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STRENGTH AND DURABILITY PERFORMANCE OF DEMOLISHED AGGREGATES AND PALM OIL MILLLING WASTE FOR ECO-FRIENDLY CONCRETE MATERIAL DEVELOPMENT

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A B S T R A C T

This research evaluated the durability and strength performance of concrete containing Palm Oil Fuel Ash (POFA), Palm Oil Clinker Powder (POCP) and demolished aggregates. These selected palm oil wastes, which are pozzolans were added as partial replacement for cement each at 10%, 20%, 30%, 40%, 50% and 100%for concrete production. The same combinations were also used for partial replacement of the natural coarse aggregates with the demolished aggregates. Compressive and Flexural strength tests were conducted on air and water cured concrete samples containing Demolished Aggregates (DA) with cement and fine aggregates, demolished aggregates with POFA and demolished aggregates with POCP at varied proportions. The result showed that the strength of concrete with demolished aggregates alone is lower compared to that of the normal aggregate concrete. Upon the addition of POFA and POCP, the concrete strength was improved, with that of POFA outperforming the POCP. Peak strengths were obtained with the use of POFA at 30% DA and 50% POFA content, and with compressive and flexural strength values of 48.32N/mm^2 and 5.50 N/mm^{2}respectively. Addition of POCP gave maximum compressive and flexural strength of 44.54N/mm^2 and 5.36N/mm^2 respectively at 20%DA and 30%POCP content. Rapid chloride penetration and water adsorption durability test result on the combinations of demolished aggregates, palm oil fuel ash and palm oil clinker powder produced 24%DA, 30%POFA and 20% POCP as the most optimal combinations for good strength and moderately durable concrete performance. This research showed that the selected palm oil waste pozzolans can enhance the strength and durability of concrete containing demolished aggregates for sustainable concrete production

Keywords: Concrete, Durability Demolished Aggregates, Palm Oil Fuel Ash, Palm Oil Clinker Powder, Pozzolans, Strength

1.0 INTRODUCTION

In many countries, agriculture has developed into one of the most important and potent economic sectors [1]. Because farming produces a lot of agro waste—which is plentiful, sustainable, and reasonably priced—it is one of the most biologically significant businesses. Its use also has the potential to be ecologically responsible (Ukanwa et al., 2019). Because of the population increase and rate of consumption, landfills have become the primary location for disposing of trash. Therefore, researchers need to figure out how to reuse agricultural wastes in big numbers for engineering uses in order to deter inappropriate waste management. [2]

Concrete, which combines cement with fine and coarse aggregate, is a composite material renowned for its strength and endurance. Its use has skyrocketed due to the quick rise in industry and urbanization. Because concrete uses so many natural resources, its growing consumption makes it the least sustainable material. Given that natural aggregate makes up over 70% of the volume, increasing the use of concrete will result in an increase in the amount consumed. Natural aggregate is produced at a far slower rate than it is currently consumed, which is causing diminishing resources. [3].

The components of recycled concrete aggregate (RCA) are the embedded aggregate (s), either crushed or uncrushed, from the original concrete and hydrated cement mortar. Their characteristics differ depending on the kind of parent aggregate, the amount of mortar used, the strength of the parent concrete, and the maximum size of the parent aggregate. Conversely, RCA's quality is typically worse than NA's (natural aggregates) and less reliable. Mineral additives can be incorporated into the bulk concrete matrix of recycled concrete aggregate (RCA) to enhance its microstructure by pozzolanic reaction, which is one way to improve the characteristics of RCA [4].

When Portland cement hydrates, calcium hydroxide is released, and pozzolan, a finely divided siliceous or aluminous siliceous substance, combines chemically with the hydroxide to form calcium silicate hydrate and other cementitious components. Pozzolan is not cementitious. A concrete mix's resistance to sulfates, weathering, durability, and strength are all enhanced by the addition of pozzolans [5]. Industrial and agricultural wastes that are presumably intended for landfills could be burned to produce pozzolans.

One of the main sources of fats and vegetable oils needed to feed the world's expanding population is palm oil. Crude palm oil/kernels and biomass are the principal products of a typical palm oil mill. Palm oil pyrolysis yields pieces of palm oil clinker (POC) and fuel ash (POFA), which are used to power boilers at elevated temperatures in the oil mill. Large volumes of POC and POFA wastes are created during combustion and left behind close to palm oil plants. With the production of palm oil reaching over 10 million tons annually, the volume of this leftover trash is also growing globally. POFA and POC are two essential biomass wastes commonly utilized in construction. [6].

