Journal of Agricultural Technology 2015 Vol. 12(4):619 -631
Available online http://www.ijat-aatsea.com
ISSN 1686-9141

A Study of Partial Replacement of Cement with Palm Oil Fuel Ash in Concrete Production

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Oyejobi, D. O., Abdulkadir, T. S. and Ahmed, A. T. (2016) A Study of Partial Replacement of Cement with Palm Oil Fuel Ash in Concrete Production Journal of Agricultural Technology 12(4):619-631.

Burning of agricultural wastes as a means of disposal contributes to environmental degradation and can be reduced by utilizing the materials for other purposes such as construction materials. Thus, the aim of this research is to study the cementitious properties of Palm Oil Fuel Ash (POFA) as partial cement replacement material in concrete. POFA was prepared and chemical properties of the ash produced were analysis. Then, concrete cubes were cast and tested at curing ages of 7, 21, and 28 days using 0, 10, 20 and 30 percent replacement levels. The slump test result showed that the workability of the concrete decreased as the POFA content increased. Results also showed that the compressive strength of POFA-concrete increased with curing age but decreased with increasing percentage of POFA compared to the compressive strength of the control. The density of the concrete produced was reducing as the percentage replacement was increasing thereby leading to the production of a lightweight concrete. For the control with 0% POFA, the compressive strength of 25.77N/mm^2 was obtained at 28 days and can be used for reinforced concrete with lightweight aggregate and reinforced concrete with normal aggregate. The optimum compressive strength of 23.77 N/mm^2 was obtained for10% replacement at 28 days of age with percentage strength to the control of 92.24%. While 20% and 30% replacement of cement with POFA yielded compressive strength of 20.67N/mm^2 and 15.36N/mm^2 respectively. The research showed that POFA has the potential of being used as a partial replacement of cement to produce lightweight, durable and cheap concrete. It also makes it possible to consume the waste produced as a result of palm oil production and thereby contributing to sustainability of our environment by reducing environmental pollution.

Keywords: POFA, compressive strength, concrete, pozzolans, partial replacement

1. Introduction

Nigeria is one of the countries in the equatorial belt that cultivate oil palm, others are Benin Republic, Colombia, Ecuador, Zaire, Malaysia and Indonesia. Malaysia is the largest producer of palm oil and its products surpassing the total palm oil produced in Africa (FAO-UN, 2013). Oil palm is one of the important economic crops in the tropical regions of Nigeria. In year 2013, Nigeria

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produced a total of 930 metric ton of palm oil at a growth rate of 2.20 % per annum (USDA, 2014). Its major products are palm fruits processed to obtain three commercial products which include palm oil, palm kernel oil and palm kernel cake. Empty fruit bunch, palm kernel and palm fruit fiber are solid by-products from the production of palm oil. These are usually used as a fuel for boilers in palm oil mills, blacksmith factories and as substitute or supplements for firewood in cooking locally. The aforementioned activities produce large amounts of ash annually as wastes called Palm Oil Fuel Ash (POFA). This waste is obtained from controlled burning of palm oil by-products. On the average, a palm oil mill requires approximately 5.5 tons of fresh fruit bunches to extract 1.0 ton of crude palm oil. The waste products generated are empty fruit bunches (28%), fibers (24%), shell (6%), decanter cake (3%) and palm oil mill effluent (itfnet.org, 2014). Oil palm decanter cake (OPDC) is solid wastes produced after the clarification process to retrieve oil from sludge. In many developing nations, waste management poses a great challenges and threat to survival of both fauna and flora and also cause environmental degradation. A good solution to these problems is by recycling agro-industrial residues by burning them in a controlled environment and use the ashes (waste) generated for more noble means (Ghavami *et al.*, 1999). Utilization of such wastes as cement replacement materials may reduce the cost of concrete production and also minimize the negative environmental effects with disposal of these wastes (Abdulkadir *et al.*, 2014). According to Sirirat and Supaporn (2010), the calcium hydroxide (unfavorable product from the cement hydration) released during the hydration of ordinary portland cement (OPC) reacts with silica present in the pozzolans and water to form additional calcium silicate hydrate which is responsible for the compressive strength in concrete. A pozzolana is a siliceous and aluminous materials which has little or no cementitious values but in finely divided form and in presence of moisture chemically react with calcium hydroxide liberated during the hydration of Portland cement to produce stable, insoluble cementitious compounds which contributes to its strength and impermeability (Karim *et al.*, 2011)

