Construction Materials and Structures
S.O. Ekolu et al. (Eds.)
IOS Press, 2014

doi:10.3233/978-1-61499-466-4-284

Palm Kernel Incinerated Ash as low cost concrete component

Emem-Obong Emmanuel AGBENYEKU[1] and Felix Ndubisi OKONTA
Department of Civil Engineering Science, University of Johannesburg, South Africa

Abstract. The incorporation of commercially available fly ash (FA) as low cost material in concrete has long been established. Large quantities of FA are utilized for research and field applications because of the pozzolanic characteristics. One of many pozzolanic materials is palm kernel incinerated ash (PKIA). The abundance of PKIA as an agricultural waste material in West Africa obtained by the incineration of palm kernel husk and shells in milling boilers paved way for this study. Specimens containing 50%PKIA were cast and cured both in water and air and their compressive strength and shrinkage behaviours were investigated with and without the addition of superplasticizer (hydroxylated carboxylic (HC) acid) in comparison with controlled specimens containing 100%OPC. Results showed that the strength development in PKIA green concrete at all ages of curing; 7,14 and 28days were lower than OPC concrete. On the addition of superplasticizer, strength of 36.9N/mm^2 was observed for specimens with superplasticizer as against 31.7N/mm^2 for specimens without superplasticizer on the 28day. The water curing method produced the best results while the predicted shrinkage strain of the green concrete in accordance to ACI 209R-92 standard was higher than the control specimens.

Keywords. Lightweight green concrete, palm nut shell, compressive strength, workability

Introduction

The use of supplementary cementitious materials (SCMs), such as fly ash (FA), rice husk ash (RHA), slag and silica fume (SF) in concrete has attracted considerable interest over the past decades. The generation of SCMs is vital to developing countries as low-cost construction constituents in self-sustaining means of shelter. The unrelenting rise in the prices of conventional materials has triggered the search for locally available resources as alternatives [1]. These alternatives are to supplement the costly conventional materials partly or fully, particularly in mortar and concrete. The pulverized fuel ash or FA as recorded by [2] is considered the most widely used in concrete construction amongst other silicon by-products. Apart from industrial waste, ashes from agricultural origin [3] such as; rice husk, cassava peels, coconut husk, corn cob, groundnut shell etc. have been identified as SCMs in many parts of the world. One of such pozzolanic materials is palm kernel incinerated ash (PKIA); an agricultural waste material derived by the combustion of palm oil husk and/or palm kernel shell in palm oil milling factories.

[1]Corresponding author: kobitha2003@yahoo.com

The oil palm is a tall or short-stemmed tree belonging to the palm family-Palmea with palm nut as its fruit (see Figures 1 and 2).

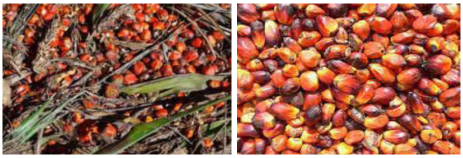

Figure 1. Palm nuts

Figure 2. Palm trees

As reported by [4] Benin Republic, Colombia, Ecuador, Nigeria, Zaire, Malaysia and Indonesia are amongst the countries in the equatorial belt that cultivate oil palm and palm oil products. These by-products are commonly used as fuel in the boilers of palm oil mills which become ashes in the form of PKIA (see Figures 3 and 4). The use of SCM such as PKIA does not only improve concrete properties but protects and conserves the environment by saving energy and natural resources [5].

Figure 3. Oil palm husk and kernel shells

Figure 4. Palm kernel incinerated ash (PKIA)

In West Africa the PKIA is popularly regarded as waste material in which case it is openly dumped creating risks of soil and groundwater contamination leading to environmental pollution. However, PKIA has been identified to possess good pozzolanic properties that can be used as substitute for cement in mortar and concrete mixes. In light of this, researchers have investigated the utilization of PKIA as a SCM and have examined various properties of the fresh and hardened concrete made from PKIA based on short and long-term laboratory investigations [6]. The PKIA as recorded by [6] has not only enabled the replacement of Ordinary Portland Cement (OPC) but has been found to play an effective role in producing strong and durable concrete. Considering the availability of PKIA in West Africa, this study opted to investigate the short-term properties of concrete containing 50% by mass of PKIA as it is within the limit to which cement be replaced for quality and economy for a targeted 28days strength, effects of admixture and curing process on the strength development of this concrete type; alongside the strength and drying shrinkage behaviour in comparison to the conventional OPC concrete set as control.

