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CHARACTERIZATION OF PULVERIZED PALM KERNEL SHELLS BLOCKS

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Abstract— The study focuses on addressing the environmental issue of palm kernel shell waste by exploring its potential use in improving conventional sandcrete blocks. Palm kernel shells are an abundant waste that contributes to environmental pollution when left untreated. The research aimed to substitute crushed palm kernel shells for sand in sandcrete blocks production. Palm kernel blocks with different proportions (2% to 30%) of crushed palm kernel shells were prepared with a standard mix ratio (1:6 cement to sand), and a fixed 0.5 water-to-cement ratio. After 28 days of curing, the blocks with palm kernel shells

Cement (OPC), Pit Sand (PS), Pulverized Palm Kernel Shell (PPKS)	showed lower density, weaker compressive strength, and higher water absorption compared to the control. Palm kernel shell blocks were found to be lighter compared to conventional sandcrete blocks. Incorporating palm kernel shells in block formulations is a feasible and sustainable solution for addressing weight-related concerns in construction. Palm kernel shell blocks are suitable for building lightweight structures. Using palm kernel shells may offer potential benefits and contribute to sustainable construction.

I. Introduction

Globally, there is an increase in the number of populated areas, and infrastructure development to suit societal needs is also on the rise. However, because of the country's economy and population's rapid growth. More infrastructure is needed to support more residents and components [1]. This has raised the demand for concrete building blocks. In Ghana, Nigeria, and other developing nations, sandcrete blocks are widely employed in construction [2]. Nevertheless, despite the importance of sandcrete blocks as a potential building material, they have some drawbacks, such as being large, heavy, difficult to handle, requiring more labour, and, over time becoming susceptible to water damage [3]. For these reasons, it has become necessary to use alternative building materials. It is impossible to overstate the value of using building materials like sandcrete blocks in construction projects. The demand for sandcrete blocks, which rely on conventional natural aggregates like sand, has led to a substantial depletion of resources [4]. Consequently, there is a growing recognition of the necessity to explore sustainable and renewable alternative construction materials. Agricultural by-products such as rice husk, palm kernel shells, sawdust, and coconut shells can serve as viable substitutes or additives for conventional construction materials, as suggested by [5].

Using sustainable construction materials like agricultural waste for building development, the construction sector may reduce resource depletion and environmental pollution brought on by construction operations. Each year, the agricultural sector generates a sizable amount of garbage. A significant contributor to environmental pollution stems from the disposal of agricultural industry waste [7]. Agricultural waste like palm kernel shells (PKS) is thrown into our environment, polluting the ecosystem. In contrast to standard sandcrete blocks and concrete, which have a significant dead load, PKS wastes can be used as lightweight aggregate to create lightweight construction materials like palm kernel shell blocks. Therefore, using palm kernel shell waste in construction projects will aid in lowering the rate at which non-renewable natural resources are being used.

Researchers are focusing on ways to improve conventional building materials using locally produced materials, industrial by-products, and agricultural waste items such as palm kernel shells [8]. Over the past few years, palm oil production has grown globally. According to [9], 45.1 million tons of palm oil were produced in the years 2009–2010. Palm kernel shells are primarily used as a source of fuel for residential and industrial uses. The disposal of the shells is an environmental issue of concern [10]. Research has shown that PKS are agricultural by-products that can be used to enhance the properties of some building materials in the regions where they are grown [9]. PKS waste has achieved success in the building sector. Over the last few decades, scientists and researchers have used PKS as an alternative to conventional materials in building and road construction.

A study on using PKS as a partial substitute for coarse aggregate affects the compressive strength of concrete [5], in the research, the coarse aggregate was partially replaced with 10, 25, 50, 75, and 100 % palm kernel shells using a mixed proportion of 1:2:4. The research findings indicate that palm kernel shell concrete exhibits normal water absorption levels compared to regular concrete. When substituting 10 % and 25 % of the content with PKS, it resulted in compressive strengths of 4.78 N/mm^2 and 4.44 N/mm^2, respectively. The study suggests that PKS can be used to partially replace coarse aggregate in lightweight concrete, with a recommended maximum replacement rate of 25 % [5]. This shows that PKS has potential for use in lightweight structures and moderate-strength applications.

