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Investigating for Pozzolanic Activity in Palm Kernel Nut Waste Ash (PKNWA) with Cement towards a Sustainable Construction

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Abstract

The earth is not inherited from our ancestors but borrowed from our children and should be returned the way we met it and even better. This is the essence of sustainability, preserving the earth. One of the main consequence of a non-sustainable world is global warming caused by the release of greenhouse gasses into the atmosphere that deplete the earth's protective layer from extreme sun radiation. This results in global temperature rise leading to tsunamis and other "natural disasters" making us more vulnerable to extreme weather elements. Urbanization and industrialization bring about high construction rate to accommodate them resulting to global demand for concrete production. Concrete production contributes about 5% of the world's carbon dioxide (CO_2) emission and bulk of these emissions are in cement production. Cement is not an eco-friendly material and the sharp decrease in its use is highly needed to improve sustainable construction. Another issue discouraging its use is the rising cost, making housing unaffordable even to the middle class. This have resulted in finding series of housing financing systems to cope with rising cost of housing. One of the ways of achieving this is by the use of pozzolanic and blended cements to reduce the quantity of cements needed to meet the global concrete demand. This study examines the Pozzolanic Potentials of Palm Kernel Nut Waste Ash (PKNWA) as a blend with cement in Nigeria. Nigeria is currently the third world leading producer of palm which bears the nut and also accounts for over half of the palm produced in Africa. Palm kernel nut becomes an agro-waste when the oil is extracted. This study shows that PKNWA can comfortably replace cement by 10% and even produce a more durable binder than when cement is wholly used. The utilization of PKNWA in blended cement production will reduce the need for cement and prevent the ecological hazard resulting from the disposal of the waste palm nuts.

Keywords: Sustainable construction, Palm kernel nut, pozzolanic cement and blended cement.

INTRODUCTION

There is this quote by Wendell Berry, published in his book titled "The Unforeseen Wilderness" that "*We do not inherit the earth from our ancestors; we borrow it from our children*". The earth must be returned back to our children intact the way we met it and we mustn't hurt the earth with our current activities but rather preserve it.

This quote by Wendell Berry is the main goal of sustainability. Its essence and applicability in building and construction is the practice of making structures using processes that are environmentally responsible and resource efficient. This is expected to span throughout the life cycle of a building from site selection, design, construction and materials, operation, maintenance and renovation and finally, deconstruction. Sustainability is achieved by improved building/construction system's efficiency to minimize energy wastage; use of machine or systems with lower energy demand without compromising output; focusing more on renewable energy sources; waste utilization and recycling to reduce environmental hazards associated with their disposition; the use of systems and processes that reduce the greenhouse gas emission; and the use of environmentally friendly building and construction materials amongst many others.

One consequence of non-sustainability is the emission of greenhouse gasses which are mainly carbon and its oxides and others are oxides of nitrogen methane and steam released into the atmosphere during domestic and industrial processes. These greenhouse gasses depletes the layer in the atmosphere that prevent some harmful radiations from the sun from reaching the earth surface which results in heating the earth thereby causing global temperature rise referred to as global warming. Many scientists believe global warming is responsible for the global rise in sea levels leading to flooding and tsunamis, increase in the intensity of extreme weather, and change the amount and pattern of precipitation. Other effects could include changes in agricultural yields, glacier retreat, species extinctions and increase in disease. Of recent, CNN reports in a video that there is a global increase of turbulence experienced in air travel as a result of global warming. These effects could severely impact the earth's ability to support life (National Ready Mixed Concrete Association (NRMCA), 2012). These are undesirable effects we will not want to pass to our children and future generations.

There is no doubt that urbanization and industrialization bring about construction to sustain and accommodate them and the inclusion of all building and construction systems mentioned above are all needed for a green and sustainable structure and construction.

According to Panttala (1997), the annual global production of concrete is about 5 billion tons as at 1997. Concrete is the worlds most consumed man-made material and as at 2002, 2.7 billion cubic meter were produced worldwide which is about 6.4 billion tons of concrete within that year (Naik, 2008). It is expected that in about 2017, the annual global concrete demand would have risen to about 13.5 tons at 28% increase in every 5 years. The current annual demand is 11.5 billion tons as of 2014 (Mehta and Monteiro, 2014).

