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Assessment of Partial Replacement of Cement with Oil Palm Fiber Ash (OPFA) in Concrete Production

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Abstract: *Sustainability of cement consumption provides opportunity to research into possibility of alternative and locally sourced cementitious material like oil palm fiber ash (OPFA) considered for this research investigation. The study aims at evaluating the characteristic properties of OPFA as a partial replacement for cement in concrete. The oil palm ash was prepared through controlled incineration and tests carried out to ascertain the pozzolanic property. OPFA were included at 0%, 5%, 10%, 15% and 20%, replacement by weight of cement in concrete mixtures (with design ratio of 1 : 1½ : 3 (cementitous : sand : granite). Slump test was used to establish the workability properties of fresh concrete and the cast concrete cubes were cured by exposure to air and immersion in water before subjected to compressive strength test. The slump showed that workability of OPFA concrete decreases as OPFA content increases, indicating that the inclusion demands more water content than normal cement concrete. Compressive strength of OPFA-concrete was observed to increase with curing age and decrease with increasing percentage of OPFA, and the optimum compressive strength of 20.49 N/mm2 was obtained at 5% replacement level at 28 days curing, also the split tensile strength results was low expressing the low tensile bonds in concrete formation. The regression analysis of compressive strength for both air and water cured specimen employs a model of the type σ = a Ln(t) + b, where a and b are regression parameters, the model results provide good comparison with experimental values with 95% reliability. The study concluded that OPFA has the potential of being used as partial replacement of cement up to 10% replacement level and higher percentage can be employed in lightweight, cost-effective and low strength concrete .*

***KEYWORDS*:** Cementitous, OPFA, Compressive strength, Concrete cubes, Curing days

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1. INTRODUCTION

Palm oil is obtained from palm fruits, however the empty fruit bunch, palm kernel and palm fruit fiber are usually treated as waste, and are usually used as a fuel for boilers in palm oil mills, blacksmith factories and as substitute or supplements for firewood in cooking locally. These activities produce quite amounts of ash as wastes known as Oil Palm Fiber Ash (OPFA). Waste management poses a great challenge in Nigeria, causing significant environmental degradation which in turn can lead to severe environmental disaster. 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). Therefore, utilizing such wastes as partial replacement of cement could assist in reengineering process of this type of waste and also possibly reduce the cost of concrete production. It has been identified that OPFA 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 OPFA mortar and concrete behavior to the pozzolanic reactions where the hydration products of mortar or concrete react with the silica contained in OPFA. Concrete produced from partial replacement of cement with OPFA has reaction by silicate, SiO2 from OPFA 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 OPFA beyond an optimum quantity of OPFA will leach out silicate which does not improve the strength of concrete (Karim *et al.,* 2011). 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.

II. MATERIALS AND METHODOLOGY

The materials used in this study includes oil palm fiber ash (OPFA),**limestone Portland cement**) (eg, Dangote cement), the cement is known to achieve **good compressive and tensile strength** after 28 days of curing, and has a fineness value of around 300 to 400 m²/kg, that ensures efficient hydration and strength development in concrete mixes.

The aggregates used complies with BS-1992 and BS 2002 respectively, Sand used was sourced from the Ogun river bed for its low chloride content. Fine aggregates from that source (Mafimisobim 2024 and Okeyode & Jibiri (2012), commonly exhibit properties such as particle size distribution with a maximum particle size typically around 5 mm, specific gravity ranging from 2.5 to 2.8, absorption capacity of 1-3%, and a fineness modulus ranging from 2.5 to 3.2, influencing the quality and performance of concrete mixes. Common types of coarse aggregates found within Lagos axis, includes gravel (with sizes ranging from 5 mm to 20 mm), crushed stone (typically with angular edges and varying sizes), granite aggregates known for their durability, Granite was selected as the coarse aggregate for this study.