As a usual practice, ashes (POFA) generated are simply disposed of without any commercial return and constitutes environmental nuisance as they form refuse heaps. However, it has been identified that POFA has good pozzolanic properties that can be used as a cement substitute in mortar and concrete mixes (Abdul and Nguong, 2010). Many researchers attributed the improvements in POFA mortar and concrete behavior to the pozzolanic reactions where the hydration products of mortar or concrete react with the silica contained in POFA. Concrete produced from partial replacement of cement with POFA has reaction by silicate, SiO_2 from POFA and slaked lime, $Ca(OH)_2$ from cement to form calcium silicate hydrate which is responsible for the compressive strength. Although the quality of concrete produced from POFA beyond an optimum quantity of POFA will leach out silicate which does not improve the strength of concrete (Karim *et al.*, 2011). In previous studies, efforts have been made to increase the use of pozzolans to partially replace cement. Some of the pozzolans investigated are sugarcane bagasse ash, rice husk ash, palm kernel husk ash, fly ash, ground blast furnace slag, silica fume, etc.

Oyejobi *et al.* (2014) reported some of the advantages of using pozzolans in concrete to include improvement in workability of concrete at low replacement levels and with low carbon content, reduced bleeding and segregation, low heat of hydration, lower creep and shrinkage, high resistance to chemical attack at later ages (due to lower permeability and less calcium hydroxide available for reaction) and low diffusion rate of chloride ions resulting in a higher resistance to corrosion of steel reinforcement in concrete. Bamaga (2013) reported that the chemical analysis of a POFA collected from palm oil mills in Malaysia yielded 59.60% Silicon dioxide (SiO_2) with 7.64% of potassium oxide (K_2O), along with other minor oxides. The sum of percentages of SiO_2, Al_2O_3 and Fe_2O_3 which forms the major oxides was 75.43%. Thus, classifying the POFA as pozzolan in accordance with American Standard for Testing and Materials (1978) that specified 70% minimum for the sum of these oxides. As a result of increasing cost of concrete production and environmental challenge posed by POFA disposal, this study investigates the suitability of POFA from a local mill in Agba-Ebira village along Ilorin-Lokoja road, Nigeria, as a partial replacement for cement in concrete production.

2. Materials and Methodology

The materials used in this work are palm oil waste (empty fruit bunches, palm kernel shells and fruit fiber), Ordinary Portland Cement (OPC), aggregates (fine and coarse) using BS (1992) and water using BS (2002). Elephant cement which belongs to Ordinary Portland Cement family was used using BS (2000). Fine and coarse aggregate were sourced from a construction site in the university of Ilorin premises

2.1 Preparation of POFA

Palm oil fuel wastes were obtained from a local palm oil mill situated in Agba-Ebira village, along Ilorin-Lokoja road consisting of palm kernel shells, empty fruit bunches and fruit fibres in dry state. The Palm oil waste was burnt at a temperature of 700°C using a controlled blast furnace for about 4 hours. The burning was done at the fabrication workshop of Mechanical Engineering

Department, Institute of Technology, Kwara State Polytechnic, Ilorin, Nigeria. The burnt ash was grinded using mortar and pestle and was sieved using 0.09mm sieve. Chemical analysis of the processed POFA was carried out at the Chemistry laboratory, Department of Chemistry, University of Ilorin, Ilorin, Nigeria (using Atomic Absorption Spectrophotometer) to determine the chemical composition of the ash. Physical tests such as water absorption capacity, particle size distribution, specific gravity, moisture content, fineness test were carried out on the aggregates and the ashes for concrete production. Also, the design mix ratio for the concrete casting was evaluated. This was used to cast 100mm x 100mm x 100mm concrete cubes at different POFA replacement levels i.e. 0%, 10%, 20% and 30%. The cubes were cured for 7, 21 and 28 days at the room temperature of (27 ± 2) ^{o}C. The corresponding compressive strengths were determined using a compressive strength testing machine. The densities of the concrete for different POFA replacement levels were also determined.