1. Materials and methods

1.1. Palm kernel incinerated ash (PKIA)

The PKIA used in this study is the combustion product of oil palm husk and palm kernel shells in oil milling boilers 220-300^{0}C collected from Ikoritungko Oil Milling

Factory located around Calabar, Nigeria. The collected ash as shown in Figure 4 was oven dried for 24hours at a constant temperature of 100^0C.

The dried ash was passed through 300-µm sieve to remove dirt and ash lumps/clinkers. It was then finely ground in a modified Los Angeles abrasion machine using steel bars (12mm diameter and 800mm long). The PKIA appeared grayish in color due to low carbon content as well as relatively spherical as seen in the electron micrograph in Figure 5.

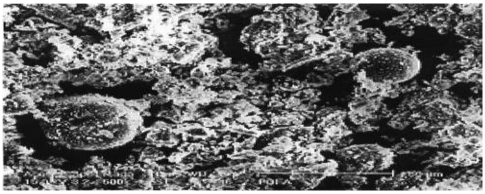

Figure 5. Scanning electron micrograph of PKIA

Table 1 shows the results of the chemical analysis carried out on PKIA which clearly revealed that the necessary chemical composition qualifying PKIA as a pozzolana was met and places it in between Class-C and Class-F in conformance to ASTM C6I8-94a standard [7].

Table 1. Chemical constituents of PKIA

Chemical Composition	Fe_2O_3	SiO_2	Al_2O_3	CaO	MgO	TiO	LIO	SiO_2+Al_2O_3+Fe_2O_3
PKIA	7.22	55.9	8.49	9.30	2.88	-	14.9	70.61

1.2. Concrete production

The materials used in this study are portable tap water for mixing and curing the concrete, Burham- an ASTM Type I Ordinary Portland Cement, crushed granite with particle size distribution in a range of 10-12mm and sharp river sand with particle size distribution in a range of 2-4mm having a fineness modulus of 2.4m^2/kg used as coarse and fine aggregate respectively. Their relative density on oven-dry basis in accordance to BS 812: Part 2 [8] was gotten as 2.72 and 2.65 while their corresponding water absorption values were 0.77% and 1.42% respectively. The Adva-cast trade name Superplasticizer (hydroxylated carboxylic (HC) acid) used in this study as shown in Figure 6 was added at the rate of 1% by mass of total binder content in the respective concrete mixes. In conformance to DOE [9] mix design, the control sample was targeted for a mean strength of 40MPa with 50 ± 10mm slump.

Figure 6. Powdery and solvent forms of Adva-cast hydroxylated carboxylic (HC) superplasticizer

A water-binder ratio of 0.40 on the introduction of superplasticizer to the mix was adopted maintaining a similar workability through the entire test. The PKIA concrete was prepared by replacing 50% by mass of OPC in the concrete with a mix ratio of 1:1.45:2.42. Details of the mix proportions for OPC and PKIA concrete are given in Table 2. The specimens were demoulded and cured by air and total submergence in a water bath for periods of 7, 14 and 28days respectively. To investigate the effect of curing condition on strength development, three curing schedules were initiated in this study namely; continuous submergence in water, 7days submergence plus air curing (7days submergence + air curing) and continuous air curing. Specifications in BS 1881: Part 110 [10] for preparation of cylindrical specimens of 150mm x 300mm dimensions was conformed to. An average laboratory temperature (T) of 25-27^{0}C and Relative Humidity (RH) of 60 ± 5% was maintained through the testing period.

Table 2. Constituent mix of OPC and PKIA concrete

Material (kg/m^3)	OPC	PKIA	Coarse Aggregate	Fine Aggregate	Water
OPC Concrete	420	-	1020	610	200
PKIA Concrete	210	210	1020	610	200

2. Test approach

The strength tests carried out in this study involved the determination of the splitting tensile and compressive strength tests over hydration periods of 7, 14 and 28days in accordance to BS 1881: Part 116 [11] and part 117 [12] respectively. The shrinkage of concrete in this study was measured using the cylindrical specimens after the initial 7days curing by submergence in water although, there are several other methods by which concrete shrinkage is measured based on sample sizes. Three specimens for each concrete mix were cast such that an average was taken to ensure consistency in results while the shrinkage strains were measured on four vertical gauge lines by flexible mechanical strain gauges spaced uniformly around the edge of the specimens and having a gauge length of 150mm. Readings from the strain gauge were recorded daily over a duration of 7days and once weekly afterwards.