A. Preparation of OPFA

The fiber ash used in this study was obtained from Okitipupa Oil palm Plc. (OOP), an oil palm estates situated at southern Ondo state consisting of palm kernel shells, empty fruit bunches and fruit fibers 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 burnt ash was grinded using mechanical grinder and was sieved using 0.09mm sieve. These aforementioned processes were carried out in University of Lagos concrete and soil laboratory. Chemical analysis of the processed OPFA was carried out at the Chemistry laboratory, Department of Chemistry, University of Lagos, Nigeria to determine the chemical composition of the ash using Atomic Absorption Spectrophotometer. Physical tests such as particle size distribution, moisture content, specific gravity, water absorption capacity, fineness test were carried out on the aggregates and the ashes for concrete production. Also, the design mix ratio was 1 : 1½ : 3. used in casting the 100mm x 100mm x 100mm concrete cubes at different OPFA replacement levels i.e. 0%, 10%, 20% and 30%. The cubes were cured for 7, 14, 21 and 28 days at the room temperature $(27 \pm 2)\,^{o}C$ (air cured). and by immersion in water. The corresponding compressive strengths were determined using a compressive strength testing machine.

III. RESULT AND DISCUSSIONS

A. Physical Properties of aggregates and OPFA

Physical properties of aggregates and oil palm fiber ash (OPFA) are crucial in understanding the potential applications as alternate material to cement in concrete. The key physical properties include gradation, specific gravity, density, porosity, texture, strength and durability, which were used in designing the mix ratio for the concrete work in accordance with codes for testing of aggregates as in BS 812: Part 2, 1995.

B. Particle size distribution

Particle size distribution (PSD) refers to the proportion of particles within a specific size range in a material. It affects workability and flow ability as well as influences strength and durability. Also it impacts porosity, permeability, mixture composition and compability. Coefficient of uniformity, Cu and coefficient of curvature, Cc 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.

C. Chemical Analysis

Chemical analysis was performed on the OPFA to determine its composition and characteristics properties, and also to establish the potential as alternative to cement in concrete production.

Table 3.1: Chemical Analysis of OPFA

Chemical analysis of OPFA 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

Table 3.1 is chemical analysis of OPFA and percentages of SiO_2, Al_2O_3 and Fe_2O_3 in processed OPFA was 77.60%, which is within the minimum percentage requirement of 70% according to ASTM C618 (1978) for Pozzolanic materials. Pozzolans are siliceous and aluminous material (Becerra and Rijas, 2022), that possess little or no cementitous value but in the presence of water and in finely ground form, reacts with calcium hydroxide to form compounds with cementing properties.

D. Test on fresh and hardened OPFA-cement concrete

i. Workability test on fresh concrete

Slump test was used for the assessment of workability of concrete mixture, and fresh concrete consistency and fluidity are expressed as measurement of slump. The slump test was carried out with reference to the procedures in ASTM C143/C143M-03.

Table 3.2: Slump Test on OPFA concrete

Type of mix	Slump (mm)
Normal mix (Control mix)	55
Special mix 1 (5% replacement)	49
Special mix 2 (10% replacement)	45
Special mix 3 (15% replacement)	40
Special mix 4 (20% replacement)	34

OPFA-Cement concrete has slump value decreasing consistently (Table 3.2) with increase in OPFA content, from 55mm at 0% OPFA content to 34mm at 20% replacement level. The result shows that w/c ratio with respect to mixing water requirement is not constant with increase addition of OPFA, which are within specified standard for fresh concrete mixtures (ASTM C143)

ii. Concrete compressive strength test

Compressive strength is an important concrete characteristics property used in design of structural components, and defined as the magnitude of compressive force that can be applied to concrete component before failure at ultimate limits

Average compressive strength = Average Compressive load/Area ie, $\sigma = F/A$ (N/mm^2)

Table 3.3: Compressive Strength of Air cured concrete

Curing Days	0% N/mm^2	5% N/mm^2	10% N/mm^2	!5% N/mm^2	20% N/mm^2
7 days	20.39	18.01	18.07	11.56	9.24
14 days	19.68	17.72	18.37	12.03	10.01
21 days	22.52	19.41	19.04	13.69	10.25
28 days	21.26	20.49	19.26	12.39	11.29

