Utilization of Palm Kernel Shell as Coarse Aggregate Replacement in Pervious Concrete: An Alternative Approach to Sustainable Pervious Concrete Walkway

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Abstract: Increased urbanization in many cities of the world brings with it the problem of multiplied impervious surfaces on infrastructure like roads. Using pervious instead of impervious surfaces will address these concerns, the use of palm kernel shell (PKS) to replace granite in the matrix will further address the cost and environmental worries. A Pervious Concrete walkway was constructed on an unpaved, waterlogged stretch using agricultural waste product-Palm Kernel Shell (PKS) to replace conventional granite in the concrete matrix. The initial laboratory tests were carried out in accordance with BS 812, Part 101 from 1984 to 1990, and Parts 110 and 112 from 1990. The batching process was weighted, with aggregate percentages for partial replacement set at 10%, 20%, 30%, 40%, and 50% PKS. The mix of 70% granite and 30% palm kernel shell produced the highest compressive strength, with values of 5.33 MPa, 6.19 MPa, and 7.36 MPa at 7, 14, and 28 days, respectively. The incorporation of PKS into the pervious concrete walkway effectively reduced waterlogging in the area while posing no environmental concerns..

Keywords: Agricultural Waste, Palm Kernel shell, Pervious Concrete, Walkway

I. Introduction

The rise in the construction of impervious navigable routes has led to increase in the surface runoff during rainfall due to these impervious surfaces inhibiting infiltration of water into the subsoil layers, thereby increasing the surface runoff during rainfall and now resulting in flooding, drainage overflow, and pollutant discharge into water bodies (ACI-522R, 2010, Bright Singh & Murugan**,** 2022). The surface runoff dissolves impurities and other materials on the impervious surface while flowing to discharge at drainage basins. This unfiltered water is released to water bodies without any form of treatment. The construction of more impervious surfaces does not only increase the volume of surface runoff, but it also causes a reduction in the groundwater as the water taken out of the ground is not replenished by infiltration (Yu *et al.,* 2019; Debnath & Sarkar 2020).

The sustainable development goals (SDGs) 3, 6, 11, and 14 seeks to resolve the impact of flooding and the overflow of water bodies, pollution caused as a result of surface run-offs from roads and the unregulated discharge of pollutants into water bodies

The growing emphasis on sustainable construction practices has led to significant innovations in material usage within the construction industry. Among these innovations is pervious concrete, a specialized form of concrete designed to facilitate water drainage and reduce surface runoff. As urbanization increases, the need for effective storm water management solutions has become critical, making pervious concrete an attractive option

Pervious concrete by definition is a composite construction material which is predominantly made up of coarse aggregates, binder, usually cement and water with little or no fine aggregates (ACI-522R, 2010). It is also called porous concrete, permeable concrete, no-fines concrete or gap-graded concrete (Tarangini *et al.*,2022). Typical pervious concrete is made up of open-graded coarse aggregate, Portland cement, (or any other cementitious material as a substitute or supplement), water, and admixtures (AlShareedah & Nassiri, 2021; Kováč & Sičáková, 2018, Taheri *et al.*,2021).

Pervious concrete is characterized by its high porosity, consisting primarily of coarse aggregates, cement, and water, with minimal fine aggregates. This unique composition allows water to permeate through the concrete matrix, thereby reducing runoff and promoting groundwater recharge. The benefits of pervious concrete include mitigating flooding, improving water quality, and contributing to urban heat island mitigation. However, its mechanical properties, particularly compressive and flexural strength, can be lower than those of traditional concrete, which raises concerns about its structural applications

The growing demand for aggregate in the construction of engineering structures has resulted in higher costs and longer project timelines. To address this, engineering-compliant palm kernel shells can be used as a substitute for coarse aggregate in pervious concrete, effectively reducing reliance on traditional materials.

The incorporation of agricultural byproducts, particularly palm kernel shell (PKS), into pervious concrete offers a promising approach to enhance both sustainability and material performance. Palm kernel shell is an agricultural waste product derived from the processing of palm oil. It is lightweight, with a density significantly lower than that of conventional aggregates, and has a porous, fibrous structure. These properties make PKS an attractive candidate for use as an aggregate in concrete applications. The organic composition of PKS, primarily consisting of cellulose, hemicellulose, and lignin, can contribute to its bonding characteristics within the concrete matrix. In addition to being lightweight, palm kernel shell (PKS) boosts the sustainability of

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concrete by repurposing a waste material that would otherwise lead to environmental pollution. Its high porosity enables it to hold moisture, which can assist in the cement hydration process during curing. These features make PKS especially well-suited for use in pervious concrete, where effective drainage and mechanical performance are essential.

environmental pollution

This approach reduces the demand for coarse aggregate (granite) and promotes the recycling of agricultural waste. Uncontrolled accumulated water during rainy seasons can lead to floods, erosion, and runoff, causing damage to lives, properties, and disrupting human activities. Hence, consideration for pervious concrete using palm kernel shell, an agricultural waste instead of granite as replacement for granite in the concrete matrix due to the cost and environmental impact of the coarse aggregate (granite). The one constructed with conventional granite is not cost effective and not environment friendly

