Nigeria and their sources were searched on several databases such as Web of Science, Scopus, and Google Scholar. The major database searched was Google Scholar, as papers in this database are the most accessible and also widely used for research. Reports of reputable ministries and parastatals were also used in this review. The expected conclusion would be to estimate the volume or tonnage of concrete the pozzolans can produce. This will be compared with the estimated annual concrete consumption, this will then determine the viability of the pozzolans under consideration.

Agro wastes and industrial wastes or bye products generated in Nigeria with known pozzolanic activities would be established. Their statistic is determined from literature from the aforementioned databases and compared with the quantity of concrete they can individually produce. Since pozzolans supplement cement, annual cement consumption could also be determined and compared with the volume of pozzolan generated per source to measure commercialization viability.

3.0 The Review of Literature

In this review, the average consumption of cement and concrete will be established in relation to the average concrete consumed in Nigeria. The pozzolanic materials in Nigeria would be identified and be reviewed with the relevant article(s). The approach to determine which agro-waste to study would be to search for crops produced in Nigeria on a significantly large scale to generate a substantial quantity of waste worthy of being explored.

3.1 Cement and concrete consumed in Nigeria

According to research analysts, Anifowose and Akinremi (2019) in the United Capital report, the average annual consumption of cement from 2010 to 2018 is over twenty million metric tons (20.7Mmt). This consumption was corroborated by a report of Nigeria's Cement Manufacturing Rep that puts the annual per capita consumption to ninety kilograms (90Kg). With the current Nigerian population of about two hundred million (207,741,800) (Worldometer, 2020), the average consumption would be about 18.7Mmt. Since most pozzolans replace cement to an average of 12%, any pozzolan that can generate about 2.2Mmt to 2.5Mmt would be commercially viable to meet the Nigerian market's projected demands.

3.2 Identifying which pozzolanic material to study

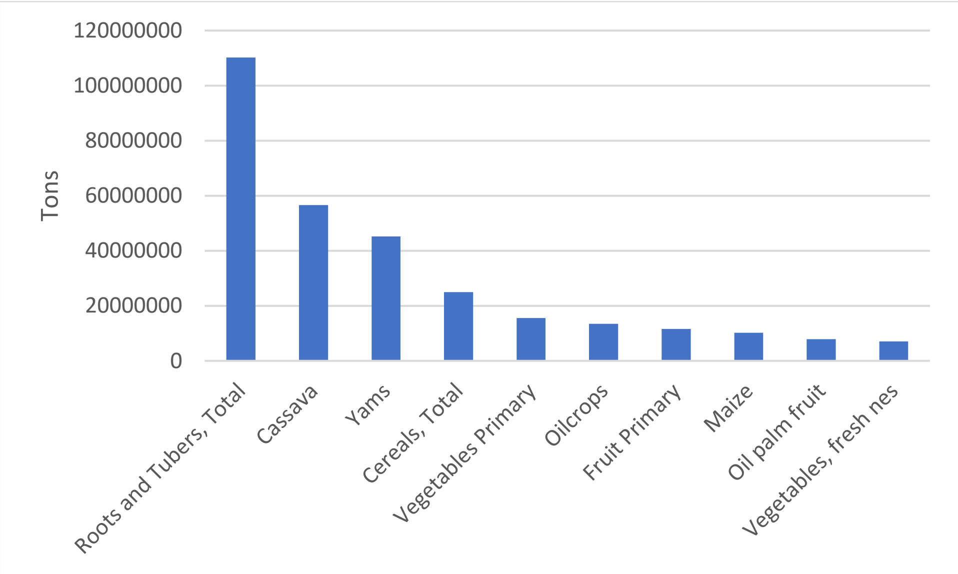

Figure 1: Most Produced Crop in Nigeria (FAOSTAT, 2018)

Since most potential sources of pozzolana are from agricultural wastes, it will be of interest to this review to identify the crop most produced in Nigeria as a pointer to the quantity of agro wastes generated. Figure 1 shows the first-ten most produced crop in Nigeria and from the list, maize and oil palm, amongst others, have the potential to generate wastes, which include corn-cub from maize and palm kernel shell, palm oil fiber, palm oil husk from oil palm fruits.