The National Ready Mixed Concrete Association (NRMCA), (2012) asserts that water, sand, stone or gravel, and other ingredients make up about 90% of the concrete mixture by weight. The process of mining sand and gravel, crushing stone, combining the materials in a concrete plant and transporting concrete to the construction site requires very little energy and therefore only emits a relatively small amount of carbon dioxide into the atmosphere. The amounts of carbon dioxide (CO_2) embodied in concrete is primarily a function of the cement content in the mix designs. Currently, the global annual demand for cement is put at 1.5 billion tons (Mehta and Monteiro, 2014) which implies that 1.5 billion tons of CO_2 is generated during the cause of meeting this demand as for every ton of cement produced, a ton of CO_2 is generated (Crow, 2008). The only ecological demerit of concrete is the emission of CO_2 during cement production (Panttala, 1997). According to Crow (2008), concrete production contributes 5% of the annual anthropogenic global CO_2 production of which bulk of the CO_2 emitted is in the production of cement. Cement is not an environmentally friendly material because its production creates greenhouse gas emission and its raw material reduces the supply of good quality limestone and the voids this extraction creates (Naik, 2008).

One of the ways to encourage a sustainable construction is to reduce the quantity of cement used in concrete production. Malhotra (2004) propose the reduced use of Portland cement in concrete by the use of blended and pozzolanic cements and this proposition was supported by Crow (2008) who also suggests the development of new concrete additives that can produce a stronger and more workable concrete whilst reducing the amount of cement required and hence the resulting CO_2 emissions.

Of recent, the attention of researchers are now being drawn to materials that can be blended with cement and these materials span from industrial bye products like silica fumes, blast furnace slag and fly ash to agriculture wastes as sugarcane bagasse ash, rice husk ash, and corn cub ash. Even the European and British codes have developed standards, BS EN 197-1: 2011, to reflect blended and pozzolanic cements. Pozzolans also improve concrete durability by being more resistant in aggressive environments like in Nitric and Sulphur environments that induce unsoundness in concrete (Olusola, *et al.,* 2012).

One of such material that this study will be looking at is the Palm Kernel Nut Waste Ash (PKNWA). When oil is extracted from the palm kernel nut, the resulting waste or byproduct is the PKNWA. Palm kernel oil is widely produced in the southern Nigeria where palm tree is most grown. In fact, in the 1960's, Nigeria was the leading grower of palm tree and hence the leading producer of palm kernel in the world but is now the third leading producer in the world behind Indonesia and Malaysia and produces about 55% of Africa's produce (Gourichon, 2013). The major use of palm kernel nut in Nigeria is the palm kernel oil that is being extracted from it. The byproduct mostly lie as waste but the animal feeds industry uses it to produce pig feeds in Nigeria, bulk of it still lies as waste.

This paper seeks to explore the use of PKNWA in cement as a blend and as a pozzolan in concrete production as this will contribute the production of sustainable concrete and hence sustainable construction. It will reduce the harmful effects concrete poses to the environment by reducing the greenhouse gas associated with concrete production by reducing the quantity of Portland cement needed in concrete.

Also, the high and increasing cost of construction materials has greatly hindered the provision of shelter and other infrastructural facilities in developing countries. This have resulted in finding series of housing financing systems to cope with rising cost of housing (Amusan *et. al.,* 2013). In an attempt to further reduce construction cost, researchers are also researching into the use of abundant local or indigenous materials in construction like incorporating laterite in sandcrete block production (Joshua *et. al.,* 2011; Joshua *et. al*., 2013; and Joshua *et. al.,* 2014), waste glass as aggregates (Ismail and Al-Hashmi, 2009) and as pozzolan (Joshua, *et. al*. 2017; and Islam *et. al.,* 2016) and many more. Amusan*, et. al*. (2017) and Ogunde, *et.al.* (2017) also used construction management tools to optimize construction cost.

Concrete is one of the most commonly used structural material in building construction and cement, the basic binder used in concrete production is very expensive. Hence research efforts over the years are being directed towards finding lower cost alternative materials which can be suitably used to partially or wholly substitute cement. Generally these groups of materials are termed pozzolans. A lot of agricultural wastes are generated annually in most tropical countries including Nigeria, which if not properly managed could constitute environmental nuisance (Ahmad *et al*., 2007). Wastes like palm kernel nut when converted to ash by burning in a kiln is being investigated in this study for pozzolanic property but, however, studies on its use in concrete are scarce.

MATERIALS AND METHODS

Sampling and Testing

The major material that was used in this study is the subject material which is the crushed palm kernel nut bye-product after its oil extraction. It was obtained from Ota in Ogun State of Nigeria. The other materials include 42.5N Dangote cement, borehole water and a standard sand to BS EN 196-1:2005.