3. Discussion of results

3.1. Tensile strength

The tensile strength of concrete was determined over the 7, 14 and 28days hydration periods. The conventional concrete is generally known to be weak in tension however; the study found the need to compare the tensile strengths of normal OPC concrete to that of PKIA concrete. A similar trend was observed for tensile strength development in both OPC normal concrete and the PKIA concrete as shown in Figure 7. The tensile strengths of OPC normal concrete were found to be 2.61, 2.77 and 3.34N/mm^2 which were higher than the PKIA concrete with values of 2.36, 2.43 and 2.98N/mm^2 over the different hydration periods respectively. Nevertheless, the general rate of early age strength gain was observed to be slow notwithstanding, there was increased strength development at later hydration periods.

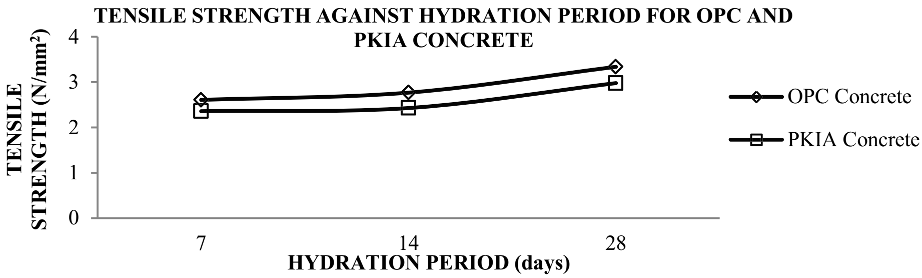

Figure 7. Tensile strength comparison between OPC and PKIA concrete

3.2. Effect of PKIA fineness on compressive strength of concrete

As in the case of conventional cement, the fineness of waste ash has been recorded to influence concrete strength development. Hence, this work investigated three different PKIA size fractions to determine their respective effects on compressive strength of concrete specimens crushed after 28days hydration period by complete submergence in water. From Figure 8, it can be seen that at 28days the concrete made with raw coarse PKIA had a strength of 17.9N/mm^2 whereas concrete made with fine ash (passing 45μm) had almost twice the strength i.e. 31.7 N/mm^2 over the same hydration period. This is a clear indication that the higher the PKIA fineness, the higher the strength expectancy. It is generally understood that hydration starts at the surface of the particles, and it is the total surface area that represent the material available for hydration. The higher development of strength in concrete with the fine PKIA was therefore due to a higher surface area of the particles in reaction which enhanced the pozzolanic activity thereby, leading to a strength increase.

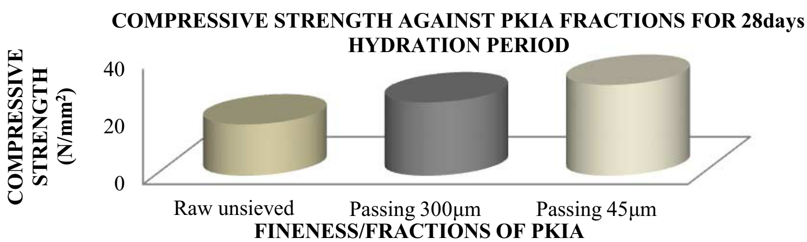

Figure 8. Effect of PKIA size fractions/fineness on compressive strength of concrete

3.3. Effect of hydration schedules on compressive strength of PKIA concrete

Results for the relative strength development of PKIA concrete based on the three different curing schedules is shown in Figure 9. Although the tests in this study was short-termed it however, clearly revealed differences in the curing sensitivity of concrete specimens. The strength values attained over the 7days water, water+air and air curing schedules had strengths of 23.5N/mm^2, 21.7N/mm^2 and 19.2N/mm^2 respectively; the continuous curing in water had the highest strength whereas, the air cured specimens attained the lowest strength. After the 28days of hydration for the respective curing schedules, a more definite trend in the compressive strength development was observed such that; the compressive strength of water cured PKIA concrete attained a strength value of 31.7N/mm^2.