This study investigated the effect of some selected wastes from the milling of palm oil from palm tree on the strength and durability properties of concrete containing demolished aggregates to partially replace the coarse aggregates in concrete. These wastes include Palm Oil Clinker Powder (POCP) and Palm Oil Fuel Ash (POFA).

2.0 METHODS

Materials

Fresh Concrete Materials

Cement, coarse aggregate, and fine aggregate make up fresh concrete. For this study, Portland cement that complies with [7] was employed. River sand, which complies with BS Aggregate ([8] and passes through a BS 4.75mm sieve, was used as the fine aggregate. The Ala River near Akure provided the sand. It was thoroughly air dried and devoid of harmful minerals such as silt, clay, and chloride impurities. Crushed granite served as the coarse/natural aggregate, with 52% of the aggregate remaining on a BS13.2mm sieve and meeting BS Aggregate [9] standards. The material was thoroughly dried and devoid of harmful substances such as silt, clay, and chloride impurities. A quarry in Akure, Ondo state, Nigeria, provided the coarse aggregate.

Palm Oil Fuel Ash (POFA)

This study followed the process that Chandara et al. [10] used to prepare the POF. Through, a 300 μm sieve, the partially burned fibers and nutshell were extracted from the POF. The POF was then crushed for 45 minutes in a ball mill to produce further fine particles. Subsequently, the ground POF was subjected to an hour-long furnace heating process at 5000 C to eliminate any remaining residue and enhance its pozzolanic characteristics, ultimately forming the POFA.

Palm Oil Clinker Powder (POCP)

The boiler at the foot of the furnace of the Ayesan Oil Palm Mill in Ita Oniyan, Akure, Nigeria, provided the palm oil clinker. The crushing machine was then used to grind the clinker—a hard, solid fibrous material—into powder.

Recycle Concrete Aggregates (RCA)

The RCAs that was used was demolished aggregates, which was collected from construction sites. The aggregates were screened to meet the continuous gradation standards of 5–20 mm. After utilizing a jaw crusher to reduce the aggregates' uniform diameter sizes to 2.5–5 mm, they were bagged and stored in an airtight environment for the duration of the experiment.

Experimental Concrete Samples Preparation

As a reference and control, plain concrete samples were prepared without the recyclable aggregate and pozzolans. The process of mixing concrete involved utilizing a 1:2:4 weight ratio of cement, sand, and natural coarse aggregate while maintaining a consistent water-to-cement ratio of 0.45. The prepared destroyed aggregate is used in the second set of mixes to partially replace the natural aggregates at weights of 10%, 20%, 30%, 40%, 50%, and 100%. The properties of the second sets of mixes are present in the third set, but POFA and POCP have replaced some of the cement at five different levels of cement weight: 10%, 20%, 30%, 40%, and 50%. With a mixer, each mix was finished. This was followed by the addition of cement with the other materials and properly mixed for an additional two minutes. Finally, water was gradually poured into the mixer to obtain a homogenous mixture. A Superplasticizer was used in all concrete mixes in order to maintain the slump value between 100 and 150 mm.

Some of the cube specimens were retained in air curing state at the designated ages in order to explore the compressive strength of the water-cured and air-dried specimens. The remaining specimens were cured in a water tank at ambient temperature until the age of testing.

504 concrete samples in all were made, and tests were conducted on them experimentally. The effectiveness of the pozzolans and destroyed aggregates on the concrete that was created was then ascertained by analyzing and assessing the experimental data database that was generated.

After the necessary analysis was carried out, the materials (DA, POFA and POCP) were combined together at proportions equal to that which generated their peak strength when tested individually. Strength test (Compressive and Flexural) and Durability test (Rapid Chloride Penetration (RCPT) and Water adsorption) was carried out on the combined materials to determine the optimum mix that would generate a strong and durable concrete

Experimental Testing Procedure

Preliminary tests were initially carried out on the demolished aggregates, natural coarse aggregates, palm oil fuel ash, palm oil clinker powder and cement. This includes:

- Physical test on the aggregates (i.e. demolished aggregates and granite) which include sieve analysis, bulk density, specific gravity, moisture content, water adsorption, flakiness index and elongation index
- Mechanical test on the aggregates which are the Los Angeles Abrasion test and the Aggregate Crushing Value (ACV) test
- X-Ray Diffraction (XRD) chemical composition test to determine the chemical elements of both POFA, POCP and cement