The kernel bye-product was heated in a kiln to 600ºC and maintained for three hours and the resulting ash was sieved through a 75µm sieve and termed the Palm Kernel Nut Waste Ash (PKNWA).

In this study, the tests carried out were the setting times on the 0% and 10% blended of PKNWA with cement and the determination of the mortar strength which were performed according to BS EN 196-1:2005 on the cement blended with 0 – 30% replacement with PKNWA in steps of 5% and cured for 28days after which the 2, 7 and 28-days compressive strengths were determined. This test is to check for possible pozzolanic reaction of the PKNWA with the cement. The 0% replacement, that is, the 100% Portland cement was used as a control in this experiment.

The standard sand in accordance to BS EN 196-1:2005 was locally prepared by washing a river-dredged sharp sand and sieved with a sieve sizes 2mm and retained in 75µm.

The chemical analysis of the PKNWA and the cement used was also determined using X-Ray fluorescence (XRF) spectrometer to evaluate for possible pozzolanic activity of the PKNWA.

The strength characteristics were determined first and further tests were carried out on the optimum PKNWA replacements alone.

RESULTS

Gradation of the Fine Aggregates Used in the Determination of Mortar Strength

From the particle size distribution of the sand in Figure 1, the sand is classified as a poorly graded sand (SP) using the USCS since the Coefficient of Uniformity (Cu) is 2.29 and the Coefficient of Curvature (Cc) is 1.05 as derived from Figure 1. Poorly graded as classed in this case does not connote its bad but that it is close to being a uniformly graded since Cu of 2.29 is closer to 1. This sand satisfies the requirements stipulated in BS EN 196-1:2005 for the determination of mortar strength of cement (binder).

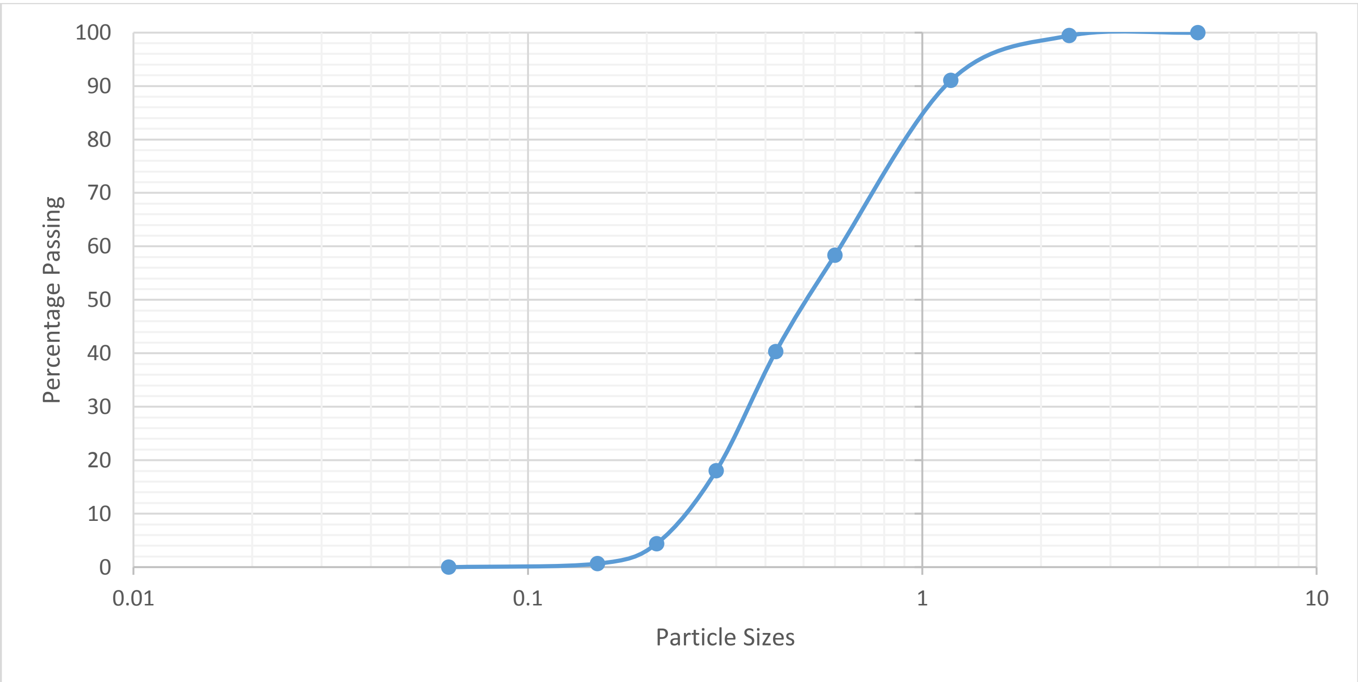

Figure 1: Particle Size Distribution of the Fine Aggregate for All Mortar Strengths