3. Results and discussion

3.1 Physical Properties of aggregates and POFA

The physical properties of the fine aggregates, coarse aggregate and POFA were examined. All these were used in designing the mixing ratio for the concrete work which will lead to the production of concrete with target strength. The tests were carried out in accordance with codes for testing of aggregates as in BS 812: Part 2, 1995. The average water absorption capacities for coarse and fine aggregates were estimated to be 9.4% and 0.55% respectively. While the average moisture content were 0.23% and 0.41% respectively. The average specific gravities for fine, coarse and POFA are 2.56, 2.68 and 2.02 respectively. The fineness level of OPC and POFA was obtained as 0.5% and 1% respectively. Considering the results of physical test, the design mix for the aggregates was evaluated using DOE method and was obtained as 1: 2.04: 2.7 for characteristic strength of 20N/mm^2 at 28 days. The target mean strength was estimated to be 26.56M/mm^2. The batching was done by volume due to lightweight of POFA. The estimate of the quantity of materials required for the production of concrete cubes for different POFA replacement levels and mix proportion of the constituents is as shown in Table 1.

Table 1: Estimate of the Quantity of Materials Concrete Cubes

% Replacement	Ash (kg)	Cement (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Water (kg)	Quantity (Unit)	W/C Ratio
0	0	3.420	6.966	9.234	1.88	9	0.5
10	0.342	3.078	6.966	9.234	1.88	9	0.5
20	0.684	2.736	6.966	9.234	1.88	9	0.5
30	1.026	2.394	6.966	9.234	1.88	9	0.5

3.2 Particle size distribution

The particle size distribution is the analysis of soil samples which involves the determination of the percentage by mass of particles within the different size ranges. The particle size distribution of coarse and fine aggregates used was determined by the method of sieving. 1000g and 3000g of oven dried samples of fine and coarse aggregates respectively were passed through series of standard test sieves having successively smaller mesh sizes. The mass of sample retained in each sieve was determined and the cumulative percentage by mass passing each sieve was calculated. This was used in analyzing uniformity and gradation of samples. Particle size distribution curve of fine and coarse aggregates are shown in Figures 1 and 2. The effective size of particle size distribution (PSD) at 10% (D_{10}), 30% (D_{30}) and 60% (D_{60}) percentage passing are 0.18%, 0.46% and 0.78% respectively for fine aggregates. Similarly, the effective size at 10% (D_{10}), 30% (D_{30}) and 60% (D_{60}) percentage passing are 8.75%, 12.00% and 15.80% respectively for coarse aggregates. Coefficient of uniformity, C_u and coefficient of curvature, C_c for fine and coarse aggregates were estimated to be 4.33 and 1.51 for fine, and 1.81 and 1.04 for coarse aggregates respectively. These results revealed that the aggregates satisfied ASHTTO classification of $Cu>4$ and $1<Cc<3$ for the aggregates.