Table 3.3 provide in compressive strength laboratory results of air cured OPFA concrete, and maximum value occurred at 5% OPFA content (20.49N/mm^2 at 28 days) which is lower than control (0% OPFA) 28 days value equals 21.26N/mm^2 , similarly results of 20% OPFA content was very low expressing low pozzolanic reaction because of the high content of OPFA

Table 3.4: Compressive Strength of water cured concrete

Curing Days	0% N/mm^2	5% N/mm^2	10% N/mm^2	!5% N/mm^2	20% N/mm^2
7 days	17.6	17.07	16.09	11.08	8.95
14 days	20.86	18.41	16.67	12.62	10.06
21 days	20.22	15.41	17.80	12.61	11.70
28 days	20.89	19.73	19.51	12.80	11.61

Behavior of water cured specimen (table 3.4) was similar to air cured specimen with maximum 19.73 N/mm^2 and lower than air cured specimen also the control maximum was 20.89 N/mm^2. It was observed that curing OPFA specimen in air provided a better result than water curing specimen, thus water curing enhances water absorption into the component which reduces the compressive strength

iii. Regression Model and Analysis of Compressine Strength Results

Regression Analysis of compressive strength results for both air and water cured OPFA-Cement Concrete specimen using regression model of trpe $\sigma = a \, Ln(t) + b$ where a and b are the regression parameters

Table 3.5: Regression Model Equation

% OPFA	Model equation
0 % (Air cured)	σ = 1.138 Ln(t) + 17.842
5 % (Air cured)	σ = 1.773 Ln(t) + 14.94
10 % (Air cured)	σ = 0.893 Ln(t) + 16.23
15 % (Air cured)	σ = 1.006 Ln(t) + 9.659
20 % (Air cured)	σ = 1.330 Ln(t) + 6.552
0 % (water cured)	σ = 2.225 Ln(t) + 13.79
5 % (water cured)	σ = 0.861 Ln(t) + 15.29
10 % (water cured)	σ = 2.292 Ln(t) + 11.23
15 % (water cured)	σ = 1.224 Ln(t) + 8.923
20 % (water cured)	σ = 2.12 Ln(t) + 4.746

Table 3.6: Compressive strength of Air cured Regression Analysis

Curing Days	0% N/mm^2	5% N/mm^2	10% N/mm^2	!5% N/mm^2	20% N/mm^2
7 days	20.06	18.39	17.97	11.62	9.14
14 days	20.85	19.62	18.59	12.31	10.06
21 days	21.31	20.34	18.95	12.72	10.60
28 days	21.63	20.85	19.21	13.01	19.98

Table 3.7: Compressive strength of water cured Regression Analysis

Curing Days	0% N/mm^2	5% N/mm^2	10% N/mm^2	!5% N/mm^2	20% N/mm^2
7 days	18.12	16.97	15.69	11.31	8.87
14 days	19.66	17.56	17.28	12.15	10.34
21 days	20.57	17.91	18.21	12.65	11.20
28 days	21.21	18.16	18.87	13.00	11.80

Table 3.6 and table 3.7 are values of compressive strength determined from the regression model equations for each replacement level. The values gave a good comparison to the laboratory results, indicating reliability of the model with about 95% confidence, and can therefore be applied to predict compressive strength within the curing period of 28 days since concrete at 28 days has attain sufficient strength for load bearing activities

iv. Split Tensile Strength Test

Tensile strength is the maximum force required for a material to fracture when subjected to tension or tensile forces.

Table 3.8 Split tensile result of Air Cured Concrete

Curing days	0% N/mm^2	5% N/mm^2	10% N/mm^2	!5% N/mm^2	20% N/mm^2
7 days	5.46	5.38	5.42	5.33	5.11
14 days	5.42	5.38	5.47	5.38	5.33
21 days	5.78	5.60	5.51	5.51	5.42
28 days	6.00	5.78	5.69	5.73	5.60

Table 3.9 Split tensile result of water Cured Concrete

Curing days	0% N/mm^2	5% N/mm^2	10% N/mm^2	!5% N/mm^2	20% N/mm^2
7 days	5.73	5.60	5.64	5.56	5.56
14 days	5.96	5.60	5.69	5.51	5.51
21 days	6.13	5.82	5.91	5.87	5.64
28 days	6.53	6.13	6.18	6.09	5.96