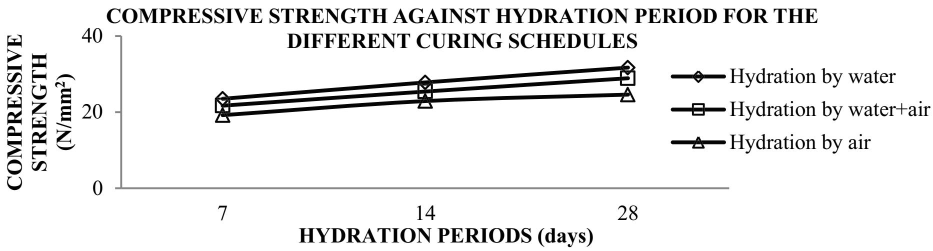

Figure 9. Effect of hydration schedule on the compressive strength of PKIA concrete

The samples cured for 7days in water and subsequently in air attained a strength value of 28.9N/mm^2 while a lowest value of 24.6N/mm^2 was recorded for samples cured in air alone. The lower strength from air curing alone can be accounted for since hydration of cement and pozzolanic concretes takes place in water filled capillaries and the RH in the laboratory could not offer sufficient moisture to enhance the pozzolanic reaction. It is therefore, due to this reason as reported by [13] that the strength development of concrete containing pozzolans is affected by short hydration periods when submerged in water as compared to OPC since pozzolans continually require moisture for strength development. Hence, the observations herein are concurrent with findings on other pozzolanic materials as reported by [14].

3.4. Effect of HC superplasticizer on compressive strength of PKIA concrete

The concrete specimens were prepared containing superplasticizer added at the rate of 1% by mass of total binder content. The resultant product was compared to the samples without admixture as well as with OPC concrete (control sample). Figure 10 shows the respective strength behaviours of OPC concrete, PKIA concrete with and without the hydroxylated carboxylic superplasticizer.

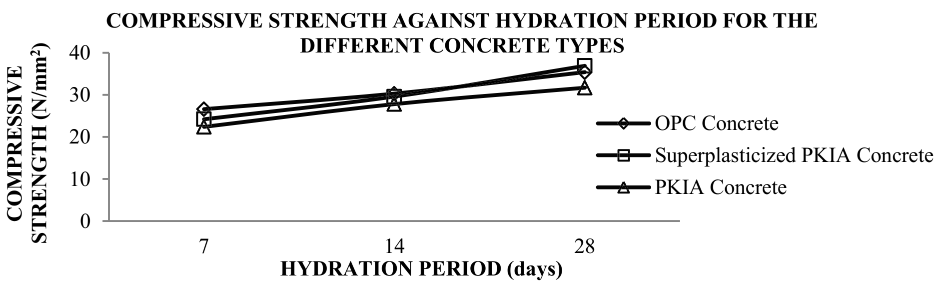

Figure 10. Effect of superplasticizer on the compressive strength development of PKIA concrete

From the comparison, it was evident that over the various hydration periods the superplasticizer had a positive effect on compressive strength development of PKIA concrete. A significant difference in the development of strength was noticed at later ages of curing however, the recorded difference in the rate of early age strength development was low. The measured compressive strength of PKIA concrete without the admixture at age 7, 14 and 28days were 22.4, 27.8, and 31.7N/mm^2 while corresponding values for the samples with superplasticizer were measured at 24.2, 29.6 and 36.9N/mm^2 respectively. Close values of 35.4 and 36.9N/mm^2 at 28days of hydration were measured for OPC concrete and the superplasticized PKIA concrete respectively. The pozzolanic reaction plus the reduced water content effect triggered by the hydroxylated carboxylic superplasticizer in the PKIA concrete mix explains the higher strength development over the PKIA concrete mix without superplasticizer. Similar observations in RHA, SF and FA concretes by [13,15,16] have been recorded such that; the use of superplasticizer is vital in concrete possessing high proportions of pozzolans.

