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Effect of Varying the Proportions of Palm Kernel Shells on the Properties of Concrete Interlocks Cured in Air

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Abstract

This study investigates the properties of concrete interlocks produced using palm kernel shells (PKS) as a partial replacement for conventional building materials, such as granite chips (GNC), to determine the optimal PKS content that meets acceptable standards. Samples of materials required were collected, measured in masses and batched in a mix ratio of 1:2:3. The palm kernel shells replacement varies with granite chips from 0% PKS with 100% GNC to 100% PKS with 0% GNC at 10-unit intervals using water to cement value of 0.5. A total of eleven (11) samples of concrete interlocks were molded, cured for 28days in the air, measured and subjected to compressive strength test. The highest compressive strength of the samples was achieved at 30% PKS with 70% GNC combination, with a compressive strength of 15.13MPa. The sample produced at 30% PKS exceeded the minimum strength requirement of 15.00MPa specified in BS 8110 (1997) and outperformed the compressive strengths of samples from factory X (13.00MPa) and factory Y (10.00MPa). However, the sand mixing ratio in this study was 25% higher than the BS 8110 (1997) recommendation but 50% lower than that used in factory Y. To meet standard specifications, the palm kernel shell content in concrete interlocks should not exceed 30%. Future studies should focus on roughening the smooth surfaces of the shell particles to enhance bonding with other concrete aggregates.

Keywords: Palm kernel shells; granite chips; compressive strength; concrete aggregates; concrete interlocks; mix ratio;30% PKS.

1. Introduction

Nigeria is a country rich in natural resources such as petroleum, minerals, agricultural commodities among others. Palm oil fruits, one of the agricultural products was extensively cultivated and exported, contributing over 60% to the nation's Gross Domestic Product (GDP) before the discovery of crude oil in 1956 (Obuka et al., 2019). Today, Nigeria has been able to cultivate over 4 tons of palm oil fruit per hectare whose shells lack proper disposal method (Udom, 2002). A large percentage of these shells are either dumped into water bodies, causing pollution, or openly burned without recovering energy from the heat. These disposal methods contribute to environmental concerns (Momoh et al., 2022).Palm kernel shells are solid residues generated from the cracking of palm kernel nuts which are in turn gotten from the milling of palm oil fruits (*Elaeis guineensis*). Palm oil fruits are contained in a bunch on a palm oil tree and are grown largely on plantations in southern Nigeria. However, the crops originated from tropical rainforest region of West Africa (Goh et at., 2017).

The disposal of palm kernel shells poses a significant environmental challenge (Samotu et al., 2015), highlighting the need for proper waste management. Economically converting these shells into high-value products can promote their use in various applications, such as the production of blocks, bricks and interlocks for building and construction (Ibearugbulem et al., 2018).

Palm kernel shells are hard (Ikubanni et al., 2020), porous solids (Ndoke, 2006) with spherical shapes (Dagwa et al., 2012), making them suitable for use as road-building materials, aggregates in masonry and concrete works, and other engineering applications (Uchegbulam et al., 2022). Although palm kernel shells contribute to environmental pollution, they have practical applications in concrete interlock production, justifying their consideration for this purpose. Concrete interlocks are masonry units used in landscaping many residential and commercial outdoors (Atoyebi et al., 2022). They have beautiful surface appearances, easy maintenance culture, and less cracking tendencies (Koganti et al., 2020). A good concrete interlock consists of a proper ratio of sand, cement, and granite chips as aggregates (Wasiu et al., 2015).

The mining of conventional building materials such as the granite chips is associated with the emissions of carbon dioxide (CO_2) into the atmosphere (Suthirat et al., 2016). Approximately 3kg of these greenhouse gases are released for every 1ton of granite rocks crushed at quarry sites. These gases often trap heat in the space leading to the warming of the earth thereby causing climate change (Suthirat et al., 2016).