Evaluation of PKS as an aggregate in concrete and laterite blocks revealed that a 1:4 ratio of laterite to kernel shells improved block strength by 15 % compared to plain laterite blocks [11]. The study revealed that PKS-reinforced laterite blocks even outperformed commonly used sandcrete blocks in terms of strength. However, when PKS replaced crushed stone aggregate, concrete block strength decreased by approximately 50 %, indicating that PKS is not a very suitable substitute for crushed stone aggregates in concrete [11].

According to [10], investigation of the association between PKS aggregate content and block density, the density of a block decreases as PKS aggregate content increases. Comparing the block with 10 % PKS aggregate replacement to the control sample with 0 % PKS aggregate replacement, it was discovered that the control block is denser. Additionally, it should be noted that the density value drops starting at 20 % PKS replacement. The study further suggests that if the emphasis is exclusively on weight, a 10 % substitution is ideal for a better partial replacement of the PKS percentage for sand in block manufacture. According to a

[10] study, an increase in PKS causes the PKS blocks to absorb more water. The study presented a convincing case that the PKS aggregates' coarse texture tends to make the block permeable as PKS content rises, which can explain the observed increase in water absorption as PKS content rises. The study found that sandcrete blocks made with more than 40 % PKS aggregate substitution for sand content are likely to be more porous since their water absorption is below the 130 kg/m^3 recommended by [12]. To determine whether the high percentage substitution of PKS aggregates in the production of sandcrete blocks would affect the sandcrete blocks regarding density, water absorption, and compressive strength, the study by [10], suggested that the PKS intended for concrete block should be pulverized to more fine particles to meet the fine aggregate grading requirement. This will help establish possible variations from those obtained in previous studies.

The effect of mixed design and different PKS particle sizes on the properties of sandcrete blocks was also investigated [9]. In the study, the size of the blocks created was 200 mm x 100 mm x 80 mm. The ratio of cement, sand, and PKS was designed as 1:1:1, 1:1:2, and 1:1:3 by the volume ratio, according to the research, the PKS particle size was retained on a 2.36 mm sieve (Size A), (b) retained on a 4.75 sieve (Size B), and (c) retained on a 9.5 mm sieve (Size C) respectively was used to carry out the study. The variation of compressive strength of the PKS blocks and the control specimens revealed that the compressive strength is affected by the mix proportion and the PKS sizes. The highest compressive strength of the PKS blocks was about 23 MPa which was obtained by mixing a proportion of 1:1:1 under dry conditions. In general, the compressive strength of the PKS block mixtures was higher than the control specimen. The maximum strength was obtained by mixing a proportion of 1:1:1 for both dry and wet treatment, while the lowest strength was obtained by mixing a proportion of 1:1:3. [9] Further argue that the addition of a large amount of PKS tends to decrease the compressive strength.

[13] Conducted a study, where they incorporated ground palm kernel shells (GPK) to partially replace ordinary Portland cement (OPC) in concrete. They assessed the optimal strength using non-destructive ultrasonic pulse velocity techniques on both cubic and cylindrical concrete samples. The GPK shells were blended into the concrete mix at varying proportions, ranging from 0 % to 50 % by weight of cement, using a mix ratio of 1:2:4 and a water-to-cement ratio of 0.8. The concrete specimens were subjected to testing at different curing periods: 7 days, 28 days, and 60 days for cubes, and 7 days and 28 days for cylinders [13]. The modulus of elasticity for the GPK shells in concrete was determined to be 31.30 MPa after 7 days of curing. Comparatively, when compared to the control mix, the modulus of elasticity of these concrete mixes decreased by 63.9 %, 60.93 %, 44.63 %, 30.13 %, and 21.89 % at various replacement percentages. After 28 days of curing, the modulus of elasticity for the control mix increased to 41.35 MPa, showing a growth of approximately 32.11 %. The modulus of elasticity ranged from 11.10 MPa to 30.72 MPa at this curing age, depending on the percentage of GPK shell replacement.