For each concrete mix, the fresh density and workability of the concrete were measured immediately after mixing as per ASTM C143 (2015). The compressive strength was carried out at the ages of 7, 14, 28 and 56 days on 100-mm cast cubes for both water and air cured samples. Flexural strength test was also conducted on 14, 28 and 56days water cured concrete samples. Rapid Chloride Penetration test (RPCT) measures the ability of concrete to resist chloride ion penetration, using 60 voltage direct current (VDC) at 6hrs of testing, and is usually taken as a good measure of concrete durability coupled with water adsorption. These two tests were performed on concrete samples of the combinations of demolished aggregates, POFA and POCP in order to determine the combinations that yielded the most durable concrete.

Experimental Analysis

Relationships and variations in the strength parameters of concrete with the addition of the selected palm oil milling wastes and demolished aggregates were displayed with the use of graphs from the results obtained from the experimental test conducted using Microsoft Office Excel 2016 Software Package.

3.0 Results and Discussion

Material Index Properties Result

Table 1 shows the physical properties of the demolished and the natural aggregates (granite) while table 2 shows the result of the chemical analysis and XRD tests performed on the cement, palm oil fuel ash and the palm oil clinker powder. The results showed that demolished aggregates has higher absorption capacity due to the mortar adhered on the surface, higher abrasion loss and higher crushing value which could be attributed to previous exposure to weathering and loading.

Table 1: Physical Characterization of the Aggregates

Physical Properties	**Natural Aggregates (Granite)**	**Demolished Aggregates**
Nominam Maximum size(mm)	20	22
Moisture content (%)	0.28	2.36
Water Adsorption (%)	0.85	4.55
Specific Gravity (Oven Dried)	2.50	3.31
Specific Gravity (Air Dried)	2.97	4.15
Loose Bulk Density (Kg/m^3)	1175	1297
Compacted Bulk Density (Kg/m^3)	1673	1484
Elongation Index	-	7.7
Flakiness Index	10.6	12.3
Los Angeles Abrasion	18	33
Aggregate Crushing Value (ACV)	14.72	28.84

Table 2: Chemical Elements of Research Materials

Chemical Elements	Cement (%)	Palm Oil Fuel Ash (%)	Palm Oil Clinker Powder (%)
Silica (SiO_2)	22.50	42.23	60
Alumina (Al_2O_3)	5.25	17.98	7
Iron (Fe_2O_3)	2.50	2.73	9
Calcium (CaO)	64	15.1	5
Magnesium Oxide (MgO)	1.40	2.21	2
Sodium (Na_2O)	0.60	5.43	-
Potassium (K_2O)	0.15	7.56	10
Manganese oxide (MnO)	0.20	-	-
Titanium (TiO_2)	-	-	1
P_2O_5	0.05	-	4
SO_3	2.31	-	-
Loss on Ignition (LOI)		10.5	-

The result from the table showed calcium, silica and alumina oxides as the dominant elements contributing up to 91.75% of the total composition of the cement used. A pozzolan is a silicious material which in itself does not possess cementitious properties but will in finely divided form and in the presence of water react with calcium hydroxide $Ca(OH)_2$. The POFA and POCP qualifies as pozzolans since the percentage sum of its SiO_2, Al_2O_3 and Fe_2O_2 components (76.9% for POFA and 76% for POCP) exceeds the minimum requirement of 50% [11].

Demolished Aggregates (DA) Performance Result

Demolished aggregates were used to partially replace the natural aggregates(granite) at varied percentages of 10%, 20%, 30%, 40%, 50% and 100% complete replacement in concrete mix for cube castings. The result of the test conducted on the cube samples were as follows:

Workability (Slump)

Figure 1 showed the result of the slump values for each percentage replacement of the natural aggregates with the demolished aggregates in concrete. From the figure, the slump results from the use of demolished aggregates concrete slump were lower than that of the control (wholly natural aggregates). This means that more water will be needed to achieve similar workability with that of natural aggregate concrete, because of higher absorption capacity of demolished aggregate which can be attributed to the presence of impurities and attached cement hydrates. Also, the workability (slump) decreases with increase in the quantity of demolished aggregates. This result is similar to that derived by Qasrawi and Marie [12], and this is attributed to the increases in void ratios of concrete with increase in the demolished aggregates content.