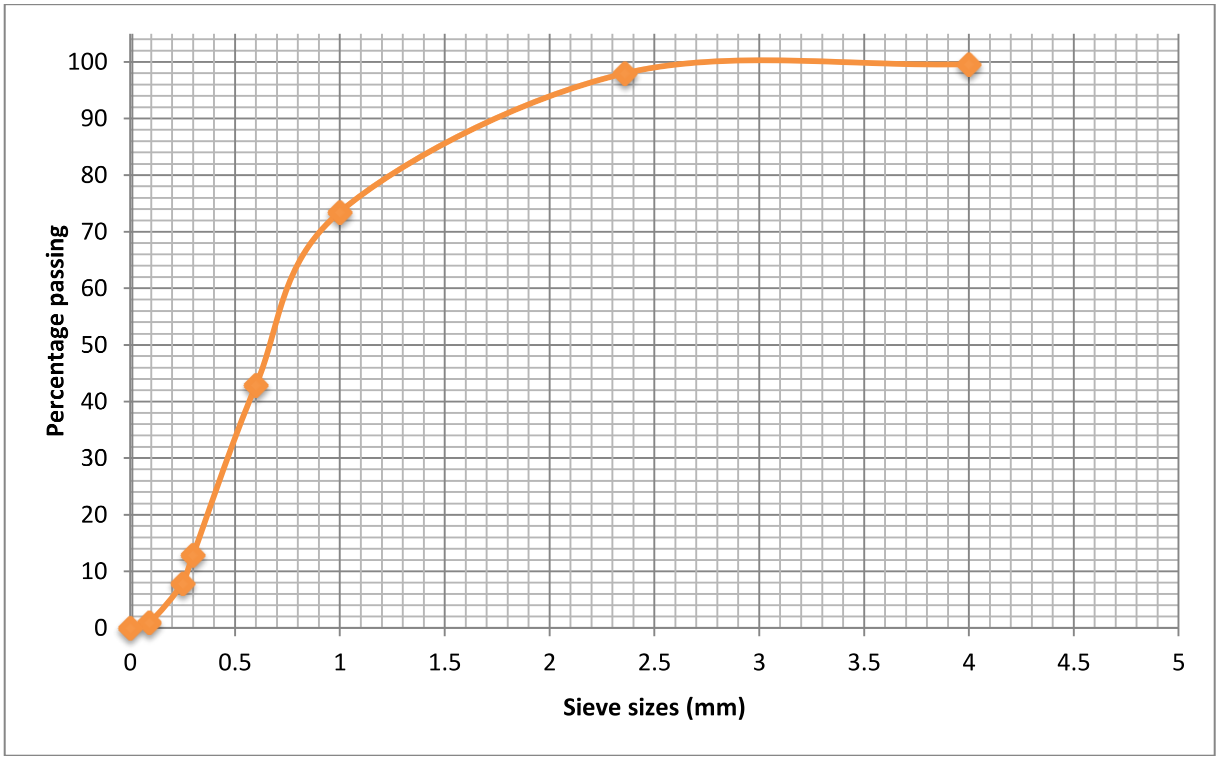

Figure 1: Particle size distributions curve for fine aggregate

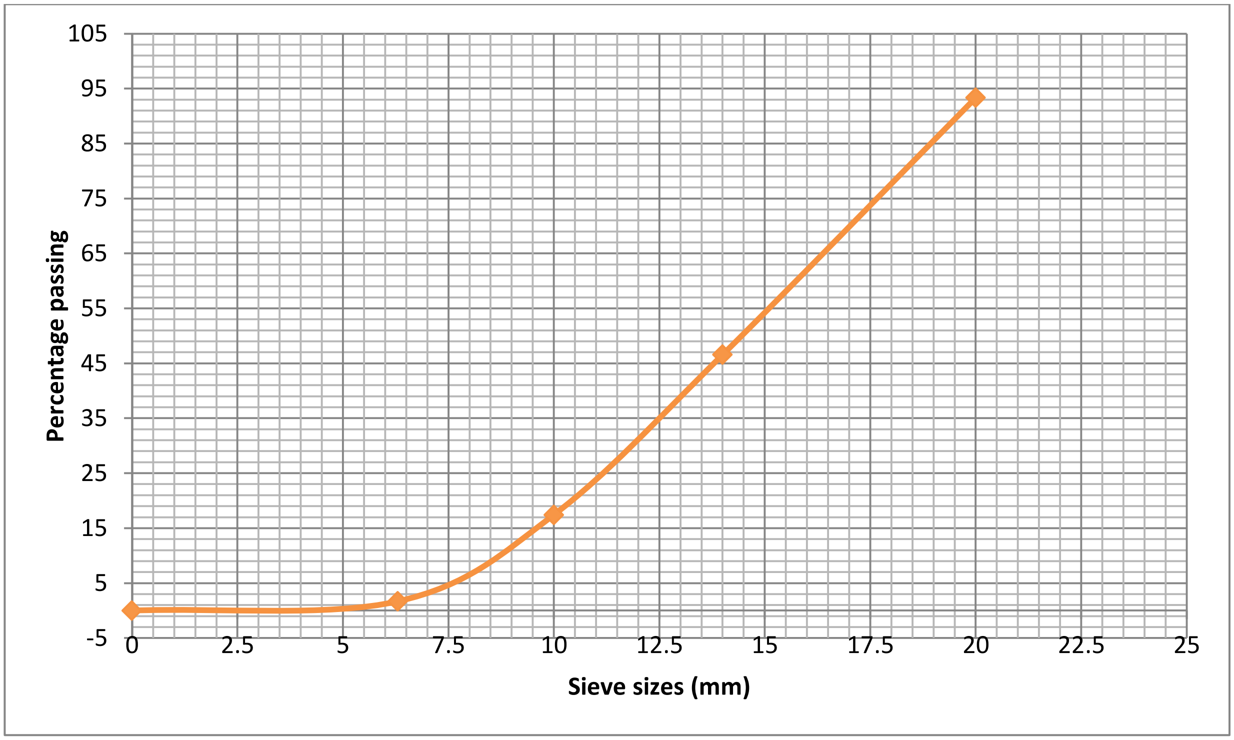

Figure 2: Particle size distributions curve for the coarse aggregate.

From the results gotten the coefficient of uniformity is less than the specified values for well graded soil, but the coefficient of curvature is in line with the condition for a well graded soil, therefore the coarse aggregate is uniformly graded. Also, the coarse aggregate has a flaky shape

3.3 Chemical Analysis of RHA

The results of the chemical analysis carried out on the processed POFA are presented in Table 2. The total sum of the percentages of SiO_2, Al_2O_3 and Fe_2O_3 in the processed POFA was 77.60%. This satisfied the minimum percentage requirement of 70% according to ASTM C618 (1978) for any pozzolanic materials. The silica will enable the concrete to have good strength and durability while the alumina will make the concrete to be corrosion resistant as well as impacting quick setting quality to the concrete. In addition to assisting in color, hardness and strength, iron oxide also helps in the fusion of raw materials during cement production.

Table 2: Chemical analysis of POFA Parameters

Oxides present	% of oxides
Silica (SiO_2)	53.52
Aluminum Oxide (Al_2O_3)	11.40
Ferrous Oxide (Fe_2O_3)	12.68
Calcium Oxide (CaO)	4.62
Magnesium Oxide (MgO)	3.28
Sodium Oxide (Na_2O)	1.56
Potassium Oxide (K_2O)	3.08
Lead Oxide (PbO)	0.18
Copper Oxide (CuO)	1.08
Loss On Ignition (LOI)	4.83

3.4 Mechanical tests on the concrete

3.4.1 Slump test

The result of workability of concrete (slump test) for 0%, 10%, 20% and 30% replacement of POFA are shown in the Figure 4. This showed that the height of the slump is reducing as the percentage replacement with POFA is increasing. The workability of fresh POFA concrete measured by the slump test reduces as the POFA content increases. This is due to the fact that POFA absorbs more water to form a paste of standard consistency than cement.