The study's findings indicated that as the mix ratio increased, the density and modulus of elasticity decreased, while these values increased across all mix ratios as the curing period extended. Notably, the "fuel" shell specimens exhibited higher density and elasticity modulus compared to regular shells [13].

The study by [14] suggested that PKS can be utilized to create sustainable lightweight construction materials. Therefore, using PKS waste in construction will aid in lowering the rate at which non-renewable natural resources such as fine aggregates are being degraded, thereby assisting in the conservation of non-renewable natural resources.

II. Materials and Methods

A. Materials

The study utilized Pulverized Palm Kernel Shells (PPKS), pit sand (PS), and Ordinary Portland Cement (OPC) to create the specimens. The palm kernel shells and pit sand were sourced from Kumasi, Ghana, which met the standards [15]. The PKS waste shown in Figures 1(a) and 1(b) were collected, washed, sun-dried for seven days, and then finely pulverized, as shown in Figure 1(c). Particle sizes of the PS and PPKS were determined according to [16]. ASTM D3282 (2009), and their Fineness Moduli (FM) were evaluated following [17]. ASTM C136 (2006). For all mixtures, OPC grade 42.5R from GHACEM, which met the specifications of [18]. ASTM C150 (2004), was chosen. Additionally, tap water was used for specimen preparation, which complied with the standards [19]. ASTM C1602/C1602M (2012).

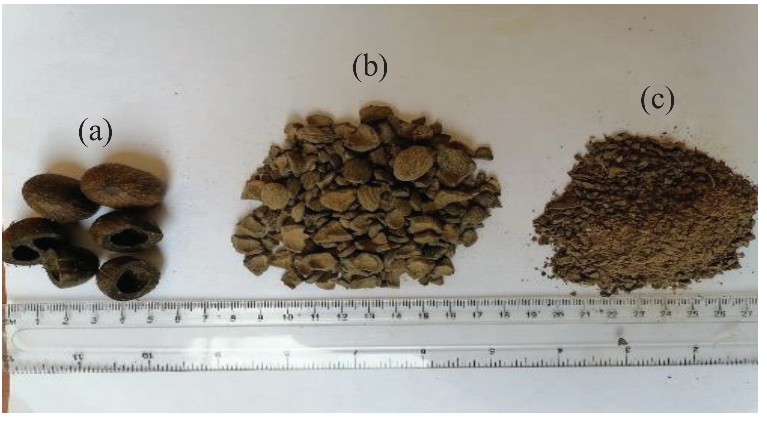

Figure 1: Palm Kernel Shells (PKS)

B. Preparation of Specimens

This study used sandcrete blocks of size 100 mm x 100 mm x 140 mm for the experiment. PPKS content of 2%, 4%, 6%, 8%, 10%, 20%, and 30% by weight of pit sand were used for preparing the specimens. The mixed design details for the study are summarised in Table 1. The 0% PPKS content serves as a control specimen for this study. A mixed ratio of 1:6 (cement: sand) at a constant water-cement ratio of 0.5 was used for preparing the specimens following [10].

The materials were mixed mechanically by an electric pan mixer, as shown in Figure 2(a). The cement was first measured into the pan, followed by PS, and PPKS was finally batched into the pan. The electric pan mixer was turned on and allowed to rotate until a homogeneous mix was attained. Batched water was then added to the mix in the pan and allowed to rotate until a homogenous mix was obtained. A hydraulic compressed block moulding machine shown in Figure 2(b) was used for moulding the specimens. Mould oil was applied to the interior of the metal mould to ensure the smooth release of specimens from the metal mould. The mass of the mixture for each specimen was weighed and placed in a metal mould in three layers. Each layer was gently compacted seven times with a wooden rod and the top level.