Sand, on the other hand, is mined by dredging it from rivers or pits. However, the recent increase in the demand for sand in building and construction works has led to indiscriminate dredging of near-shores thereby threatening the livelihood of the local communities where the dredging activities are carried out (Adekunbi et al., 2018). The ever-rising cost of these building materials is another problem militating against the infrastructural development of the nation (Gana and Asebiomo, 2019).

The use of palm kernel shells as aggregates in the production of concrete interlocks is believed to bring about a direct declined in the depletion of natural resources such as the granite rocks which will in turn bring a reduction in the emission of carbon dioxide into the atmosphere from the quarries and granite mining sites. This study aims to utilize palm kernel shells in concrete interlock production to assess their effect on the final product and determine the optimal quantity needed to achieve acceptable strength. By addressing disposal challenges and reducing carbon dioxide emissions from rock crushing at quarries, the study contributes to sustainable practices. Additionally, it provides valuable insights for concrete interlock producers, building engineers, and other stakeholders in tackling the high cost of building materials, environmental pollution, and global warming.

2. Materials and Methods

2.1 Materials Used

The materials used in this experimental work are cement, sand, granite chips, palm kernel shells, diesel oil and water. The palm kernel shells used in this study were the waste collected from a home in Ughelli, Nigeria. The shells were crushed, washed, sun dried and sieved to obtain particle sizes ranging from 5mm to 10mm.The granite chips used in this study were procured from a vendor in Ughelli, Nigeria. The chips were washed, sun dried and sieved to obtain particle sizes ranging from 5mm to 10mm.The cement used in this study was the Portland limestone cement produced by Dangote Industries with a strength grade of 42.5N. The sand used in this study was sharp sand dredged from a river with particle sizes passing through the 3mm sieve holes. The water used in this study was a portable fresh water.

2.2 Sample Preparations

A total of eleven (11) samples of concrete interlocks were produced in a small scale in the laboratory. Prior to production, all aggregates (i.e. cement, sand, granites and PKS) were measured in masses and batched in the ratio 1:2:3 with water to cement value of 0.5 as shown in Table 1.

The first sample of concrete interlocks was prepared by mixing cement, sand, and 0% PKS with 100% GNC uniformly with the gradual application of water. (Control sample).The second to eleventh sample of concrete interlocks were prepared by replacing granites chips with 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% of PKS. Each prepared mix sample was poured into diesel-lubricated wooden molds measuring 150mm × 80mm × 50mm. All eleven molds were left to cure in the air for 28 days before the samples were removed for measurement and compressive testing.

Table 1: Weight ratios of aggregates (g) of varying samples of concrete interlocks

Sample Mix	Weight ratios of aggregates in grams 1 : 2 : 3			Water (cm^3)	Water to cement value
	Cement (g)	Sand (g)	PKS/GNC (g)		
0% PKS with 100% GNC	200	400	00/600	100	0.50
10% PKS with 90% GNC	200	400	60/540	100	0.50
20% PKS with 80% GNC	200	400	120/480	100	0.50
30% PKS with 70% GNC	200	400	180/420	100	0.50
40% PKS with 60% GNC	200	400	240/360	100	0.50
50% PKS with 50% GNC	200	400	300/300	100	0.50
60% PKS with 30% GNC	200	400	360/240	100	0.50
70% PKS with 30% GNC	200	400	420/180	100	0.50
80% PKS with 20% GNC	200	400	480/120	100	0.50
90% PKS with 10% GNC	200	400	540/60	100	0.50
100% PKS with 0% GNC	200	400	600/00	100	0.50