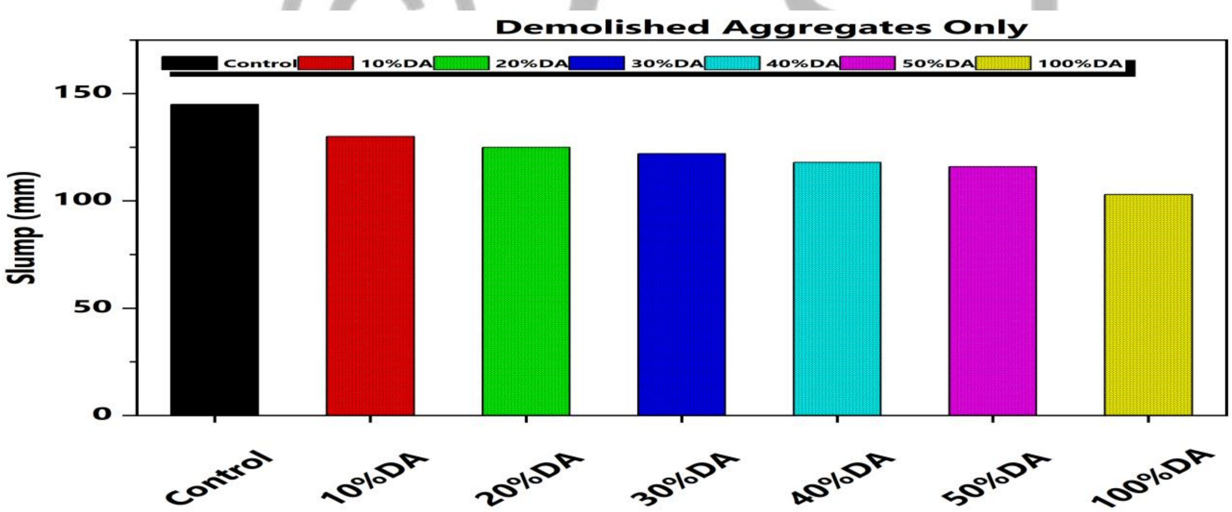

Figure 1: Slump Characteristics of the Demolished Aggregates Concrete

Compressive Strength

Figure 2 shows the compressive strength result for both air-cured and water-cured concrete samples containing varied percentage replacement of the natural aggregates with the demolished aggregates.

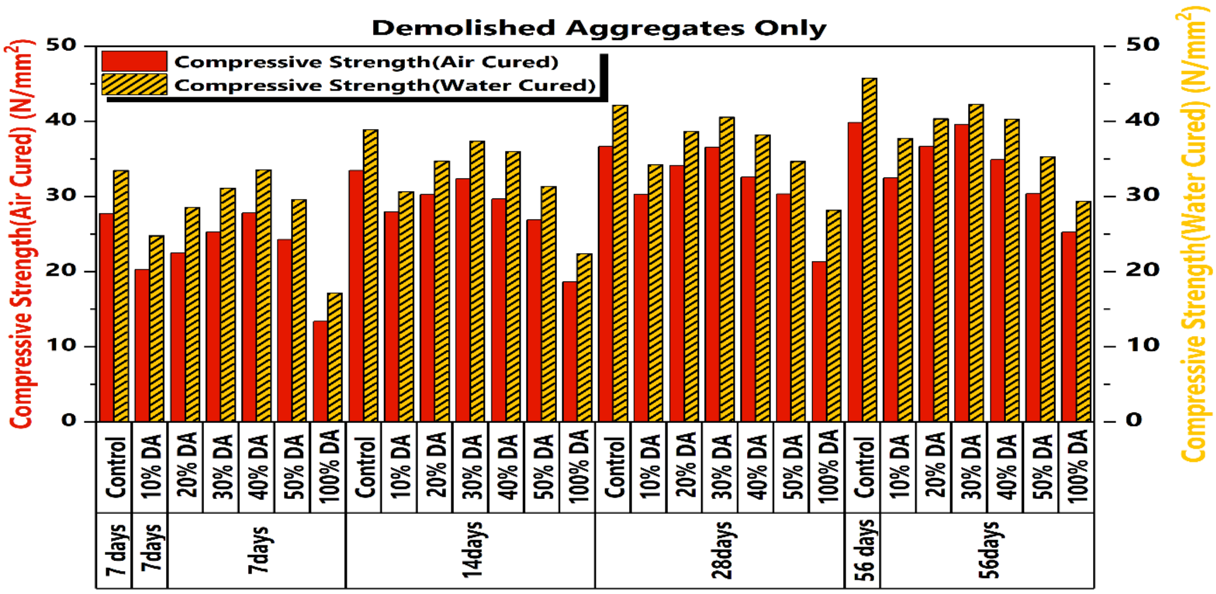

Figure 2: Compressive Strength Characteristics of the demolished aggregate concrete