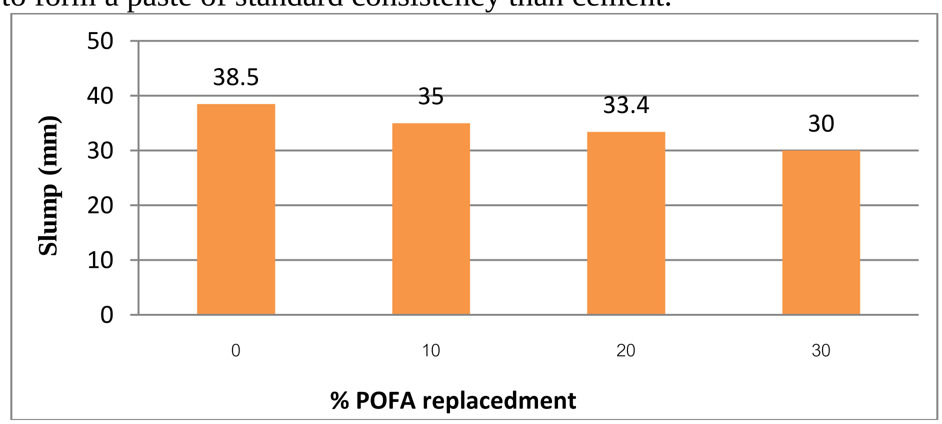

Figure 4: Slump test

3.4.2 Mean compressive strength of POFA concrete

For different concrete cubes produced with various percentage replacement of cement with POFA, compressive strengths and densities were measured at different ages of curing and the average computed. Figures 5 showed variation of compressive strength for the various percentage replacement of POFA at different curing age. Figure 5 showed variation of average densities for different percentage of POFA replacement while Figure 6 showed that the compressive strengths of the concrete are increasing as the curing age increases. Consequently, compressive strengths of the concrete are reducing as the percentage of POFA replacements are increasing in Figure 6. The compressive strength of 10%, 20% and 30% replacement are 92.24%, 80.21%, 59.60% of that of the control at 28th day of curing respectively. The compressive strength were not up to the target mean strength designed for the concrete, this may be as a result of some factors like method of mixing (hand mixing), compaction and additional water added to make the concrete workable.

