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Mechanical properties of green concrete with Palm Nut Shell as low cost aggregate

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Abstract. The cost saving benefits of aggregate replacement in concrete works are well documented. The utilization of Supplementary Aggregate Materials (SAMs) in concrete engineering without compromising standards in concrete works remain very attractive to both infrastructure developers and design engineers. However, there is continual search for low cost beneficial substitute materials. The mechanical properties of green concrete produced from Palm Nut Shell (PNS) as coarse aggregate was investigated. The abundance of PNS (light weight waste product of palm oil production) in West Africa created the impetus for the study. Series of laboratory tests such as; Slump, Compaction factor, Density, Schmidt hammer and Compressive strength tests were conducted on specimens of 10, 20, 30, 40 and 50% replacements of dry weight of PNS as coarse aggregate and specimens of natural aggregate as control sample. The specimens were cured at relative humidity (RH) of 95-100% and temperature (T) of 22-25°C in a chamber for periods of 7, 14, 21 and 28 days. The results showed the PNS samples to have relatively medium to high workability ranging from 24-47 mm for slump height and values of 0.85 to 0.90 for compaction factors. A general strength development was observed across the different samples with the PNS sample reaching strength of 48.7 N/mm^2 at 28 days curing. The 50% replacement specimens which mobilized UCS of 28.7 N/mm^2 met the requirement for lightweight concrete however, 30% is the optimum for a partial aggregate replacement in green concrete as UCS of 39.2 N/mm^2 was mobilized in 28 days. Thus PNS is a suitable concrete constituent and can be a major cost reduction factor especially in low cost rural projects with streamlined loading requirements.

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

Introduction

The construction industries in many developed countries have identified and resorted to the utilization of natural waste materials, particularly agricultural wastes as potential alternatives to conventional aggregates without compromising standards of structural members with less construction complexities [1]. This has led to the drastic transformation in the development and construction of light weight green concrete (LWGC) to serve as structural members. Nevertheless, the advantageous use of LWGC in Africa and most parts of the developing world by the construction industries have not been sufficiently recorded. Conventionally, the insistent rise in the demand for concrete in construction industries have led to a rapid depletion in the natural gravelly

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and granitic stone deposits such that it has resulted in the excessive usage of natural stone deposits [2]. This is increasingly causing environmental challenges ranging from gulling to severe erosion problems and ground instability thereby affecting ecological balance. The need to source and explore natural alternative waste materials that could serve as partial or total substitutes to the very scares and costly conventional aggregates have gained attention in recent times [3]. Aggregates constitute over 60 to 80% of the total volume of concrete. Having this large proportion of the concrete mass occupied by aggregate, it is expected for aggregate to have a significant effect on the general behavioral performance of the concrete product and its properties. Aggregates are essential in concrete production especially when needed as engineering materials for structural emphasis. They possess a unified influence on moisture reduction with respect to related deformations (i.e., shrinkages) and additionally, provide concrete with volumetric stability [3].

Figure 1. Palm nuts

Figure 2. Palm trees

Palm Nut Shell is a by-product from the manufacturing process of palm nut fruits, dumped as agricultural waste in palm oil producing localities. Palm nut is the fruit from a palm tree (see Figures 1 and 2). Palm trees are grown in regions with long and heavy down pours as well as very hot temperatures such as the case of Nigeria, Benin Republic, Ecuador, Colombia, Malaysia e.t.c. Currently Malaysia is known to be the largest producer of palm oil and its related products. The palm nut fruit consists of two major sections as shown in Figure 3: a yellowish fruit called the Pulp and when crushed, palm oil is produced and the Kernel which is covered in the shell of the seed which produces palm kernel oil when crushed. The demand for palm oil as a significant part of West Africa's diet is continually on the rise as such, there is increased cultivation of oil palm to meet the pressing demand. However, one significant challenge in oil palm processing as recorded by [3] is the vast quantities of waste generated in the forms of; Palm Nut Shells (PNS), Oil Palm Mill Effluent (OPME) and Empty Fruit Bunches (EFB). These waste products are stockpiled and openly dumped. It creates a ghastly site and constitutes a nuisance to the environment and the vicinity of the factories as large quantities of these wastes are generated daily.