Table 2: Dimensions of varying samples of concrete interlocks produced

Sample Mix	Length (cm)	Breadth (cm)	Height (cm)	Volume (cm^3)
0% PKS with 100% GNC	15.00	8.00	5.00	600.00
10% PKS with 90% GNC	15.00	8.00	5.00	600.00
20% PKS with 80% GNC	15.00	8.00	5.00	600.00
30% PKS with 70% GNC	15.00	8.00	5.00	600.00
40% PKS with 60% GNC	15.00	8.00	5.00	600.00
50% PKS with 50% GNC	15.00	8.00	5.00	600.00
60% PKS with 40% GNC	15.00	8.00	5.00	600.00
70% PKS with 30% GNC	15.00	8.00	5.00	600.00
80% PKS with 20% GNC	15.00	8.00	5.00	600.00
90% PKS with 10% GNC	15.00	8.00	5.00	600.00
100% PKS with 0% GNC	15.00	8.00	5.00	600.00

Table 3: Compressive forces or loads of varying samples of the concrete interlocks

Sample Mix	Compressive Length (mm)	Compressive Breadth (mm)	Compressive Area (mm^2)	Compressive Force (KN)
0% PKS with 100% GNC	120.00	50.00	6000	78.50
10% PKS with 90% GNC	120.00	50.00	6000	84.10
20% PKS with 80% GNC	120.00	50.00	6000	86.20
30% PKS with 70% GNC	120.00	50.00	6000	90.80
40% PKS with 60% GNC	120.00	50.00	6000	88.00
50% PKS with 50% GNC	120.00	50.00	6000	74.60
60% PKS with 40% GNC	120.00	50.00	6000	48.90
70% PKS with 30% GNC	120.00	50.00	6000	34.70
80% PKS with 20% GNC	120.00	50.00	6000	27.40
90% PKS with 10% GNC	120.00	50.00	6000	25.60
100% PKS with 0% GNC	120.00	50.00	6000	17.60

2.3 Measurements

The eleven samples of concrete interlocks produced were taken to the laboratory for measurements and compressive strength testing. Prior to testing, the dimensions of each sample produced were taken using a ruler as contained in Table 2 and their masses were measured using Zhengya weighing apparatus. The volume and density of each sample produced were calculated using Equations 1 and 2 respectively.

$$Volume\ of\ each\ sample\ (V)\ =\ l \times b \times h \quad (1)$$

$$Density\ of\ each\ sample\ (e) = \frac{m}{v} \quad (2)$$

2.4 Mechanical Testing

During testing, each of the samples was subjected to the Universal compressive testing machine. Both ends of each sample were crushed in each test session for even distribution of load or force by the machine. The compressive area of each sample was calculated using Equation 3 and the compressive forces were recorded from the testing machine as shown in Table 3.After testing, the compressive strength of each sample tested was calculated using Equation 4and were recorded as shown in Table 4.

$$Compressive\ area\ of\ each\ sample\ (A)\ =\ lc \times bc \quad (3)$$

$$Comprehensive\ strength\ (E) = \frac{F}{A} \quad (4)$$

3. Results and Discussion

3.1 Samples of Concrete Interlocks

Figure 1 shows the eleven concrete interlock samples produced in this study, each with varying percentage replacement ratios of palm kernel shell aggregates with granite chips.

From Figure 1, it can be seen that the surfaces of the samples produced become rougher as the percentage replacement ratios of the palm kernel shells increases from 0% to 100%. This might be due to the spherical shapes of the shells which are too smooth to form proper bonding with the cement, as also reported by Azunna, (2019).

3.2 Experimental Results

Table 4 shows the results of the weight, density and compressive strength tests of the eleven samples of concrete interlocks produced. The weights of the samples were obtained using Zhengya weighing apparatus while the density of each sample produced were calculated using Equation 2. The compressive strength of each sample tested was then calculated using Equation 4.