Table 1: Mix Design and Quantity of Materials Per Mould

Mix Design	Cement (kg)	Sand (kg)	PKS (kg)	Water (kg)	Cement/Sand Ratio	Water/Cement Ratio
0% PPKS	0.429	2.571	0.000	0.214	1:6	0.5
2% PPKS	0.429	2.520	0.051	0.214	1:6	0.5
4% PPKS	0.429	2.468	0.103	0.214	1:6	0.5
6% PPKS	0.429	2.028	0.543	0.214	1:6	0.5
8% PPKS	0.429	2.365	0.206	0.214	1:6	0.5
10% PPKS	0.429	2.314	0.257	0.214	1:6	0.5
20% PPKS	0.429	2.057	0.514	0.214	1:6	0.5
30% PPKS	0.429	1.800	0.771	0.214	1 6	0.5

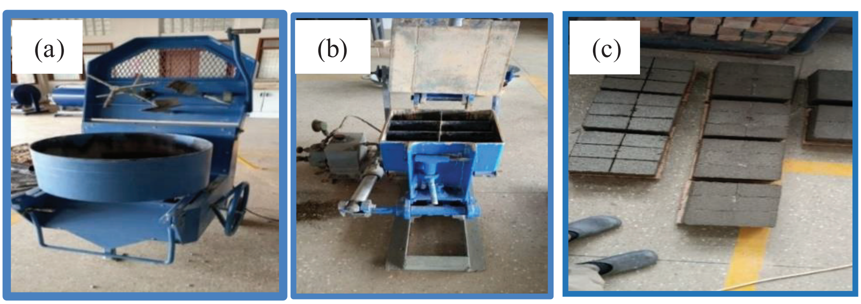

Figure 2: (a) Electric pan mixer, (b) Hydraulic compressed block moulding machine, (c) Specimen Samples

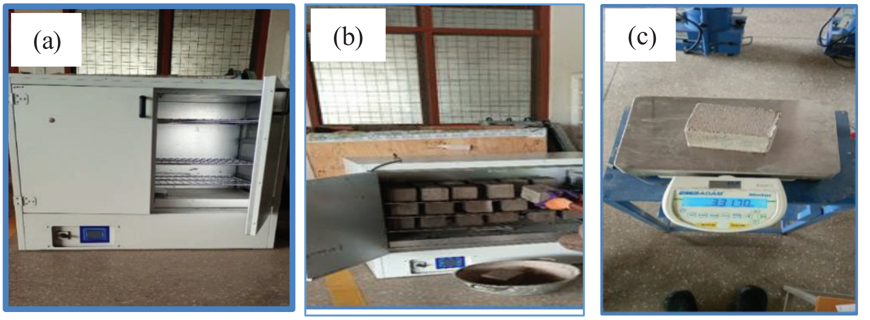

Figure 3: (a) Oven, (b) Specimens conditioned in the oven, (c) Mass of specimens on an electronic balance

The top plate of the metal mould was placed in position and tightened firmly. Finally, a pressure of 140 bar was applied from the hydraulic jack of the mould until the materials in the mould were fully compressed. The specimens were gently removed from the mould and placed under a shed for drying, as shown in Figure 2(c). Curing of the specimens was done under wet jute sacks at an average temperature of 27 °C for 28 days. The specimens cured for 28 days were used to analyse density, water absorption, and compressive strength.

After 28 curing days, the samples were subjected to a controlled temperature of 105 °C in a ventilated oven, as illustrated in Figure 3(a) and 3(b), to ensure consistent mass. The masses of the oven-dried samples were measured using the electronic balance depicted in Figure 3(c). The volume of the samples was measured and documented. Subsequently, the samples underwent testing for parameters such as density, water absorption, and compressive strength. To ascertain the dry density, the study followed the guidelines outlined in [20]. Water absorption was determined following [21]. Crushing of the specimens was done using a universal testing machine, adhering to [21].