1. Brief review of related studies

It has been established by [4] that PNS aggregates are capable of producing concrete with compressive strengths of over 25 MPa. Outside the environmental friendliness of utilizing PNS in the production of concrete, this aggregate further offers an option as partial or total substitutes to the scares and expensive conventional concrete aggregates. This is an indication of the cost benefits from its use in the production of LWGC for rural low cost housing and development. For instance, the use of this new concrete type in West Africa is yet to be largely tested. However, as recorded by [4] a model low-cost housing of 58.68 m^2 area was built in Sarawak-Malaysia using 'PNS hollow blocks' for walls and 'PNS concrete' for footings, lintels and beams. These LWGC components are presently performing well and no structural deficiencies have at yet been experienced or recorded. Nevertheless, it was noted by [4] that fly ash (FA) used as cement replacement for PNS concrete had negative effects on the compressive strength of the concrete product with a strength reduction of up to 29%. It was also revealed that the compressive strength of PNS concrete was found to be within the range acceptable for structural LWGC, which was about 50% lower than the ordinary concrete, and that the PNS concrete gained its highest strength within a 56days hydration period. The use of PNS therefore, as coarse aggregate in LWGC production with different hydration schedules over a 56days period will have effects on compressive strength, density and workability of the LWGC product.

Certain established methods such as; ACI method for normal weight concrete and other similar methods as recorded by [5, 6 and 7] could not be applied as mix design for PNS concrete. A trial mix design for concrete with PNS aggregate as coarse aggregate yielded a compressive strength of 24 N/mm^2 for a hydration period of 28 days [5]. Fly ash as mineral admixture and calcium chloride as an accelerator were also used to study the improvement in strength of the concrete. Meanwhile, High Strength Concrete according to [8] is set to achieve 40 Mpa (6000psi) compressive strength over 28 days hydration period although, it should be taken into cognizance that it depends on geographical and concreting conditions. Hence, the abundance of PNS in West Africa has paved way for PNS to be studied as replacement for coarse aggregate in green concrete where series of laboratory tests are conducted on the fresh and hardened LWGC specimens.

2. Materials and methods

The materials used in this study are portable tap water for mixing and curing the concrete, ASTM Type I Ordinary Portland Cement, coarse aggregate with particle size distribution between 5 to 14mm, PNS were obtained in sufficient quantities from Ikoritungko Oil Milling Factory located around Calabar, Nigeria (see Figure 4). All impurities and injurious contents such as oil remains and dirt were removed from PNS by a thermal process. The PNS was left in the oven under high temperatures of about 150-170^{0}C for close to 24 hours. Series of laboratory works were conducted to investigate the effects of PNS on workability and compressive strength of the new concrete type, when used as partial replacements for coarse aggregates. The tests carried out included; the slump test which was done in accordance to B.S. 1882 part II, the compaction factor test was done in conformance to B.S. 1881:1970 part II to test the workability of concrete, the Schmidt hammer or Surface Hardness-rebound test based on BS 1881 Part 202 and the compressive strength test which was done according to BS 1881 Part 116 for strength determination of concrete.

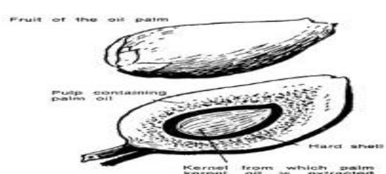

Figure 3. Inner cot of palm

Figure 4. PNS collected as waste

All the samples were cured at relative humidity (RH) of 95-100% and temperature (T) of 22-25 ^{0}C in a chamber for different hydration ages of 7, 14, 21 and 28 days [9]. A mix proportion for LWGC as earlier stated is different from the mix proportion of high strength concrete or normal strength concrete. For the LWGC, which is to be produced from using PNS as aggregate partially replacing the conventional coarse aggregate, requires an average cement/water ratio as indicated by [6]. Thus, a cement/water ratio of 0.5 was initiated in this study with mixing ratio of 1:2:4. The cubic samples were cast in metal moulds with dimensions of 100 x 100 x 100 mm^3. For every batch of PNS concrete mix, Table 1 shows the weight of cement, the fine sand and the crushed aggregates used.

Table 1. Quantities of concrete constituents in every batch of PNS concrete mix

Samples	%PNS	OPC	Sand	Gravel	PNS	Total
P_0	0	1.157	2.314	4.63	0.0	8.101
P_{10}	10	1.157	2.314	4.17	0.43	8.101
P_{20}	20	1.157	2.314	3.70	0.93	8.101
P_{30}	30	1.157	2.314	3.24	1.39	8.101
P_{40}	40	1.157	2.314	1.39	3.24	8.101
P_{50}	50	1.157	2.314	2.32	2.32	8.101
Total		**6.942**	**13.884**	**19.45**	**8.31**	**48.61**

3. Discussion of results

3.1. Slump test

The workability of concrete batches for the respective percentages of PNS mix using the slump test was presented in Figure 5. The mix samples with constant w/c ratios of 0.5 were found to display medium to high workability. It further showed that as the percentage replacement of PNS increased, workability of LWGC reduced except for 10%PNS where it showed a spike in workability. The specific surface was also found to increase as the PNS content increased. The plausible explanation to these behaviours can be because the control aggregate was denser than the PNS aggregate and the replacement in this study was done by weight. This led to more cement paste been required to lubricate the aggregate as such, reduced the entire fluidity of the mix which subsequently reduced the height of the slump.