Yahaya (2020) identified the top twenty (20) crops most produced in Nigeria as sorghum, millet, maize, rice, beans, yam, cassava, cocoyam, potatoes, groundnuts, sesame (benniseed), soyabeans, cocoa, rubber, oil palm, cotton, sugarcane, tobacco, coconuts and cashew. Not all these crops generate significant wastes because they are mostly wholly or directly consumed but the ones this review will study are coconut shells, rice husk, palm oil fuel ash, corn-cob, and bagasse. Figure 2 shows the average annual production of these crops in Nigeria between 2013 and 2018. Calcined clay was also studied in this review.

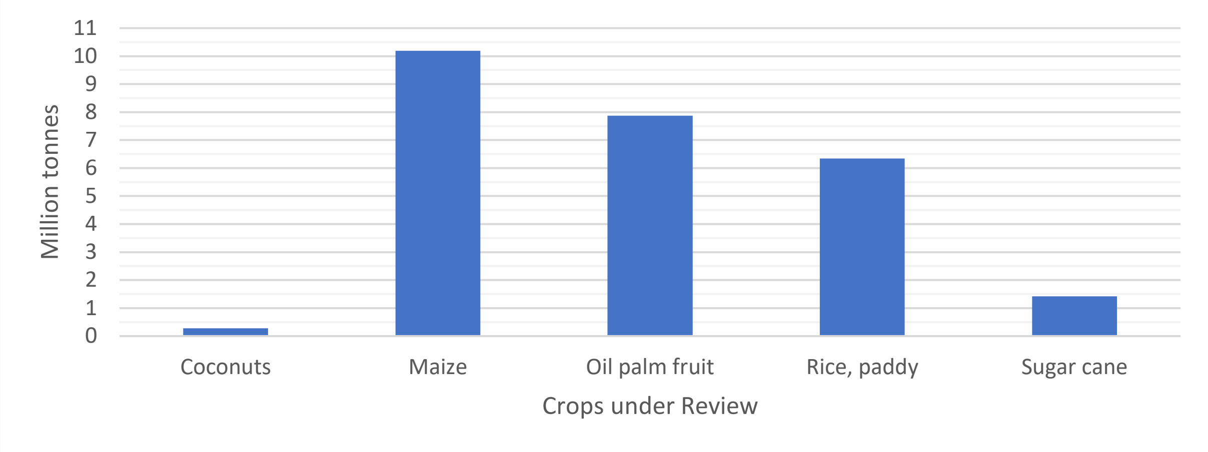

Figure 2: Average Annual Crop Production Between 2013-2018

3.3 Coconut shell Ash (CSA)

A study on CSA's pozzolanic activity by Joshua (2018) shows that it can replace cement optimally at fifteen percent (15%). The total percentage of the alumina, silica and the ferrous oxide in CSA was 80.64%. According to the Food and Agriculture Organization Corporate Statistical Database (2018), Nigeria is the 19th largest producer of coconuts globally and 2nd to Ghana in Africa with two hundred and eight-five thousand metric tons 285,000mt capacity from twenty-two (22) states in Nigeria.

According to Bello *et al.* (2016), the average percentage weight of the shell in the coconut is averaged at 15.18%. Comparing this percentage to the Nigerian production capacity, 43,263mt of the shell can be generated. After calcination, this weight is further reduced to about 50% (Joshua *et al.*, 2018), therefore, about 0.022Mmt pozzolan with coconut can be produced from Nigeria. This is about 1% of the quantity needed for commercial viability, it is, therefore, better to wait till the annual average production can be increased at least to ten times (10x) the current production capacity before it can be recommended for investment locally for a processing facility to explore for CSA.

3.4 Rice Husk Ash (RHA)

A study of RHA's pozzolanic property indicates that it can replace cement optimally at 20% and possess a very high pozzolanic index with a combined sum of silica, alumina, and ferrous oxide of 87.38% (Zareei, 2017). Zareei (2017) concluded that 200kg husk is recovered per ton of the rice produced and 40kg RHA when the husk is calcinated. This implies that only 4% of RHA pozzolan can be obtained per ton of rice produced.