III. Results and Discussion

A. Particle Size Distribution of Pit Sand (PS) and Pulverized Palm Kernel Shells (PPKS)

The particle size analysis of the PS and PPKS respectively shown in Tables 2 and 3 were assessed using [16]. In the PS sample, it was observed that 0%, 0%, 90.05%, and 9.5% of the particles were clay, silt, sand, and gravel, respectively as depicted in Figure 4. Conversely, the PPKS aggregate had particle sizes resembling clay, silt, sand, and gravel at 0%, 0%, 83.2%, and 16.8%, respectively as illustrated in Figure 5.

Table 2: Particle Size Distribution Table of Pit Sand

Sieve Sizes (mm)	Weight Retained (kg)	Weight Retained (%)	Cumulative Weight Retained (%)	Weight Passing (kg)	Weight Passing (%)
5.00	0	0	0	0.815	100
2.36	0.063	7.730	7.730	0.752	92.270
1.18	0.042	5.153	12.883	0.710	82.117
0.60	0.374	45.890	58.773	0.336	41.227
0.30	0.262	32.147	90.920	0.074	9.080
0.15	0.053	6.503	97.423	0.021	2.577
Pan	0.021	2.577	100	0	0
Total	**0.815**	**100**	**∑F = 267.729**		

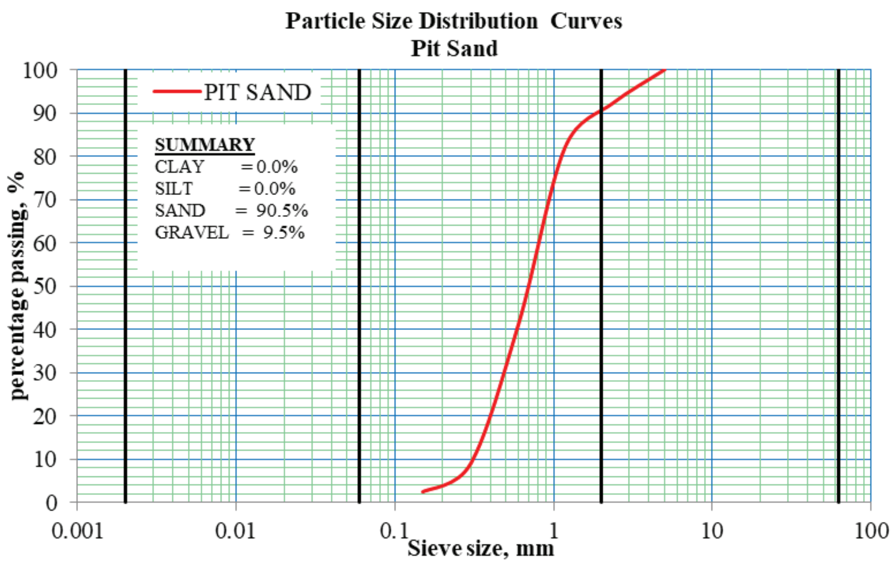

Figure 4: Particle Size Distribution Curve of Pit Sand

Table 3: Particle Size Distribution Table of PPKS

Sieve Sizes (mm)	Weight Retained (kg)	Weight Retained (%)	Cumulative Weight Retained (%)	Weight Passing (kg)	Weight Passing (%)
5.00	0	0	0	1.00	100
2.36	0.142	14.200	14.200	0.858	85.800
1.18	0.132	13.200	27.400	0.726	72.600
0.60	0.395	39.500	66.900	0.331	33.100
0.30	0.256	25.600	92.500	0.075	7.500
0.15	0.067	6.700	99.200	0.008	0.800
Pan	0.008	0.800	100	0	0
Total	**1.00**	**100**	**∑F = 300.2**		