The result showed that the demolished aggregate compressive strength was lower than that of the natural aggregate concrete (control) for all percentage replacement. Also, apart from the early strength at 7 days, the compressive strength of the demolished aggregates increases with increase in percentage replacement until it peaks at 30%, after which subsequent increase leads to a decline in compressive strength. This result is in tandem with that gotten by Garg. [13] which found that up to 30 % virgin aggregate can be substituted with RCA without any effects on concrete strength, and was observed to be due to the concrete age and gradation of the recycled aggregates. The highest compressive strength was observed at 56 days for 30% replacement at a value of 42.22N/mm². Also, for all curing days and percentage replacement, the air-cured concrete samples possess lower compressive strength to those of the water-cured concrete samples.

Flexural strength

Figure 3 showed the flexural strength result for both air-cured and water-cured concrete samples containing varied percentage replacement of the natural aggregates with the demolished aggregates. The demolished aggregate flexural strength was lower than that of the natural aggregate concrete (control) for all percentage replacement. After 7 days, the flexural strength of the demolished aggregates increases with increase in percentage replacement until it peaks at 30%, after which subsequent increase leads to a decline. The maximum flexural strength also occurs at 30% replacement at 56 days, at a value of 5.03N/mm².

The reduction in the flexural strength of the demolished aggregate concrete compared to that of the natural aggregate concrete was not as lower as observed for the compressive strength. This is in accordance with Sherif *et al.* [14], as its flexural strength reduction compared to the natural aggregate concrete was a paltry 10% compared to the 25% strength reduction observed in its compressive strength.

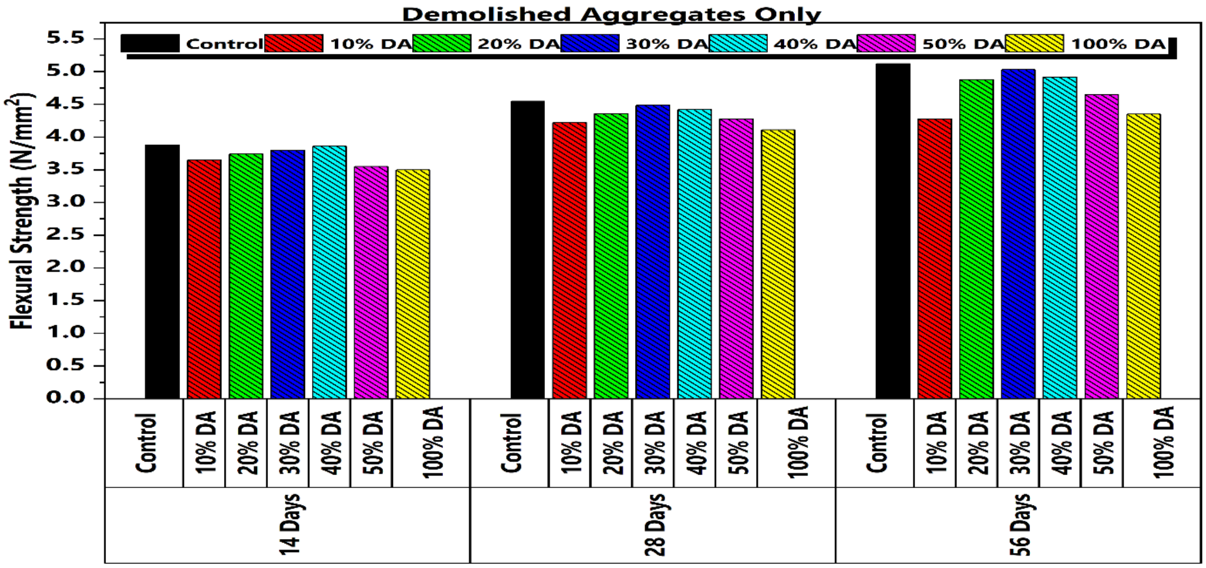

Figure 3: Flexural Strength Characteristics of the demolished aggregate concrete

Effect of Oil Palm Waste Pozzolans on the Properties of Demolished Aggregate Concrete

The effect of POFA and POCP on the strength properties of the demolished aggregate was observed by plotting the peak strength values at each %DA replacement as against the DA without the pozzolans.