Table 1: Percentage Oxide Composition of Palm Kernel Nut Waste Ash (PKNWA)

Oxide composition	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	P_2O_5	K_2O	SO_3	TiO_2	MnO	$SiO_2+Al_2O_3+Fe_2O_3$
Percentage % composition	40.60	3.71	15.74	19.60	1.30	2.73	13.80	0.44	0.35	0.28	60.05

Where SiO_2 is Silica oxide, Al_2O_3 is Aluminum oxide, Fe_2O_3 is Iron trioxide, CaO is Calcium oxide, MgO is Magnesium oxide, P_2O_5 is Phosphorus oxide, K_2O is Potassium oxide, SO_3 is Sulphur trioxide, TiO_2 is Titanium oxide and MnO is Manganese oxide.

Table 2: Setting Times of the Control And 10% Replacement with PKNWA

% of replacement With PKNWA	Setting time (minutes)	
	Initial	Final
0 (Control)	126	350
10	134	386

From Table 1, the fact that the sum of SiO_2, Al_2O_3 and Fe_2O_3 is greater than 70% and percentage composition of SiO_2 alone is greater than 40% is indicative of a pozzolan by Indian and American standards, IS1344:1981 and ASTM C618-12a, which is subject to confirmation by the strength properties. This finding also conforms to the observations made by Awal and Hussin (1997).

Table 2 shows that the 10% replacement sets slower than the control and both met the requirements set out in BS EN 197-1:2011.

It is observed in Figure 2 that the strength was greatest at 10% replacements which confirms a pozzolanic activity of PKNWA.

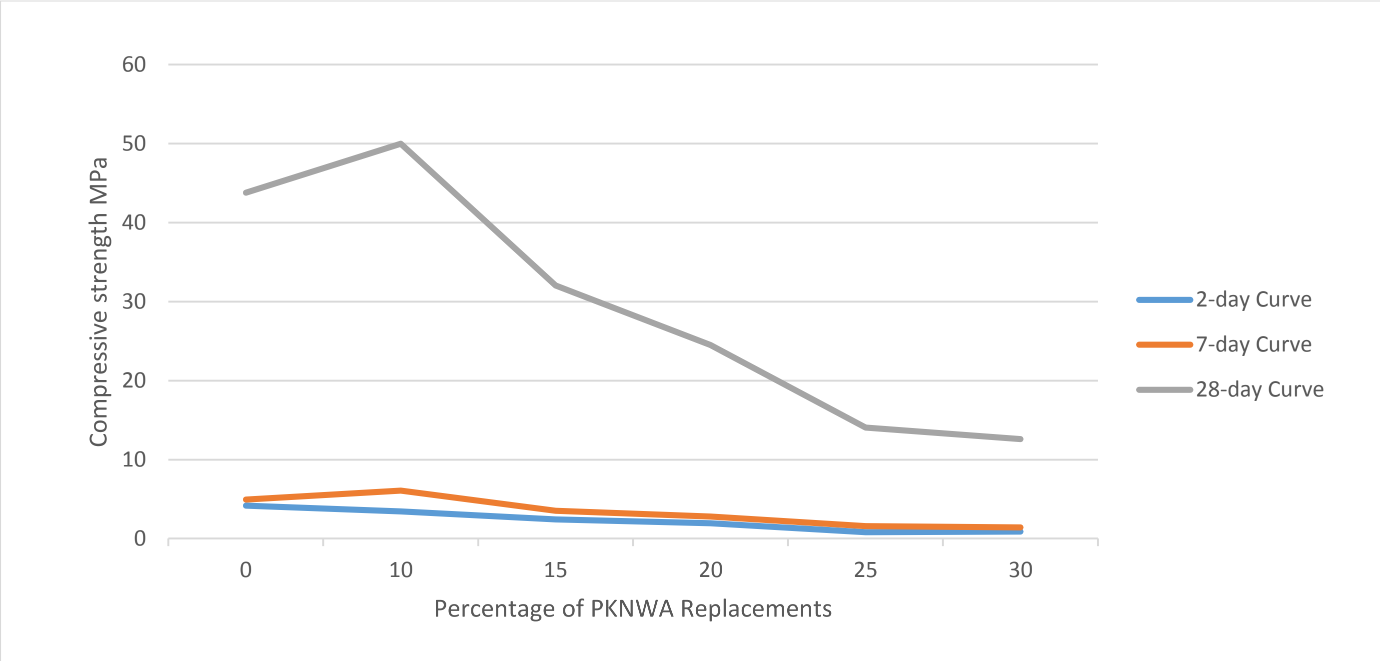

Figure 2: Compressive Strength at Various Curing Ages at Different Percentage Replacement With PKNWA.