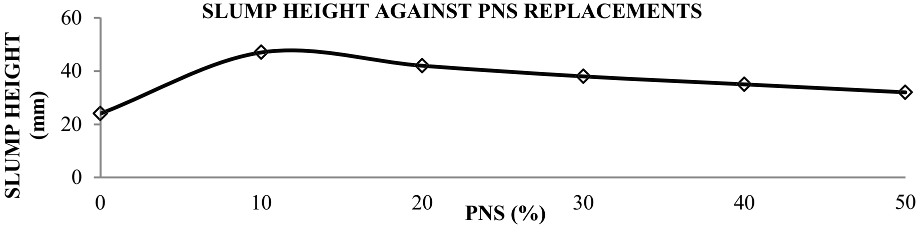

Figure 5. Effects of PNS replacements on slump height of respective mixes

Consequently, the decreased slump height in the 20, 30, 40 and 50% mixes as the percentage of PNS increased was attributed to w/c ratio; having w/c ratio of 0.5 used for the respective mixes, the hydrated cement paste became more watery and less viscous. This process allows the penetration of cement into the PNS aggregate.

Additionally, it reduces the amount of cement paste available for lubrication and hydration which resulted in decreased free flow of cement paste in the mix and thereby, causing a decreased slump. A test by [2] was conducted using Palm Kernel Shells (PKS) as replacement for the control aggregate which displayed similar behaviours recorded by PNS aggregate in this study. As the percentage of PKS increased, the workability of the concrete was reported to reduce as such, the height of slump reduced.

3.2. Compaction factor test

The compaction factor test was conducted to check the workability of the respective concrete mixes. Although the workability of the concrete was first checked by slump test however, the compaction factor test was further conducted to validate the accuracy of the results. The compaction factor of the concrete mixes for the respective percentages of PNS as replacement for the coarse aggregate was shown in Figure 6.

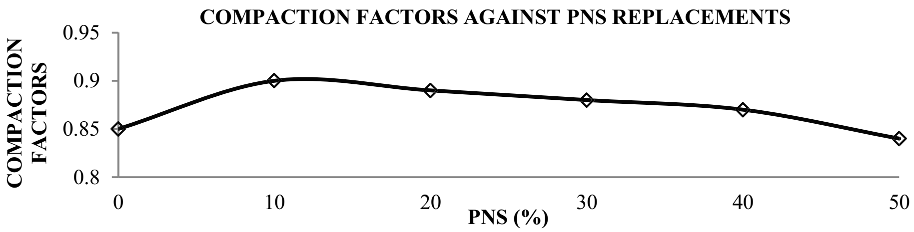

Figure 6. Effects of PNS replacements on compaction factors of respective mixes

From the results gotten from the compaction factor test, it was observed that the 10%PNS sample had the highest compaction factor of 0.9. It can also be seen that similar to the slump test, after the 10%PNS replacement, the compaction factor decreases. The decrease in the compaction factor value after a steep rise from 0-10% PNS replacement may have resulted from the sensitivity of workability test or because the control aggregate was denser than the PNS aggregate and the replacement in this study was done by weight. Furthermore, it was seen that all compaction factor values for the entire sample mixes were within the acceptable ranges from medium to high workability.

3.3. Density of specimens

The densities of the tested samples were determined to find the possibility of using LWGC as a structural element. Average densities of three specimens were determined as the actual density of each percentage mix. Table 2 shows the densities of the samples with the respective percentage of PNS replacements. Figure 7 shows the densities to reduce as the percentage of PNS increases vice versa, with the range of densities for PNS concrete for 28 days to be between 2278–1975 kg/m^3, while the 0%PNS concrete (as control) had a density of 2473 kg/m^3. The highest density, 2473 kg/m^3, was recorded for 0%PNS, while the least density 1975 kg/m^3 was recorded for 50%PNS.

As established in hypothesis of this study, concrete strength was expected to decrease as the %PNS increases. This contributes to the properties of LWGC from PNS aggregates having a density lesser than 2000 kg/m^3. This became approximately 60%

lighter as reported by [4 and 7] in comparison to the conventional crushed stone aggregate, which then results in the production of LWGC. The LWGC having a density lesser than 2000 kg/m^3 indicated that the 40 and 50%PNS samples are considered LWGC with densities of 2047 and 1975 kg/m^3 respectively. An expected density for control sample was in the range of 2400 kg/m^3 as such, the 0%PNS concrete was considered a normal weight concrete.