Compressive Strength

Figure 4 shows the compressive strength comparison between the demolished aggregate, demolished aggregate with palm oil fuel ash and the demolished aggregate with palm oil clinker powder.

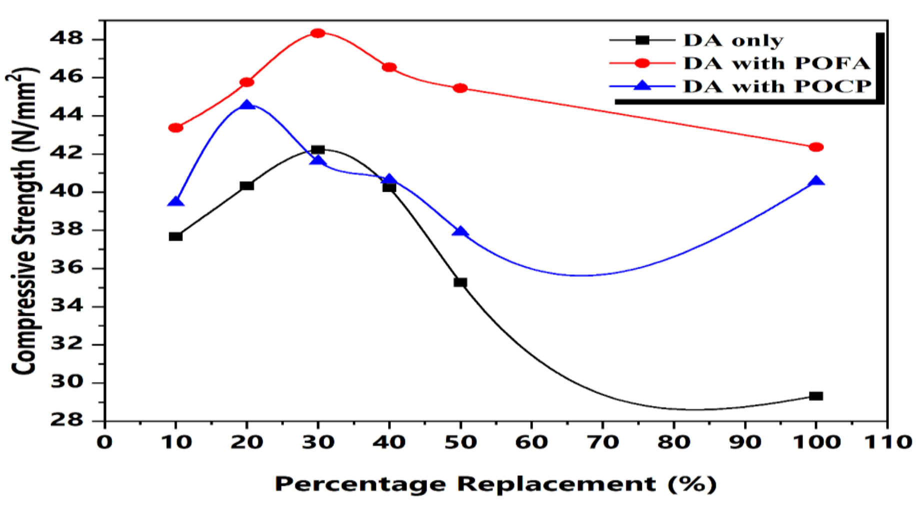

Figure 4: Variation in the properties of DA with addition of Oil Palm Waste Pozzolans

From figure 4, it was observed that POFA showed better performance on the demolished concrete compared to POCP. It showed higher strength values at all DA percentage replacement. The use of POFA increases the compressive strength to a peak at 30% DA replacement, after which it gradually decreases. The peak compressive strength occurs at 50% POFA content and 30%DA with strength value of 48.32N/mm^2

The POCP also enhances the compressive strength of the demolished aggregate concrete up to 20% DA content as showed in figure 4, after which the strength decreases at 30 and 40% DA replacement. However, at 50 and 100 % DA replacement with POCP, there was a slight improvement compared to the DA only despite its declining compressive strength. The peak compressive strength was obtained at 20% DA and 30% POCP content with strength value of 44.54N/mm².

Flexural Strength

Figure 5 showed the flexural strength comparison between the demolished aggregate, demolished aggregate with palm oil fuel ash and the demolished aggregate with palm oil clinker powder

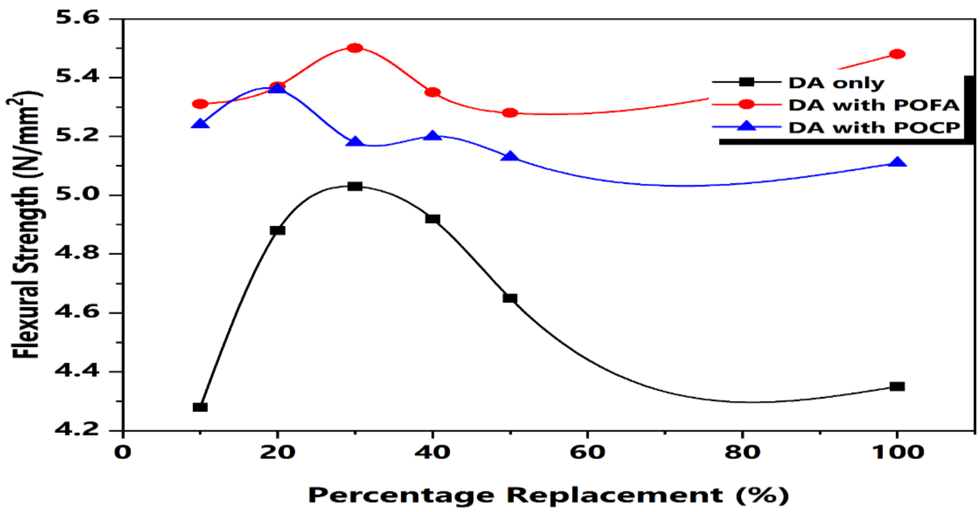

Figure 5: Variation in Flexural Properties of DA concrete with Palm oil milling wastes