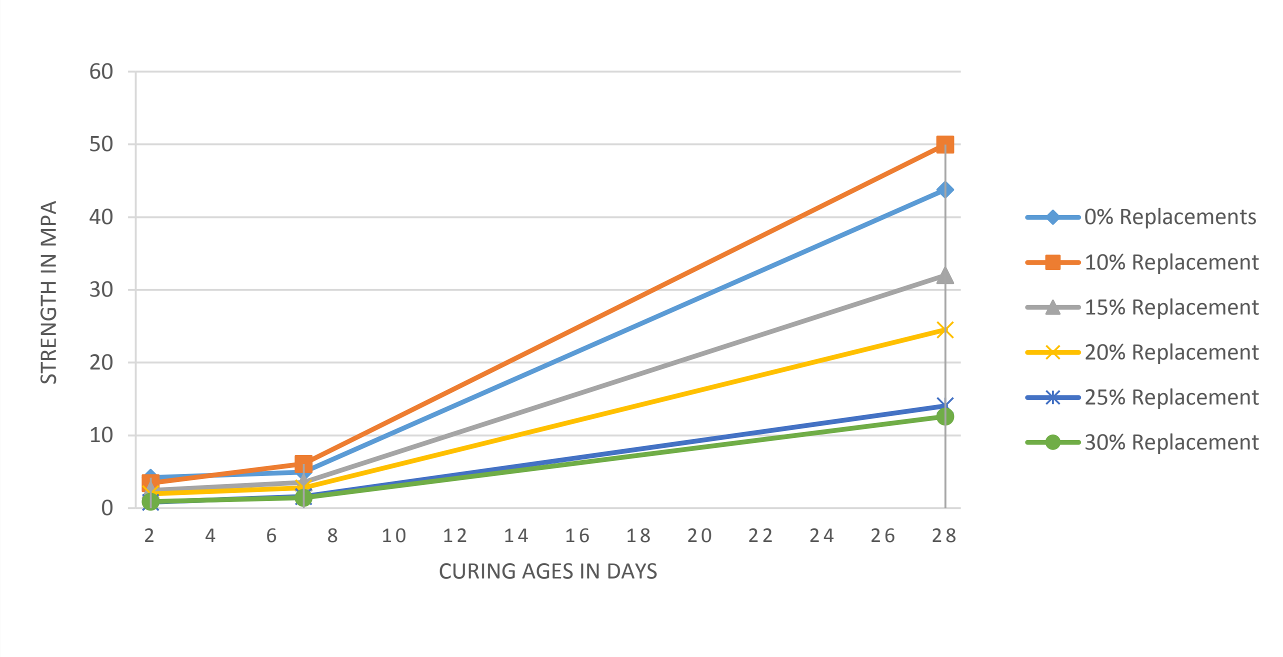

Figure 3: Compressive Strength at Various Replacements at Different Curing Ages.