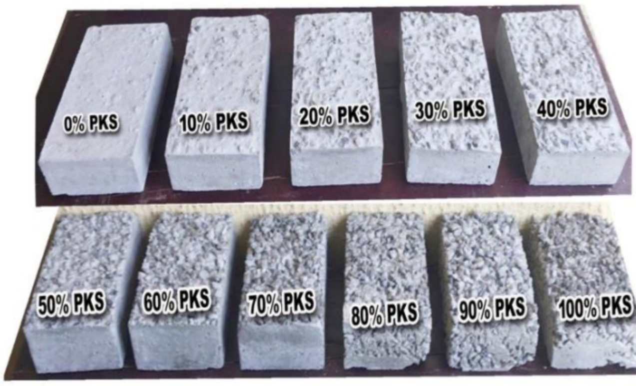

Figure 1: Eleven (11) samples of concrete interlocks with varying percentage ratios of PKS.

Table 4: Weight, Density and Compressive strength test results

Sample Mix	Weight (g)	Density (kg/m^3)	Compressive Strength (MPa)
0% PKS with 100% GNC	1220	2033	13.08
10% PKS with 90% GNC	1280	2133	14.02
20% PKS with 80% GNC	1350	2250	14.37
30% PKS with 70% GNC	1390	2317	15.13
40% PKS with 60% GNC	1170	1950	14.67
50% PKS with 50% GNC	1130	1883	12.43
60% PKS with 40% GNC	1050	1750	8.15
70% PKS with 30% GNC	980	1633	5.78
80% PKS with 20% GNC	860	1433	4.57
90% PKS with 10% GNC	840	1400	4.27
100% PKS with 0% GNC	790	1317	2.93

3.2.1 Effect of Weight and Density on the Samples

The frequency polygons in Figures 2 and 3 show similar relationship between the weight and density of the concrete interlocks produced with respect to the percentage replacement ratios of palm kernel shells.

From both Figures 2 and 3, it can be seen that the weight and density of the samples increases as the percentage replacement ratio of the palm kernel shells increases from 0% to 30% and then begin to decrease as the percentage replacement ratio of the palm kernel shells kept on increasing from 30% to 100%. This finding is in line with the work done by Dadzie and Yankah,(2015).

The highest weight and density of the samples in both figures was at the 30% PKS having a weight value of 1390g and density value of 2317kg/m^3 while the lowest weight and density of the samples was at the 100% PKS having a weight value of 790g and density value of 1317kg/m^3.

Also, the control sample was at 0% PKS having a weight value of 1220g and density value of 2033kg/m^3 which were lower than the weights and densities of the samples ranging from 10% PKS to 30% PKS but higher than those ranging from 40% PKS to 100% PKS. This shows that the aggregates in the samples ranging from 10% to 30% are more closely packed and compacted leading to higher weight and density of the samples as posited by Baiden and Asante, (2004).

3.2.2 Effect of Compressive Strength on the Samples

The frequency polygon in Figure 4 shows the relationship between the compressive strength of the samples produced and percentage replacement ratios of the palm kernel shells with granite chips.

From Figure 4, it can be seen that the compressive strength of the samples increases as the percentage replacement ratios of the palm kernel shells increase from 0% to 30% and then begins to decrease as the percentage replacement ratios of the palm kernel shells keep on increasing from 30% to 100%. This phenomenon is in accordance with the work done by Dadzie and Yankah (2015), where the compressive strength of their samples increases as the palm kernel shell replacement increases from 0% to 10% before the strength starts decreasing as the palm kernel shell replacement kept on increasing from 10% upwards. The rise in strength of the samples in this study from 0% PKS to 30% PKS replacement could be attributed to the high concentration value of the chromium element present in palm kernel shells. An experiment carried out by Fono-Tamo and Koya (2015) using X-Ray Fluorescence (XRF) tests showed that palm kernel shells contain 6034ppm of chromium element, a value that is far higher than other constituents of the shells. It is believed that the chromium in palm kernel shells raises the samples' compressive strength from 0% to 30%. However, when the amount of palm kernel shell replacement increased from 30% to 100%, the smoothness and porosities of the shells became more noticeable, resulting in a decrease in the samples' strength. The highest compressive strength of the samples was at the 30% PKS, having a compressive strength value of 15.13MPa, while the lowest compressive strength of the samples was at the 100% PKS, having a compressive strength value of 2.93MPa. Also, the control sample at 0% PKS has a compressive strength value of 13.08MPa, which was lower than thecompressive strength of the samples ranging from 10% PKS to 40% PKS but higher than those ranging from 50% PKS to 100% PKS. These figures suggest that the aggregates of the samples ranging from 10% to 40% contain certain chemical elements influencing the strength increment of the samples.