Table 2. Density of respective specimens

Hydration period	0% PNS	10% PNS	20% PNS	30% PNS	40% PNS	50% PNS
7	2430	2241	2121	2065	1978	1899
14	2451	2254	2134	2088	1992	1923
21	2462	2263	2172	2120	2011	1932
28	2473	2278	2194	2133	2047	1975

The 40 and 50%PNS is been considered a lightweight concrete for the fact that the 10,20, and 30%PNS had a higher coarse aggregate to PNS aggregate ratio. This shows that coarse aggregate has a larger volume in the mix than PNS aggregate, and since coarse aggregate is heavier than PNS aggregate, the concrete specimen was denser.

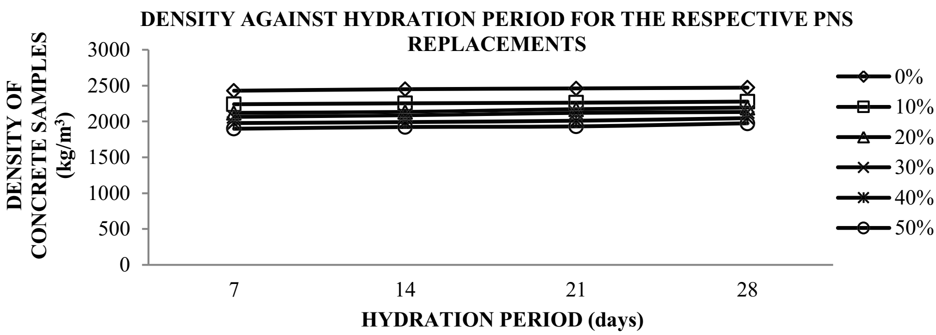

Figure 7. Density of samples with respect to hydration periods

The LWGC maybe have been produced due to the amount of w/c ratio used in the study. An increase in w/c ratio resulted in a decrease in cement content and increased the water content which reduced the overall weight of the concrete. An additional possibility could be the actual weight of coarse and PNS aggregate used. Hence, the Table 2 and Figure 7 show that an increase in PNS aggregate led to a decrease in the density of the product. Nonetheless, since PNS aggregate is lighter in weight, the replacement of coarse aggregate at different percentages resulted to a lesser amount of coarse aggregate in the mix; the absorption of cement paste was reduced as PNS aggregate do not firmly bond with cement thereby, reducing the overall density of concrete and then creating a LWGC.

3.4. Schmidt hammer test

The Schmidt hammer test was conducted to determine the strength of samples by measuring the surface hardness of concrete. Schmidt hammer test results for PNS samples showed that the strength of the samples increased with age as seen in Figure 8. This test is very similar to the compressive strength test. The results from the test revealed a substantial extension in concrete strength as the hydration period extended and as the %PNS in each sample reduced, with 0%PNS recording the highest strength and 50%PNS had the least concrete strength 47.3 N/mm^2 and 22.7 N/mm^2 at 28 days. In the case of the Rebound hammer test however, the concrete strength depreciated when compared to the compressive strength test results in Figure 9. The difference was accounted for by the concrete surface area which is affected by its rough surface due to the presence of PNS in the sample.

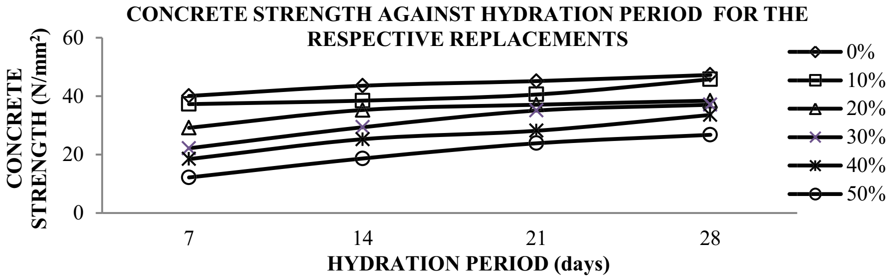

Figure 8. Concrete strength of samples with respect to hydration periods

Inclusive factors maybe in relation to the angle of inclination or the Schmidt hammer. It is clear from the results that both Schmidt hammer and compressive strength test have a strong correlation which can be the reason 0%PNS had a higher strength and 50%PNS is made of higher quantity of organic materials that happen to be lighter and less stronger than the conventional coarse aggregate.