From Figure 5, POFA and POCP both enhance the flexural strength of DA concrete for all percentage DA replacement, with the difference in flexural strength enhancement being very high for both pozzolans. Both POFA and POCP followed the same pattern observed for the compressive strength. They both peak at 30% DA and 20% DA, at 50% POFA and 30% POCP content respectively with flexural strength values of 5.50 and 5.36 N/mm² respectively.

Workability (Slump)

Figure 6 showed the fresh concrete properties (slump) of the demolished aggregates and POFA replacement of granite and cement replacement in concrete respectively while Figure 7 showed the replacement of cement with POCP.

From Figure 6, at all percentage replacements for both POFA and demolished aggregates, the slumps were lower than that obtained for the natural aggregate concrete. However, with each addition of POFA and DA, the slump gets closer to that gotten from the natural aggregate concrete. The closest was observed at 50% POFA and 30%DA replacement for cement and natural aggregates respectively at a slump value of 140mm, after which there was a gradual decline in slump of the concrete mixes. The slump values observed at 100% DA replacement category were much lower than that observed at 10% DA. This is due to the gradation of the DA, as the POFA tends to fill up the voids in the DA, thereby reducing its w/c ratio. However at large percentage of DA, the POFA would not be able to completely occupy those void spaces, leaving large pores behind, hence leading to high w/c ratio, which ultimately leads to low slump values.

From Figure 7, for all combinations of POCP with DA, the slump values were lower compared with the control. This result was very much similar to that obtained with combinations of DA and POFA. Also, the slump of DA concrete reduces with addition of POFA with the exception of 30% and 50% DA content. The highest slump value was obtained at 10% POFA content and 20% DA content with a slump value of 132mm.

Figure 6 showed the fresh concrete properties (slump) of the demolished aggregates and POFA replacement of granite and cement replacement in concrete respectively while Figure 7 showed the replacement of cement with POCP.

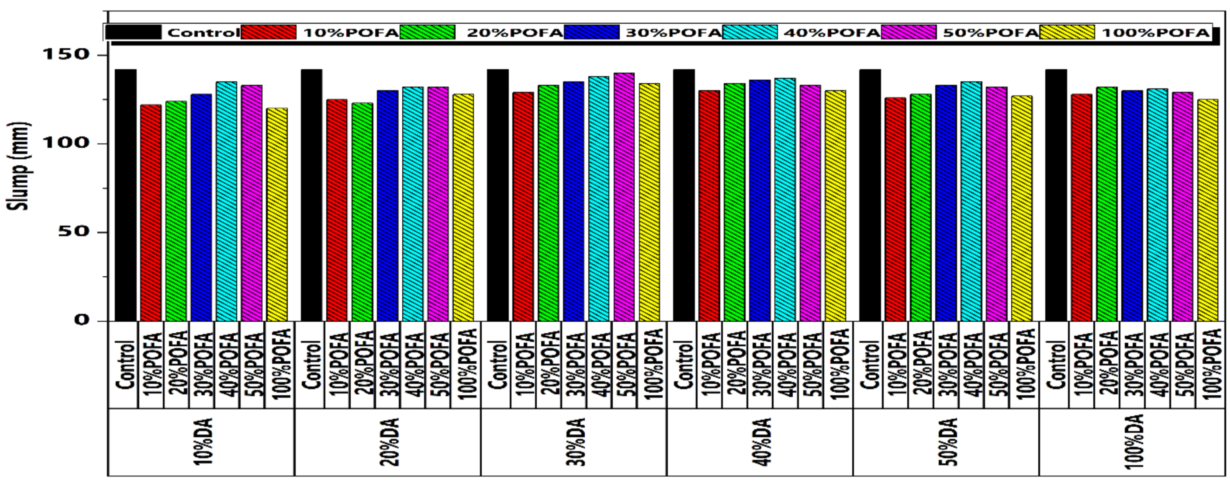

Figure 6: Slump Result for Demolished Aggregate with Palm Oil Fuel Ash Concrete Mixes