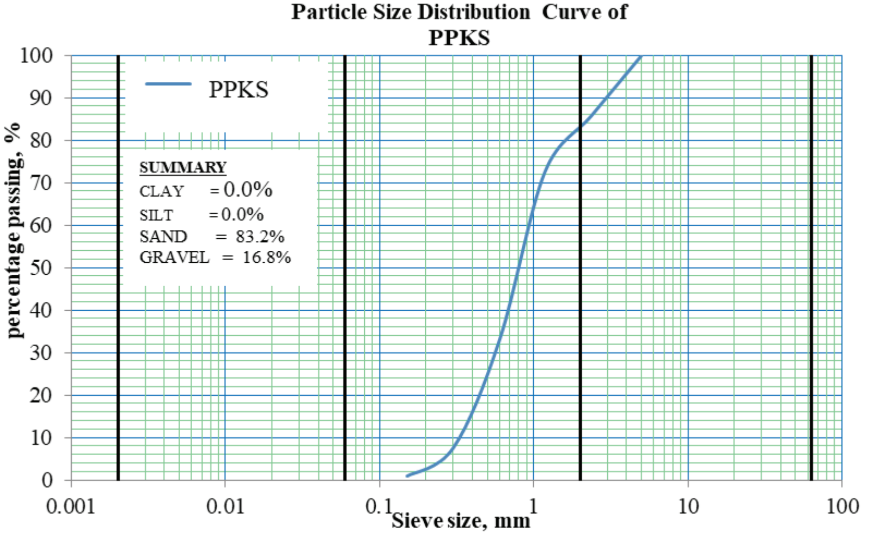

Figure 5: Particle Size Distribution Curve of PPKS

$$FM\ of\ PS = \frac{F\Sigma}{100} = \frac{267.729}{100} = 2.7 \quad (1)$$

where:

FM = Fineness Modulus

PS = Pit Sand

$F\Sigma$ = Summation of Cumulative Weight Retained (%)

$$FM\ of\ PPKS = \frac{F\Sigma}{100} = \frac{300.2}{100} = 3.0 \quad (2)$$

where:

FM = Fineness Modulus

$PPKS$ = Pulverized Palm Kernel Shells

$F\Sigma$ = Summation of Cumulative Weight Retained (%)

The Fineness Modulus (FM) for both PS and PPKS was determined following [17]. The FM values for PS and PPKS were 2.7 and 3.0, respectively. These results demonstrate that the particle sizes of PS and PPKS used in the study adhere to the fine aggregate grading criteria recommended by [17], indicated in Table 4.

Table 4: Fineness Modulus (FM) of Various Aggregates [17]

Aggregate Type	Fineness Modulus (FM)	
	Minimum	Maximum
Fine Aggregate	2.0	3.5
Coarse Aggregate 20mm	6.0	6.9
Coarse Aggregate 40mm	6.9	7.5
Coarse Aggregate 75mm	7.5	8.0

B. Density Test

Figure 6 depicts the outcomes of density tests performed on specimens with varying PPKS replacement levels (ranging from 0% to 30%) after 28 days of curing. The control specimen had an average density of 2253.167 kg/m^3. Replacing sand with PPKS content from 2% to 30% led to a reduction in specimen density, ranging from 84% to 40% lower than the control specimen. This finding supports the notion that PKS is a lightweight material, and the density of the PPKS aggregate played a crucial role in lowering specimen density. Density reflects how tightly particles are packed into a given space, with denser materials having more closely packed particles. This observation aligns with the arguments presented by [9].

Additionally, the smooth surface of PPKS particles compared to pit sand may have caused weaker bonding with the cement, resulting in particle disintegration and lower density. These results are consistent with the findings of [10]. It is noteworthy that specimens with 2% and 4% PPKS replacement content exhibited densities of 1885.095 kg/m^3 and 1802.619 kg/m^3, respectively, meeting the minimum density requirement of 1680 kg/m^3 for lightweight non-loadbearing masonry units recommended by [22, 23].