3.5. Compressive strength test

The compressive strength of the crushed specimens in this work is reciprocal to the %PNS used. From Table 3 and Figure 9 respectively, the compressive strength development of concrete with age is observed.

Table 3. Compressive strength of respective specimens

Hydration period	0% PNS	10% PNS	20% PNS	30% PNS	40% PNS	50% PNS
7	42.3	37.1	33.6	22.8	18.6	13.7
14	49.6	39.6	37.3	33.1	26.3	22.5
21	54.4	42.5	39.5	36.7	29.8	24.8
28	59.5	48.7	41.6	39.2	32.1	28.7

It shows the effect of the different amount of PNS on the strength of the concrete. The rate of strength gain was pronounced as the hydration period increased i.e., as the %PNS increased, the compressive strength of the concrete decreased, vice versa. While the strength of the concrete decreased as the %PNS increased. The 0%PNS had the highest strength although, as PNS replaced the coarse aggregate the concrete strength gradually decreased. The plausible explanation is the fact that PNS are organic materials lighter and less strong than the conventional coarse aggregate. It also could be attributed to the highly irregular shapes of PNS, which prevented full compaction with normal coarse aggregate hence, affecting the strength of the concrete. Furthermore as recorded by [5], the weak bond between PNS and cement paste as compared to the control samples may have caused the reduction in strength due the smoothness of the sample.

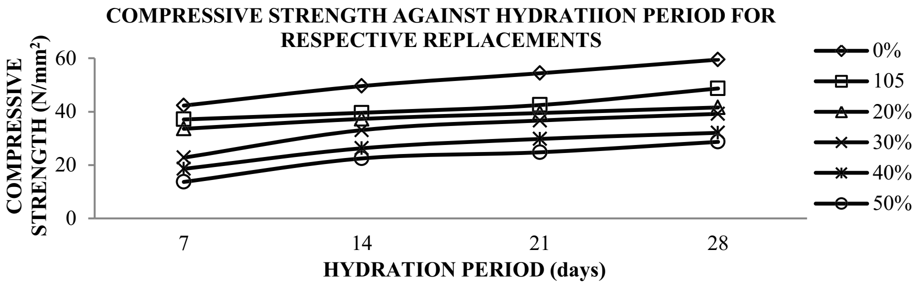

Figure 9. Compressive strength of samples with respect to hydration periods

Nevertheless, with respect to the general strength of samples, it was observed that all mixes produced high strength concrete at age 28days. As defined by [8] a high strength concrete generally is a high performing concrete with specific compressive strength of up to 40 MPa (6000psi) and beyond. Considering the 28days in reference to hydration periods; 0, 10 and 20%PNS satisfied the requirements of high strength concrete. Even though at 7days early hydration stages, some concrete samples obtained very high strength values. The compressive strength developed for 50%PNS in 28days, was above the range of 20.10–24.20 N/mm^2 requirement for structural LWGC elements.

4. Conclusions

This study illustrated some mechanical properties of green concrete produced from PNS as coarse aggregate. The abundance of PNS in West Africa paved way for PNS to be studied as replacement for coarse aggregate in green concrete. From a perspective of strength and workability, and in conformance to waste recycled materials, PNS aggregate was founded to be a good substitute of coarse aggregate in concrete production. From results and analysis however, the following conclusions were reached;

- The PNS samples had relative medium to high workability ranging from 24-47mm for slump height, and 0.85-0.90 for compaction factor.
- Not all PNS concrete samples fully satisfied the structural light weight concrete requirement, with only 28 days 50%PNS concrete sample been within the density limit of 2000 kg/m^3 for structural lightweight concrete although, 10,20,30 and 40%PNS samples could be considered as partial lightweight concrete.
- The general strength of 10,20 and 30%PNS concrete samples produced high strength concrete with compressive strength reaching up to 48.7 N/mm^2 for 28 days, which satisfied the requirement for high strength concrete. The 30%PNS is therefore, the ideal percentage of PNS which is in the boundary limit for the production of high strength concrete, however it is considered as partial lightweight concrete.
- The samples with 10%PNS and 50%PNS had the highest and least compressive strength respectively, which signified that the compressive strength of PNS concrete samples is dependent on the amount of PNS aggregate in the sample; although, the strength of the samples are dependent on the amount of PNS and

the hydration period, the least desirable structural requirement for light weight concrete was met.

- Finally, this paper demonstrates how the use of PNS as yet another option in transforming abundantly available cheap agricultural waste into useful resource for developing countries. Hence, the green concrete product can at the moment be utilized in the construction of light weight simple foundations and masonry walls while further investigations are recommended to be carried out on the effect of admixtures on PNS concrete over an extended hydration period of up to 120days.

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