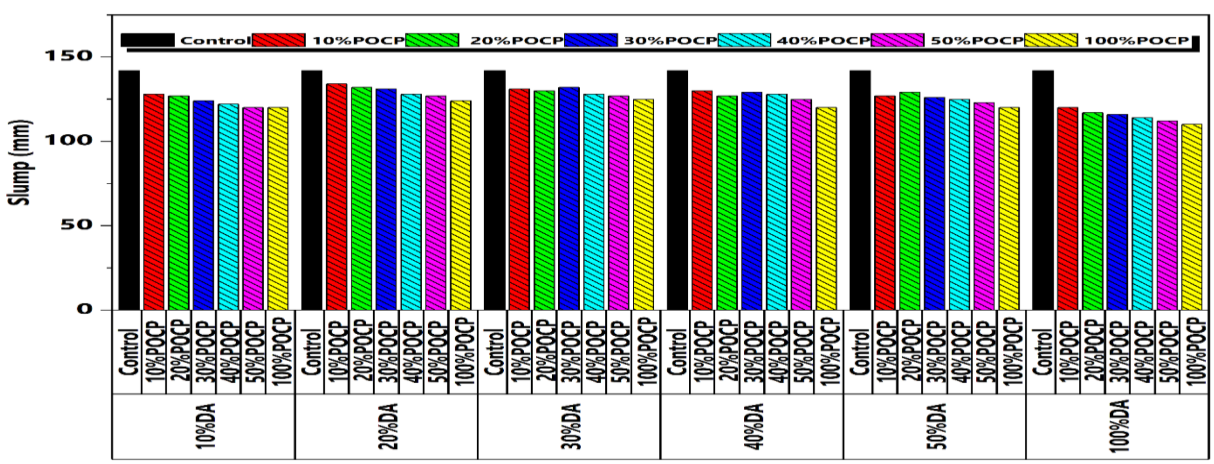

Figure 7: Slump for Demolished Aggregate with Palm Oil Clinker Powder Concrete

Optimum combinations of demolished aggregates and Oil Palm Waste Pozzolans

Table 3 shows the strength and durability test results for the combination of POFA and DA that yields the peak strength (i.e. 30%DA and 50%POFA) with that of POCP and DA combination that also yielded the peak strength (i.e. 20%DA and 30%POCP). However, in order to cover for the differences in DA content, the test was conducted on mixes between 20% DA and 30% DA with increment of 2%.

Table 3: Strength and Durability Results of Peak DA and Pozzolans

DA (%)	POFA (%)	POCP (%)	CS N/mm²	FS N/mm²	RPCT		Water adsorption (%)
					Coulombs	Class	
20	50	20	47.38	5.46	2468	Low	2.5
22	50	20	48.56	5.59	3124	Moderate	3.0
24	50	20	50.27	5.75	3625	Moderate	3.4
26	50	20	51.33	6.03	4010	High	3.9
28	50	20	50.74	5.94	4388	High	4.3
30	50	20	49.9	5.82	4892	High	4.4

The optimum combinations that produced the highest strength are 26%DA, 30%POFA and 20% POCP. However, this combination produced high chlorine penetration and water adsorption, thus its choice would not be durable. However, the choice of 24%DA, 30%POFA and 20% POCP produced good strength values, moderately durable in both chloride penetration and water adsorption and is therefore the optimal combinations for concrete production.3

4.0 Conclusion

- The strength of demolished aggregate concrete alone in terms of strength and workability is lower and does not measure up to the strength of the concrete with the natural aggregate.
- The Palm Oil Fuel Ash and the Palm Oil Clinker Powder both enhances the strength capability of the demolished aggregate with Palm Oil Fuel Ash performing better than the Palm Oil Clinker Powder.
- 30%DA and 50%POFA is the optimum combination of demolished aggregates and palm oil fuel ash with peak compressive strength of 48.32N/mm2 and flexural strength of 5.50N/mm2.
- 20%DA and 30%POCP is the optimum combination of demolished aggregates and palm oil clinker powder with peak compressive strength of 44.54N/mm2 and flexural strength of 5.36N/mm2.
- However, for both POFA and POCP combinations with the demolished aggregates, none of the pozzolans could increase/raise the slump (workability) of the demolished aggregates over that of the normal aggregate concrete.

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