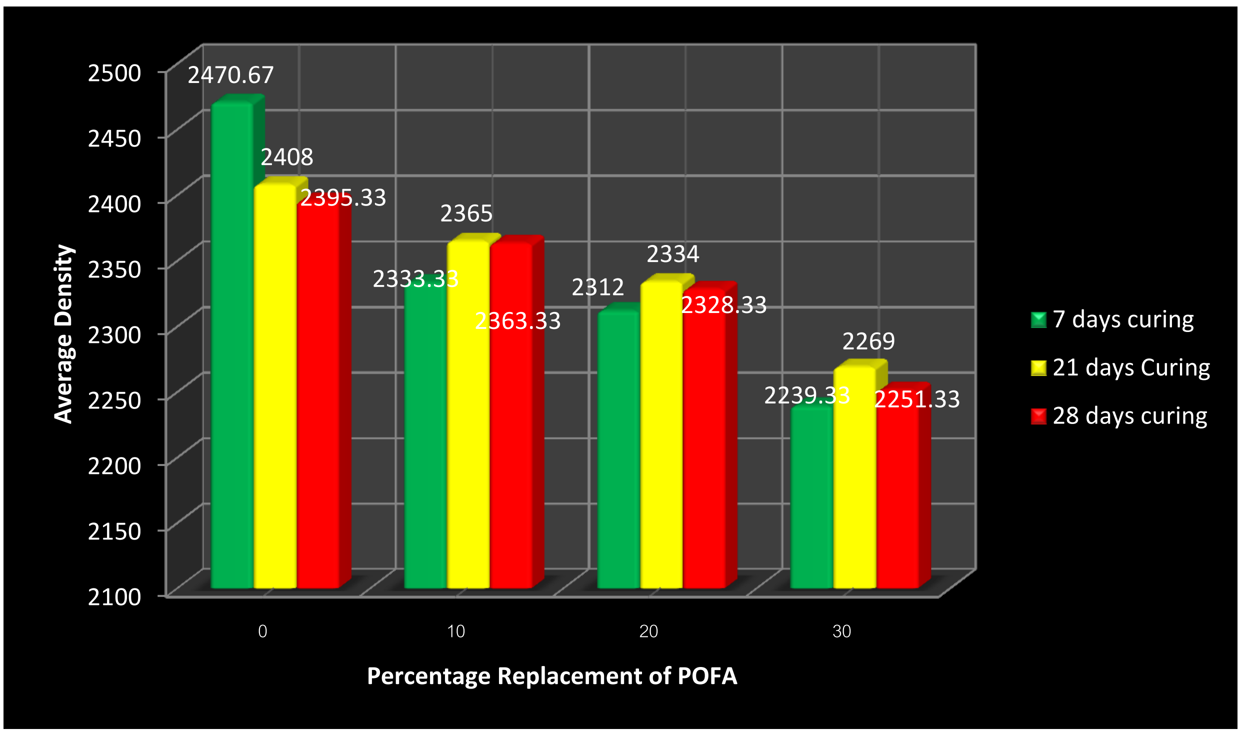

Figure 5: Chart showing the densities for different percentage replacement

Figure 5 showed that the concrete cubes produced can be classified as lightweight concrete because their density is below the range of the density for heavy concrete which is between 3360kg/m^3 and 3840kg/m^3. Lightweight concretes can be produced with an over-dry density range of approximately 300 to a maximum of 2000 kg/m^3, with corresponding cube strengths from approximately 1 to over 60 MPa (Newman and Seng, 2003). However, the density is a little bit larger than the specified density for light weight concrete but it is far lesser than the specification for heavy weight concrete, so it can be classified as light weight concrete. Also, as the percentage replacement of OPC with POFA is increasing, the weights of the concrete cubes were reducing leading to a reduction in their densities.

BS (1985) specifies the minimum strengths for plain concrete as 7N/mm^2, 15N/mm^2 for reinforced concrete with lightweight aggregate, 20N/mm^2 for reinforced concrete with normal aggregate, 30N/mm^2 for post-tensioned concrete and 40N/mm^2 for pre-tensioned concrete. The POFA-concrete produced with 10% and 20% replacement can therefore be used for reinforced concrete with normal aggregate while that of 30% replacement is useful for reinforced concrete with lightweight aggregate.

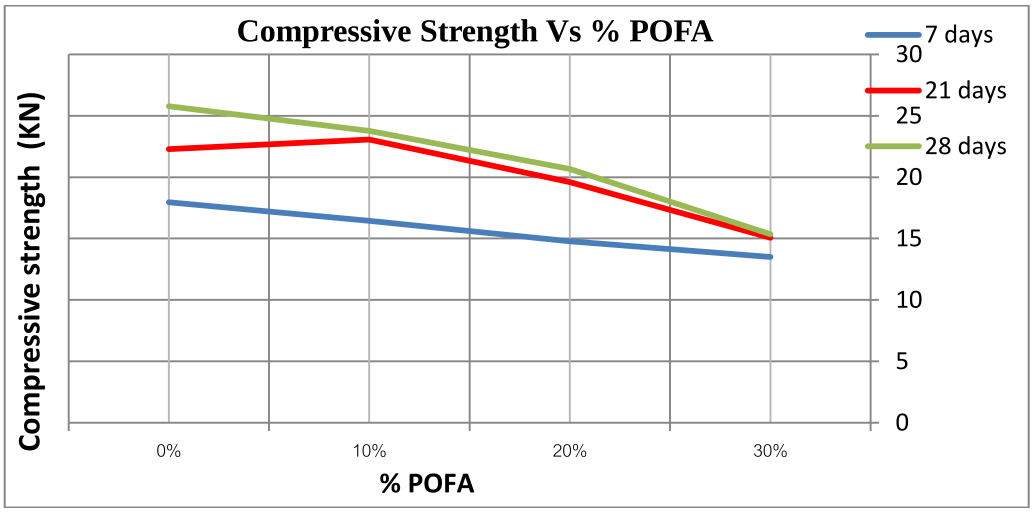

Figure 6: Compressive strength for various %replacement of POFA at different age

The densities for the different percentage of replacement of cement with POFA at different ages of curing are as shown in Figure 7. This Figure showed that the densities of the POFA concrete fell into the range of 2239.33 - 2395.33 kg/m^3 at 28th day curing. Lightweight concretes can be produced with an oven-dry density range of approximately 300 to a maximum of 2000 kg/m^3 and the density for a normal concrete is 2240 to 2400 kg/m^3.With these conditions, concrete produced can be classified as normal weight concrete. Also, the density of the concrete reduces as the percentage replacement of OPC with POFA increases. This is due to reduction in weights of the concrete cubes.