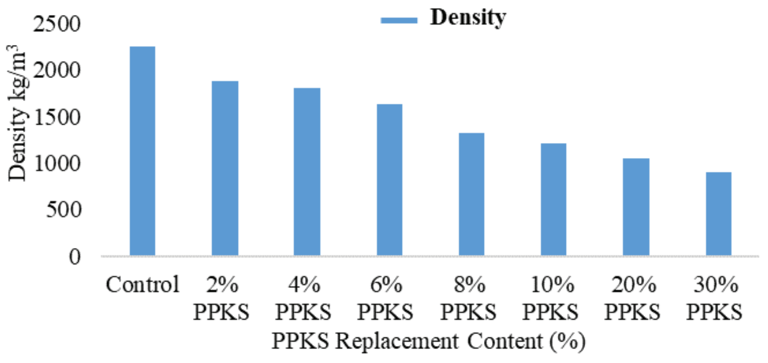

Figure 6: Density of Specimens

C. Water Absorption Test

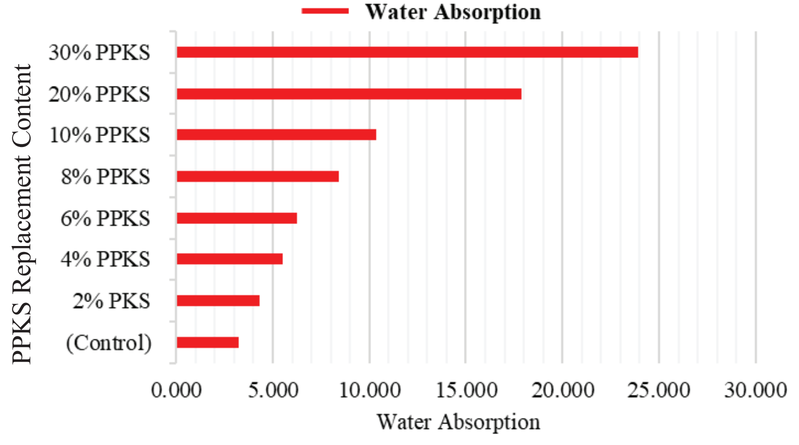

Figure 7: Water Absorption of Specimens

In Figure 7, the study displayed the outcomes of a water absorption test conducted on samples with varying levels of PPKS replacement content (0%, 2%, 4%, 6%, 8%, 10%, 20%, and 30%) after 28 days of curing. The results indicated that the control sample had an average water absorption rate of 3.212%. When sand was replaced with PPKS content ranging from 2% to 30%, the water absorption of the PPKS samples increased, ranging from 1.133% to 20.722%, respectively. The increase in water absorption in specimens of 2% to 30% PPKS content, may suggest the presence of micropores, as argued by [9]. Research has shown that the existence of micropores in a material can led to higher water absorption, and these findings align with the study [10]. Additionally, the water absorption values (4.345%, 5.530%, 6.246%, 8.391%, and 10.344%) for specimens with 2%, 4%, 6%, 8%, and 10% PPKS content were below the recommended maximum water absorption of 12% for masonry units recommended by [12].

D. Compressive Strength Test

Figures 8 and 9 present the results of the compressive strength test and depict specimen crushing, respectively. It is revealed that the control specimen exhibited an average compressive strength of 15.267MPa. Notably, the presence of PPKS had an impact on the compressive strength of the blocks, with conventional sandcrete blocks showing superior strength. As the PPKS replacement content increased from 2% to 30%, there was a corresponding decrease in compressive strength, ranging from 93.019% to 20.957%, respectively. This decline in strength can be attributed to reduced workability in the mixes, affecting the compaction of PPKS specimens and, consequently, reducing their compressive strength. These findings align with those reported in [10]. Additionally, it's worth noting that compressive strengths for specimens with PPKS content of 2%, 4%, 6%, 8%, 10%, and 20% were 14.203MPa, 12.070MPa, 10.637MPa, 10.075MPa, 9.742MPa, and 5.210MPa, respectively, all exceeding the minimum compressive strength requirement of 4.14MPa for non-load bearing masonry units as recommended by [23].