3.5. Concrete shrinkage

The concrete shrinkage test carried out was recorded over a 28days period and the measured values are expressed in Figure 11. The test results show the shrinkage strain of PKIA to be higher than that of OPC normal concrete. The magnitude of shrinkage of PKIA concrete was gotten as 335×10^{-6} while that of OPC concrete was gotten to be 278×10^{-6} with a difference of about 20.5% lower than the shrinkage value measured for the PKIA concrete. Findings close to the one herein were reported by [17] who recorded 40% palm oil fuel as (POFA) to exhibit higher shrinkage values in drying condition.

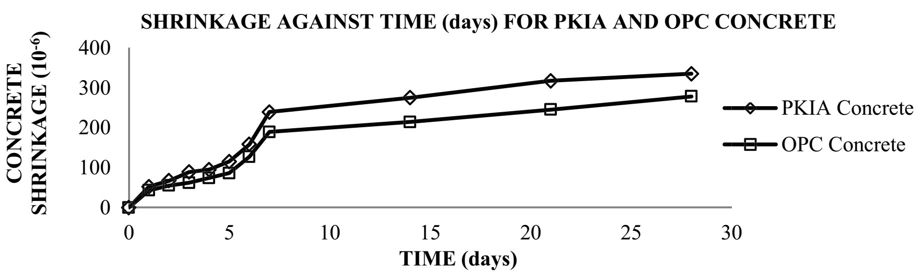

Figure 11. Shrinkage for PKIA and OPC concrete measured daily for 7days and weekly till 28days

The reason for a higher value according to [17] was due to the differences in the rate of moisture diffusion caused by the different porosity and pore size distribution. Observations made by [18] confirms the findings in this study such that [18] demonstrated that a constant water-cement ratio for high proportion of FA concrete resulted in a 20% higher shrinkage magnitude when compared to normal OPC concrete.

3.6. Concrete shrinkage prediction

The time dependent predictions of shrinkage strain development in concrete have been expressed by different equations amongst which, the equation generated by ACI 209R-92 [19] is mostly considered where structural or non-structural emphases are required. Although the equation is used to estimate ultimate shrinkage of wide ranges of water cured concretes, the prediction of concrete shrinkage using this equation is subjected to significant changes. An improvement in the accuracy of prediction of shrinkage was therefore made by [20] where long-term shrinkage values can be obtained by extrapolating the short-term 28day tests period. Eq. (1) was therefore applied to predict one-year shrinkage of PKIA and OPC concrete.

$$S_h\,(t,\,\tau_0) = S_{h,28} + 100[3.61\log_e(t - \tau_0) - 12.05]^{1/2} \quad (1)$$

Where; $S_h\,(t,\,\tau_0)$ = long-term concrete shrinkage (10^{-6}) at an age t, after dried at age τ_0

$S_{h,28}$ = shrinkage (10^{-6}) after 28days

$(t - \tau_0)$ = time difference since the start of drying must be greater than 28days (>28days)

Thus, the one-year values computed from the concrete shrinkage prediction using Eq. (1) are:

$S_{h,365}$ for PKIA concrete = 633×10^{-6},

$S_{h,365}$ for OPC concrete = 576×10^{-6}

The predicted magnitude of shrinkage for PKIA concrete was computed as 633×10^{-6} while that of OPC concrete was computed as 576×10^{-6} with a difference of about 9.9% lesser than the predicted shrinkage value for the PKIA concrete over a one-year period.

4. Conclusions

This study investigated the strength and shrinkage behaviours of concrete made by replacing 50% by mass of OPC with PKIA. The availability of PKIA generated by the processing of palm oil from milling boilers in West Africa paved way for the study of PKIA as a constituent in low cost concrete production. From results and analysis presented, the following conclusions were drawn;

- That the finer the ash, the higher the compressive strength of concrete due to the high surface area of the particles enhancing pozzolanic activity.
- The tensile and compressive strength of the 50%PKIA concrete were found to be lower than those of normal concrete. However, on the addition of superplasticizer, a significant improvement in compressive strength development due to the reduced water content triggered by the hydroxylated carboxylic superplasticizer in the PKIA concrete mix was recorded.
- The curing of PKIA concrete in water had a positive effect on the strength; the water curing schedule revealed the best result when compared to water+air and air alone.
- The shrinkage strain development values of PKIA concrete were higher than the values obtained for OPC concrete. However, from the extrapolated short-term test values a long-term concrete shrinkage effect was predicted.
- This paper finally demonstrated the use of PKIA as an option in transforming cheap and abundantly available agricultural waste into a useful end product which can be utilized in developing countries. As such, the green concrete product can be used in the construction of simple foundations and masonry walls with less structural complexities while further investigations are recommended to be carried out on the effect of prolonged curing of up to 120days on the concrete durability.