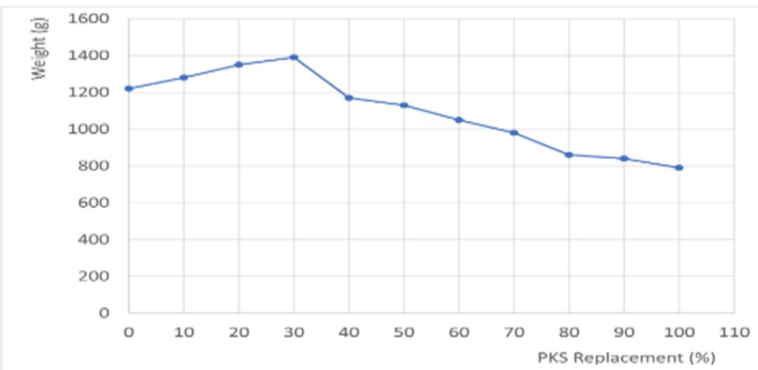

Figure 2: Weight of concrete interlocks versus varying ratios of PKS with GNC

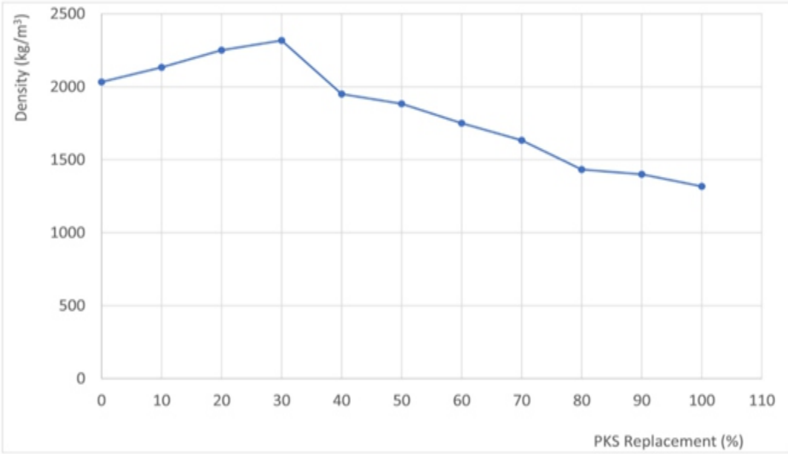

Figure 3: Density of concrete interlocks versus varying ratios of PKS with GNC

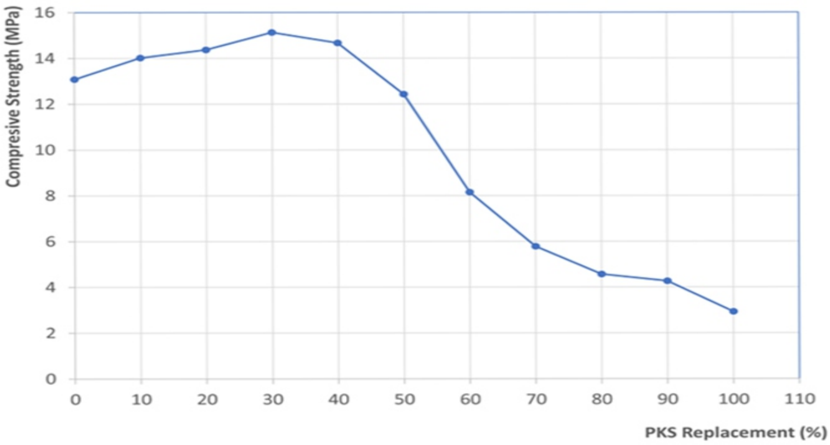

Figure 4: Compressive strength of concrete interlocks versus varying ratios of PKS