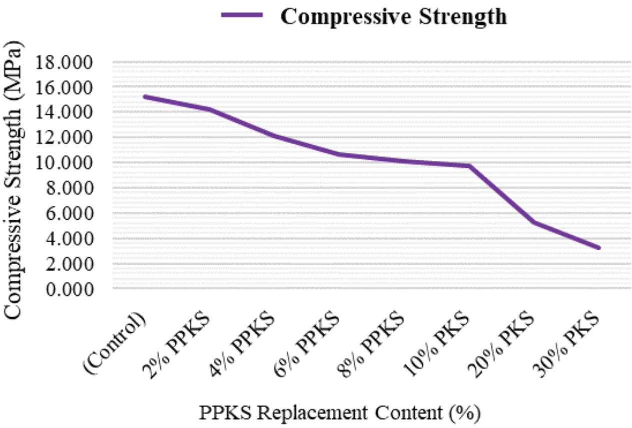

Figure 8: Compressive Strength of Specimens

Figure 9: Crushing of Specimen

E. One-way ANOVA of Compressive Strength

Table 5 shows the results of the analysis of variance (ANOVA) test conducted on compressive strength, along with multiple comparisons against the control group, to assess the variations in the behaviour of different blends. The ANOVA test indicated significant differences in the behaviour of the construction and control groups, with p-values of ≤ 0.001 and ≤ 0.039, respectively. Additionally, the outcomes of the multiple comparison test suggested that the control specimen may outperform PPKS specimens ranging from 2% to 30% for construction purposes. This highlights that the replacement of sand with PPKS has a substantial and negative impact on the compressive strength of the specimens. Therefore, the ANOVA analyses provide compelling evidence that substituting sand with PPKS will adversely affect the compressive strength, density, and water absorption of PKS blocks. Nevertheless, it's worth noting that the compressive strength achieved by specimens containing 2% to 20% PPKS in this study is suitable for use in non-load-bearing walls.

Table 5: Descriptive and One-way ANOVA of Compressive Strength

Treatment Name	N	Missing	Mean	Std Dev	SEM
Control (0%)	3	0	15.267	0.751	0.433
2%	3	0	14.203	0.725	0.418
4%	3	0	12.070	0.901	0.520
6%	3	0	10.637	0.467	0.270
8%	3	0	10.075	0.158	0.0910
10%	3	0	9.742	0.166	0.0961
20%	3	0	5.210	0.274	0.158
30%	3	0	3.200	0.200	0.115

SEM: standard error of the mean; Std Dev: standard deviation

Comparison	Diff of Means	T	P	P<0.050
Control vs. 30%	12.067	25.861	<0.001	Yes
Control vs. 20%	10.056	21.552	<0.001	Yes
Control vs. 10%	5.525	11.841	<0.001	Yes
Control vs. 8%	5.191	11.126	<0.001	Yes
Control vs. 6%	4.630	9.922	<0.001	Yes
Control vs. 4%	3.196	6.850	<0.001	Yes
Control vs. 2%	1.064	2.280	0.039	Yes

IV. Conclusion

The study emphasises the importance of creating new solutions to address environmental issues, such as utilizing palm kernel shells (PKS) for sustainable construction. PKS, known for its low density, helps decrease the overall weight of PKS blocks compared to traditional sandcrete blocks. Using PKS in block production is a practical and eco-friendly way to address construction weight concerns by significantly reducing the dead load of a building. PKS blocks are ideal for constructing lightweight structures, offering possible advantages and promoting sustainable construction, while also following the principles of a circular economy in the management of PKS waste.

V. Acknowledgement

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