References

[1] Tay, J. H., Ash from oil-palm waste as concrete material, *Journal of Materials in Civil Engineering*, Vol. 2, No. 2, 1990, pp. 94-105.

[2] Nimityongskul, P. and Daladar, T.U., Use of coconut husk, corn cob and peanut shell as cement replacement, *Proceedings of the International Symposium on Urban Housing Issues on Environment and Technology*, Asian Institute of Technology, Thailand, 1993, pp.353-362.

[3] Salihuddin, R. S., Relationships between Engineering Properties and Microstructural Characteristics of Mortar Containing Agricultural Ash, *Ph.D. Thesis, Universiti Teknologi Malaysia*, 1993.

[4] Rashid, M. and Rozainee, M., Particulate emissions from a palm oil mill plant–a case study, *Journal Teknologi*, Universiti Teknologi Malaysia, Vol. 22, December, 1993, pp.19-24.

[5] Elinwa, A.U. and Mahmood, Y.A., Ash from Timber Waste as Cement Replacement Material, *Cement and Concrete Composites,* V. 24, No. 2, 2002, pp. 219-222.

[6] Awal, A.S.M.A. and Hussin, M.W., Some aspects of durability performances of concrete incorporating palm oil fuel ash, *Proceedings of the 5th International Conference on Structural Failure, Durability and Retrofitting*, Singapore, Nov. 1997, pp.210-218.

[7] American Society for Testing and Materials, Standard Specification for Fly Ash and Raw or Calcined Natural pozzolan for Use as a Mineral Admixture in Portland Cement Concrete, *Annual Book of ASTM Standards, ASTM C618-94a*, 1994.

[8] British Standards Institution, *Methods for Determination of Physical Properties*, BS 12: Part 2:1975.

[9] Teychenné, D C, Franklin, R E and Erntroy, H C. Design of normal concrete mixes. Department of the Environment. HMSO, 1997, Report 331, ISBN 9781860811722

[10] British Standards Institution, *Method for Making Test Cylinders from Fresh Concrete*, BS 1881: Part 110: 1983.

[11] British Standards Institution, *Method for Determination of Tensile Splitting Strength*, BS 1881: Part 117: 1983.

[12] British Standards Institution, *Method for Determination of Compressive Strength of Concrete Cubes*, BS 1881: Part 116: 1983.

[13] Neville, A.M., *Properties of Concrete*, Fourth Edition, Longman Group UK Ltd, 1995.

[14] Malhotra, V.M., Carette, G.G. and Sivasundaram, V., Role of silica fume in concrete: a review, *Advances in Concrete Technology, CANMET*, Ottawa, 1994, pp.925-991.

[15] Sirivatnanon, V., Cao, H.T., Khatri, R.P. and Bucea, L., *Guidelines for Use of High Volume Fly Ash Concretes, Technical Report 7R95/2*, Division of Building, Construction and Engineering, CSIRO Australia, 1995.

[16] Habeeb, G.A. and Mahmud, H.B., Experimental investigation on the mechanical properties of Grade 40 concrete incorporating rice husk ash (RHA), *Proceedings of the 7th Asia Pacific Structural Engineering and Construction Conference and 2nd European Asian Civil Engineering Forum*, Vol.2, August 2009, pp. 678-682.

[17] Ishida, T., Creep and Shrinkage of Palm Oil Fuel Ash Concrete, *M. Eng. Thesis, Universiti Teknologi Malaysia,* 1999.

[18] Brooks, J.J. and Neville, A.M., Creep and shrinkage of concrete as affected by admixtures and cement replacement materials, Creep and Shrinkage of Concrete: Effect of Materials and Environment, *ACI Publication SP-135*, 1992, pp. 19-36.

[19] American Concrete Institute, Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures, *ACI Manual of Concrete Practice*, Part 1: Materials and General Properties of Concrete, ACI 209R-92, 1994.

[20] Neville, A.M. and Brooks, J.J., *Concrete Technology*, Longman Group UK Ltd, 1987.