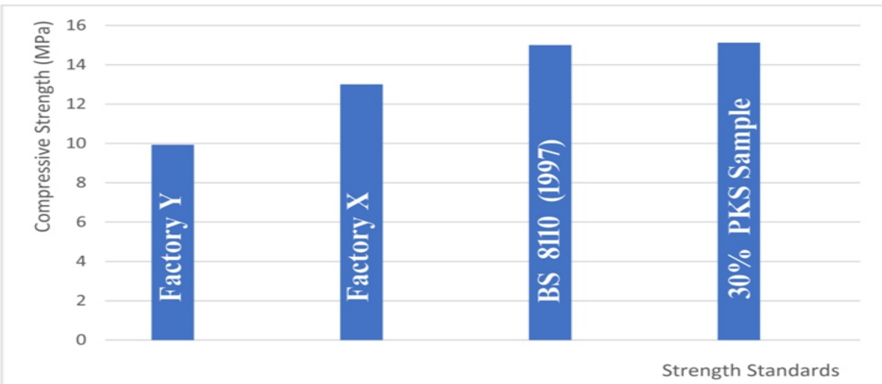

Figure 5: Comparing different compressive strengths

3.3 Comparison of Compressive Strength

BS 8110 (1997) recommends a minimum compressive strength value of 15.00MPa for structural low-weight concretes at 28 curing days having a mixing ratio of 1:1.5:3 (BS 8110-01 1997; Okorafor et al., 2019).Factory X produces samples with an average compressive strength value of 13.00MPa at 28 curing days having a mixing ratio of 1:2:3 (located in Patani Road, Ughelli, Delta State of Nigeria).Factory Y produces samples with an average compressive strength value of 10.00MPa at 28 curing days having a mixing ratio of 1:3:3 (located in Afiesere Road, Ughelli, Delta State of Nigeria).

This study produces samples with an optimal compressive strength value of 15.13MPa at 28 curing days having a mixing ratio of 1:2:3 (study conducted in the mechanical laboratory of the Delta State University, Abraka, Nigeria).

The histogram in Figure 5 compares the compressive strengths as recommended by BS 8110 (1997), factory X and factory Y, as well as the samples produced with 30% PKS in this study.

From Figure 5, it is revealed that the compressive strength of the samples produced at the 30% PKS surpassed the minimum strength recommended by the BS 8110 (1997) as well as the strengths of the samples produced at factories X and Y, respectively. However, the sand mixing ratio of this study was 25% higher than that recommended by the BS 8110 (1997) but 50% lower than that of factory Y.

The analysis of the results thus far has shown that samples of concrete interlocks produced with palm kernel shell aggregates are heavier, denser, and stronger than the conventional concrete interlocks when the percentage replacement ratios of the palm kernel shells do not exceed 30%.

4. Conclusion

The study aimed at the incorporation of palm kernel shells in the production of concrete interlocks. The results obtained so far have shown that the 30% PKS with 70% GNC combination has the highest compressive strength value of 15.13MPa. The analysis of the results has shown that producing concrete interlocks at 30% PKS with 70% GNC combination by factory X and factory Y could reduce palm kernel shell wastes in their immediate environments. It should be noted that the palm kernel shell surfaces were not roughened before using them for the study due to the unavailability of palm kernel shell roughening devices or machines. Future work in this field of study should focus on roughening the surfaces of the shells so as to enhance bonding of the shells with other aggregates of the samples. Concrete interlocks produced with palm kernel shell aggregates in the mixing ratio 1:2:3 at 30% PKS with70% GNC combination therefore have a good commercial potential as a result of their high compressive strength value, which surpasses the strength values recommended by BS 8110 (15.00MPa), factory X (13.00MPa), and factory Y (10.00MPa), respectively.

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