According to a report of the Food Agricultural Organization of the United Nations (FAOSTAT) (2018), Nigeria's average annual rice production is about 6.8Mmt. By implication, 0.272Mmt of RHA can be generated from the rice produced in Nigeria. Thrive Agric (2020) puts 2019 annual production at 8Mmt and the largest rice producer in Africa, producing up to 55% of Africa's total production. By implication, 0.32Mmt of RHA can be generated annually in Nigeria.

This will be about 7.2%, on average, of the quantity needed to be commercially viable in Nigeria. Ikenwa (2019) reports in Nigeria Infopedia that rice is mostly grown in Kebbi, Ebonyi, Jigawa, Niger, Benue and Kaduna States. A RHA pozzolan processing facility could potentially be locally viable in the locations within these States. Cement manufacturing plants closest to these sources could harness these wastes to produce RHA blended cement.

3.5 Palm Oil Fuel Ash (POFA)

Palm oil fuel ash (POFA) is a by-product obtained during the burning of waste materials such as palm kernel shell, palm oil fiber, and palm oil husk; it can be utilized to partially replace cement in a concrete mix (Hamada 2018). Production of POFA is due to the heating of significant amounts of palm oil fiber, shell, and empty palm fruit bunches. This author concludes that it's 25% of the total oil palm produce that is the oil, the rest 75% is the biomass that could be used to produce the POFA. In most cases, the biomass is burnt as fuel to generate energy and the resulting residue is POFA, which is about 5% of the biomass. According to a review carried out by Hamada (2018) on POFA from forty-four studies and sources, when optimally calcined and pulverized, the mean replacement of cement is 20% and the mean combined percentage sum of silica, alumina and ferrous oxide is 66% determined by the X-Ray Fluorescence (XRF) analysis.

From the FAOSTAT (2018), the annual production of oil palm in Nigeria from 2013-2018 is 7.9Mmt, as shown in Figure 2, making it the fourth globally. 75% of these are the wastes biomass resulting to 5.93Mmt. 0.3Mmt of POFA can then be obtained from the biomass when burnt to produce energy. This is 7.24% of the quantity needed to be commercially viable in Nigeria. According to the Nigeria Investment Promotion Commission NIPC, (2019), the Central Bank of Nigeria (CBN) is in talks with the eleven (11) South-south and South-Eastern Nigerian states to invest in oil palm production with the aim of resuming the leading position in oil palm production.

A POFA processing facility can be proposed to be located between the two (2) Nigerian geopolitical zones to localize its utilization within the zones.

3.6 Corn Cob Ash (CCA)

According to a review of eighteen (18) articles on CCA by Adebisi *et al.* (2019), the average optimum allowable replacement of cement with CCA was 14% with a statistical mode of 10% by fourteen of the articles. Three (3) of the articles indicate pozzolanic activity with an average combined sum of silica, alumina and ferrous oxide of 75%. The average annual production of maize in Nigeria from 2013-2018 is 10.2Mmt, as shown in Figure 2. As of 2014, Nigeria is the second-largest maize production in Africa (FAOSTAT, 2018).

The cob-kernel average weight ratio is 0.83, as deduced from Basa *et al.* (2016), this implies that for every unit weight of maize, the cob weight is 0.83. This implies that 8.5Mmt of corn cob is generated annually. Taking an assumed 70% loss in weight when calcinated, the total CCA that could be produced is over 2.3Mmt. This implies that CCA is a pozzolan that could be commercially viable if the logistics of harnessing the corn cob can be perfected. The setback to this is that maize is produced in almost all the Northern and South-Western parts of Nigeria.

Two (2) processing facilities to process CCA could be located in Kaduna and Oyo states to harness corn cob in the Northern and Southern-Western Nigeria, respectively. This is because of their central location in the producing states.