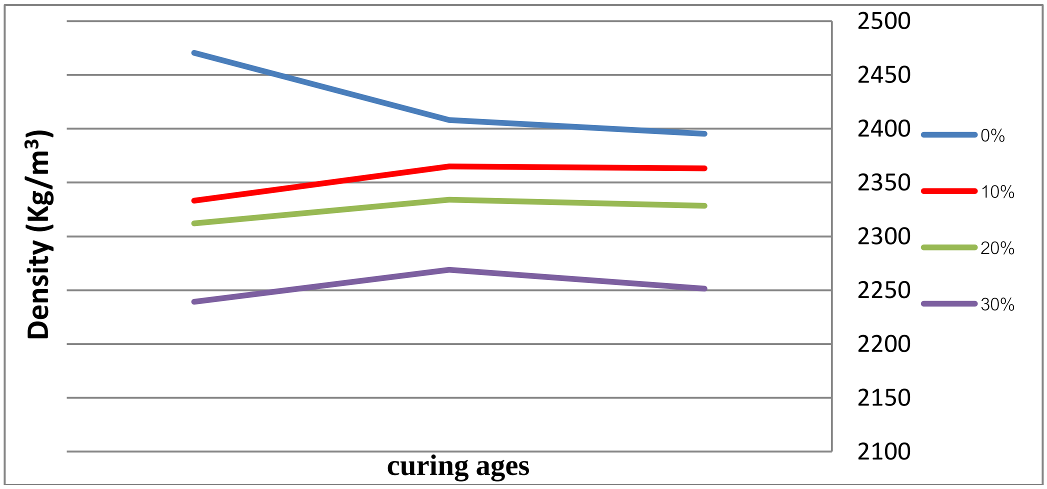

Figure 7: Graph of densities for the different percentage of replacement and curing ages

4. Conclusion

From the analysis, it can be concluded that the calculated target mean strength of 26.56N/mm^2 was not achieved. This may be as a result of some factors like mode of mixing (hand mixing), compaction and the reactivity of the palm oil fuel ash (POFA). The compressive strength of the concrete cubes was observed to be increasing with increase in the curing age but decreases as the POFA content increases. The percentage reduction of compressive strength for 10%, 20% and 30% replacement of cement with POFA compared with control were 7.76%, 19.79% and 40.40% respectively.

Compressive strengths of 0%, 10%, and 20% POFA are 25.77N/mm^2, 23.77N/mm^2 and 20.67N/mm^2 respectively. They all satisfied the minimum strength required for reinforced concrete with normal aggregate and they can be used for this type of concrete. For 30% replacement of cement with POFA, the compressive strength was 15.36N/mm^2 and this can be used for reinforced concrete with lightweight aggregates. From the density result, the percentage reduction in density for 10%, 20% and 30% replacement of cement with POFA are 1.34%, 2.78% and 6.01% respectively, thus, POFA concrete can be classified as normal weight concrete. The workability of fresh POFA concrete measured by the slump test reduces as the POFA content increases. Therefore, it was clearly shown that POFA is a pozzolanic material that has the potential to be used as partial cement replacement material and can contribute to the sustainability of the construction materials.

5. Recommendations

It is recommended for use as partial replacement for cement in concrete production at a percentage up to 30%. There will be an appreciable fall in the compressive strength value for percentage beyond this level. For environmental sustainability, POFA can be utilized for the production of lightweight, durable and cheap concrete because of it availability in significant quantities across the country considering the fact that every household in Nigeria consumes palm oil and its products.

Chemical and limited mechanical analysis had been carried out in this study, there is a need for extensive studies on mechanical properties; tensile strength of POFA concrete; freezing and thawing resistance; de-icing salt scaling resistance, also the corrosion resistance and abrasion resistance of POFA concrete.

Acknowledgment

The authors acknowledged the management of Departments of Civil Engineering and Chemistry, University of Ilorin, Ilorin Nigeria and the Department of Mechanical Engineering, Institute of Technology, Kwara State Polytechnic, Ilorin, Nigeria for providing technical supports and other useful information for the studies.

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(Received: 29 September 2015, accepted: 2 July 2016)