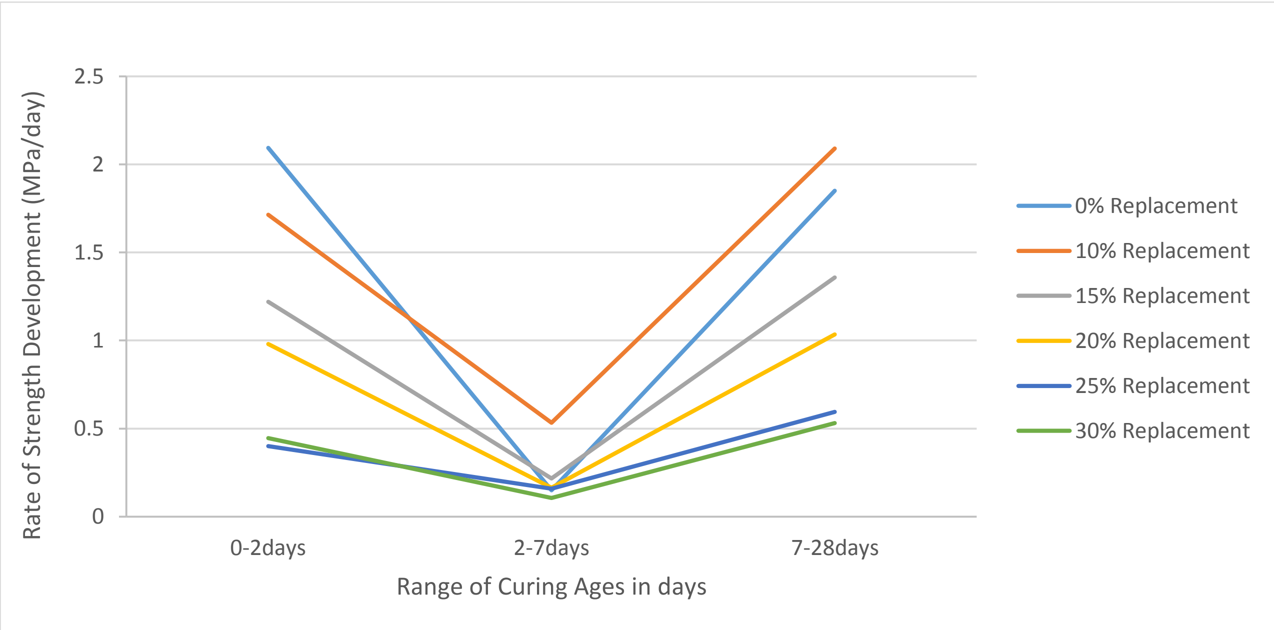

Figure 4: Rate of strength development at various percentage replacements at different curing ages.

It was observed that the highest strength was the 10% replacement after 2 days as evident in Figure 3, this proves that 10% produce a stronger mix than other replacements including the control. Though the strength development was initially slower than the control but the rate of strength development increased at older curing ages after 2 days. The Strength Activity Index (SAI) is about 60% from Figure 2 and Figure 3, though less than 70% recommended for fly ash. This indicates that PKNWA possess lesser pozzolanic activity than fly-ash.

It was observed that the control had the fastest rate of strength development as at 2days assuming a zero strength just after the initial set. At older curing ages, the 10% replacement had the highest rate of strength development.

It's generally believed that pozzolans have slower early strength development but this study shows that from 7days curing age, the rate of strength development of the various replacements were higher than that of the control even though the control developed a higher strength value than other replacements except for the 10% replacement with PKNWA replacement.

Comparing Table 2 with Figure 4, it can be deduced that it is possible to have a slower setting rate and faster strength development. The faster early strength development up to day two curing age could be attributed to its earlier setting rate while the strength development of the blends is greater.

Limitations

The major limitation in this work is that the 2 and 7-day strength requirement of the cement used didn't conform to BS EN 197-1:2011 but the 28-day strength did. And secondly, a result up to 56 days curing age would give a better picture on the rate of strength development than the 28 maximum curing days in this study.

CONCLUSION AND RECOMMENDATION

Conclusion

i. The sand used in the determination of the strength of cement conform to the specification of BE EN 196-1:2005.

ii. Palm Kernel Nut Waste Ash (PKNWA) is a confirmed class C pozzolan as indicated in Table 1 and Figure 2 according to ASTM C618:12.

iii. PKNWA can successfully be blended with cement by replacing cement by 10%. This blend even performs well than when cement is wholly used as a binder. See Figure 2 and Figure 3.

iv. This permissible blend of cement by 10% with PKNWA results in a more eco-friendly material by reduced cement use, and the environmental nuisance resulting in disposing the waste Palm Kennel Nut that the result of this study will prevent.

v. It is a confirmed sustainable material as PKNWA is an agro-incorporated waste in cement. It's only heated to 600ºC as against 1450ºC and a lighter density material than cement hence its production is less energy demanding.

vi. The rate of strength gain of strength from the onward of 7 days curing age is greater than when cement is wholly used though the 2 and 7days strength of the control cement didn't conform to BS EN 197-1:2011 but conforms to the 28-day strength in the standard. The rate of gain of strength as specified in the standard is higher than the optimum blend of 10%.

Recommendation

I. Though PKNWA could be blended with cement in concrete production, it is recommended that further studies be conducted to check its effect on other durability parameters in concrete production and not in mortar as performed in this study.

II. This same study could be conducted at higher calcination temperatures than the 600ºC and sieved with a finer sieve of 65µm than used in this study to check for possible improved pozzolanic activity.

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