3.7 Sugar Cane Bagasse Ash (SCBA)

Bagasse is a waste generated when the sugar juice is extracted from sugar cane. Bagasse is then calcined to obtain SCBA. Mangi *et al.* (2017) concluded that the optimum replacement of cement with SCBA is 5% and that the combined sum of silica, alumina and ferrous oxide is 78%. Shruthi (2014) proposed a 10% optimum replacement and sum of silica, alumina and ferrous oxide as 72%. Otoko (2014) suggests an optimum replacement of 2% at oxides sum of 51%. Agredo (2014) studied SCBA from two different sources and recommended an average of 20% with sum of oxides compositions of 84.7% and 72.5%. In a review on SCBA by Kumar and Dhriyan (2018), it was observed that approximately 26% of bagasse and 0.62% of residual ash are produced from one ton of sugarcane

The average annual production of sugar cane in Nigeria is 1.43Mmt, as shown in Figure 2. It is mostly grown in Northern Nigeria. Though Nigeria is the highest consumer of sugar in Africa, the bulk is still being imported to meet the local demand reported by Yahaya (2020) in Nigeria Infopedia. From Kumar and Dhriyan (2018) assertion, 0.009Mmt of SCBA could be produced annually, which implies 0.4% of what is needed to be viable. This cannot be profitable for commercial exploration.

3.8 Calcined Clay (CC)

In a study by Joshua *et al.* (2018), CC optimally replaced cement by 20% and the sum of the three main oxide compositions is 91.98%. In a review of CC by Shukla (2020), most of the literature reviewed suggests optimum replacement with CC of between 20% and 30% in concrete and that all contributed significant strength and durability properties. The sum of the main percentage oxide compositions is above 90% in all cases. In the study by Shukla (2020), the forms of clay in the study were metakaolin and shale. They all performed excellently in concrete as supplementary cementitious material (SCM).

It is of no doubt that clay is almost everywhere in Nigeria. According to Madasun (2010), more than eighty (80) clay deposits have been reported from all parts of the country, these deposits are in Abak, Akwa Ibom State, Uruove near Ughelli in Delta State, Ifon in Ondo State, Mokola in Oyo State, Sokoto in Sokoto State, Gombe in Gombe State, Kutigi/Dangara in Niger State, Umuahia in Abia State, Onitsha in Anambra State, and many more.

The availability of clay for pozzolan in Nigeria is undoubtedly more than enough as it can satisfy more than required for concrete applications in Nigeria