Concrete characteristics generally defined its tensile ability has very low because of low tensile bonds during concrete formation, tables 3.8 and 3.9 confirms the low tensile strength of concrete with maximum occurring at 5% replacement level and and 28 days (5.78 N/mm^2 air cured) and (6.13 N/mm^2 water cured) respectively

IV. CONCLUSION

Based on the results of experiments, observations, and analysis, followings are conclusion determined from the study

1. The average compressive strength decreases as the OPFA content increases.
2. The maximum compressive strength of the concrete is achieved at 28 days of curing.
3. The 10% OPFA content is optimum content to achieve a balance between strength and workability.

The following recommendations are revealed after thorough analysis of research methods and previous studies:

1. Curing duration: The concrete should be cured for at least 28 days to achieve the maximum compressive strength.
2. Oil palm fibre (OPFA) ash content: The OPFA content should be kept to 10% to achieve a balance between strength and workability.

3. Other factors: Other factors that can affect the compressive strength of concrete include the type of cement, the water-to-cement ratio, and the aggregate content.

REFERENCES

Abdul Awwal A. S. M. and Nguong S. K. (2010), A Short-term Investigation on High Volume Palm Oil Fuel Ash (OPFA) concrete 35th Conference on Our World in Concrete & Structures: 25 - 27 August, Singapore Article Online Id: 100035023.

ASTM C 618-78 (1978) "Specification for Fly Ash and Raw or Calcium Natural Pozzolana for Use as a Mineral Admixture in Portland Cement Concrete", American Standard for Testing Materials

ASTM C143/C143M-03: Standard Test Method for Slump of Hydraulic-Cement Concrete. American Standard for testing Materials

Bamaga, S. O., Hussin, M. W. and Mohamed, A. I. (2013), Palm Oil Fuel Ash: Promising Supplementary Cementing Materials. Korean Society of Civil Engineers (KSCE) Journal of Civil Engineering 17(7): pp1708-1713

BS 882: (1992), "Specification for Aggregates from Natural Sources for Concrete," British Standards Institution. Technical Information Services Department, CNL. Technical

BS EN 197-1: (2000), Cement, Composition, Specification and Conformity Criteria for Common Cement, British Standards Institution. Technical Information Services Dept., CNL. Technical Information Service Department, BSI 389 Chiswick High Road, London

Bacerra-Duitama J and Rijas-Avellaneda D (2022), Pozzolanic: A review. Engineering and Applied Science Research. Vol 49 (4), Pp 495-504

Mafimisebi P (2024), Sedimentology and Petrographic Studies of Ogun River Bridge Sediments, Dahomey Basin, Southwestern Nigeria. Irish Interdisciplinary, Journal of Science and Research. Vol 8 (04) Pp 16-27

Okeyode I and Jibiri N N (2012), Grain Size Analysis of the Sediments from Ogun River, South Western Nigeria. Earth Science Research, Vol 2 (01), Pp 43--51

E.B. Oyetola and O.M. Owoyele (2017) Properties of Oil palm fibre ashBrick as a Supplementary Cementitious Material" International Journal of Civil Engineering and Technology

Sa'ad M. M (2006). Comparative Study of Pozzolanic Activities of Selected Nigerian Burnt Bricks. An unpublished M.Sc. Thesis, Dept of building. Ahmadu Bello University, Zaria.

Shetty M. S (2004). Concrete Technology Theory and Practice Sixth edition (Multicolor revised edition)

Verbitsky V. D. (1976). Improvement to production techniques building trade journal Reb. 13. p. 57-59.

ASTM C109/C 109M – 02 Compressive Strength of Hydraulic Cement Mortars.

Carr, J. G.:J An Investigation on the Effect of Brick Dust on Lime-Based Mortars Degree of Masters of Science, University of Pennsylvania, 1995.

Neville, A.M (1981): properties of concrete 3rd Ed. Pitman publishing ltd, London.

Lea's (2004). Chemistry of Cement and Concrete. Fourth edition, edited by Peter C. Hewlett.