4.0 Conclusion and Recommendation

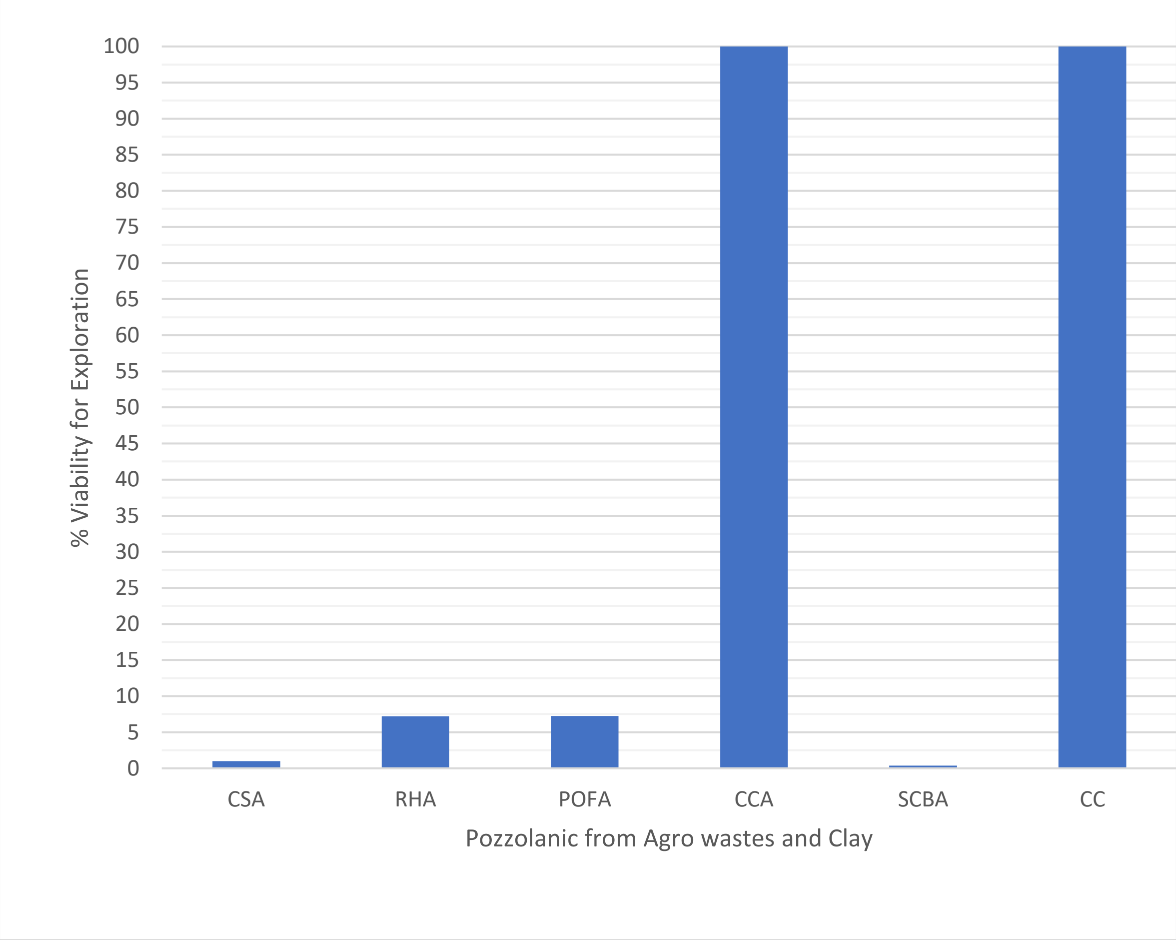

Figure 3: Summary of Fraction of Required Quantity of Pozzolan for Viable Exploration

The conclusions and recommendations from this review are as follows:

- Since most pozzolans replace cement to an average of 12%-20%, any pozzolan that can generate about 2.2Mmt to 2.5Mmt would be commercially viable to meet the projected demands of the Nigerian market.
- From the most crops produced in Nigeria, coconut shells, rice husk, palm oil fuel ash, corn-cob and bagasse were discovered in this review to potentially be explored for exploration as a pozzolan.
- From Figure 3, CSA and SCBA in this review could generate 1% and 0.4% of the quantity needed for commercial viability, it is, therefore, better to wait till the annual average production can be increased to significant capacities before they could be recommended for investment locally for a processing facility to explore them.
- RHA could only generate 7.2% of Nigeria's consumption from Figure 3. A RHA pozzolan processing facility could potentially be locally viable in source communities within Kebbi, Ebonyi, Jigawa, Niger, Benue and Kaduna States. Cement manufacturing plants closest to these sources could harness these wastes to produce RHA blended cement.
- POFA could generate 7.24% of Nigeria's consumption. POFA processing facility could be proposed to be located somewhere between the South-south and South-east Nigerian geopolitical zones to localize its utilization within the zones.
- CCA and CC both possess good potentials for commercial exploration for pozzolana as their quantity could meet the Nigerian demand for concrete. However, the logistics to gather the

corn cob will need to be perfected as they are generated almost everywhere nation-wide. CCA processing facility could be cited in Kaduna and Oyo States.

- Other wastes like cassava and other root tuber's skin could be assessed for pozzolanic exploration.
- Above all, the best way to harness these pozzolans, especially the crop-based ones, is for cement-making factories closest to them, harness them into pozzolanic blended cement. Cement-making factories already have the infrastructure to harness them into pozzolanic cement. For example, cement factories in the South-East and South-South could be manufacturing POFA-Cements alongside their Portland cement; cement factories closest to both Abakaliki and Kebbi manufacture RHA-Cements; and factories nearest to Badagry manufacture CSA-Cements.

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