II. Review of Literature

Numerous researchers (Sandanayake et al., 2020; Adewuyi and Adegoke, 2008; Ogunfayo et al., 2015; Adeala and Soyemi, 2021) have advanced the study of using local and waste materials in concrete production, highlighting its practical benefits for waste reuse and sustainability. Ayegbusi and Soyemi (2023) examined the mechanical properties of impervious concrete utilizing palm kernel shell (PKS) as a substitute for coarse aggregate. Their study focused on the impact of aggregate on the engineering properties of pervious concrete with a mix ratio of 1:5 and a water-cement (W/C) ratio of 0.35. Shetty (2006) and Ravindrarajah and Yukari (2008) explored the use of pervious concrete, an eco-friendly material for sustainable construction, incorporating varying amounts of low-calcium fly ash as a cement substitute. Characteristics such as porosity, unit weight, compressive strength, weight loss during drying, shrinkage, and water loss have been examined in studies of pervious concrete. Kukami et al. (2013) found that aggregate constitutes 66% to 78% of the concrete. Research has demonstrated that recycling non-biodegradable materials can create robust concrete for non-structural building components (Ghernouti et al., 2009; Chen et al., 2015; Amalu et al., 2016; Sreenath & Harish-Shankar, 2017; Soyemi et al., 2023). Additionally, this approach offers the benefit of producing lightweight materials. The incorporation of palm kernel shell as an aggregate in pervious concrete can lead to significant cost saving and according to Elinwa & Okhide (2020), utilizing PKS can reduce the overall material costs in concrete production, especially in regions where palm oil production is prevalent and the environmental advantages of using palm kernel shell in pervious concrete are multifaceted. Zhang *et al*., (2017) demonstrated that pervious concrete with PKS enhances water infiltration and drainage, which is crucial for managing storm water runoff. This capability reduces the risk of urban flooding and contributes to groundwater recharge, thus supporting local ecosystems. Yeih et al. (2015) studied the engineering properties of pervious concrete made with air-cooled electric arc furnace slag. Their experiments indicated that porous concrete using sand aggregates exhibited greater mechanical strength and water permeability compared to concrete made from natural river gravels. Additionally, the soundness tests showed that aggregates from sand lost less weight than those from river gravel. The results indicated that sand-based pervious concrete outperformed gravel-based in terms of water permeability and compressive strength, achieving a permeability of 0.01 cm/s and a strength exceeding 21 MPa. Yang and Jiang (2003) evaluated pavement material characteristics and introduced porous materials for road use. They found that incorporating superplasticizers, silica fume, and smaller aggregates could enhance the strength of pervious concrete, achieving maximum compressive and flexural strengths of 50 MPa and 6 MPa, respectively. Aginam and Nwakaire (2016) explored the use of quarry dust as a partial substitute for coarse aggregate in concrete. Various ratios of quarry dust were tested, revealing that a 10% replacement of gravel with quarry dust was feasible, with the highest compressive strength of 32.3 N/mm² achieved using Ibeto brand Portland cement. Regular concrete has a density ranging from 2200 kg/m³ to 2600 kg/m³, while lightweight concrete ranges from 300 kg/m³ to 2000 kg/m³. Research on clogging in pervious concrete has been limited, although past studies on pervious asphalt identified drainage issues. Understanding clogging in pervious concrete is crucial for future maintenance planning, as effective water conveyance is a fundamental property. Despite its advantages, pervious concrete has lower compressive strength than traditional concrete, limiting its application in high-traffic areas. Factors like paste strength and thickness significantly influence compressive strength, with recommendations for using smaller aggregates and mineral admixtures to enhance performance. Schaerfer *et al*., (2006) also note that pervious concrete's primary characteristic is its high permeability, with a void ratio of 14% to 31% and a permeability range of 0.0254 to 0.609 cm/s, which tends to increase with higher void ratio.

III. Materials and Methods

The sand, coarse aggregate, and crushed palm kernel shell (PKS) underwent sieve analysis. The coarse aggregate has a nominal size of 12.5 mm and is of normal weight. Properties such as bulk density, particle size distribution, porosity/water absorption, and specific gravity of the coarse aggregate were tested in accordance with BS 812, Part 101 (1984 to 1990), Part 110 (1990), and Part 112 (1990). Specific gravity is crucial when dealing with light and heavyweight concrete. Palm kernel shell has a specific gravity between 1.17 and 1.37, compared to the typical range of 2.5 to 3.0 for other aggregates.

Portable, clean water was used to mix the aggregate efficiently and thoroughly, ensuring no segregation. The water amount was carefully controlled, as it directly affects concrete properties such as workability and compressive strength

Figure 1: Freshly prepared Granite and PKS concrete cube

The compressive strength was tested using a universal testing machine (UTM). Cubes with standard dimensions of 0.15m x 0.15m x 0.15m were demoulded, cured in a curing tank, and allowed to harden for 7, 14, and 28 days before being crushed. The results from the cube crushing tests were recorded. Subsequently, a stretch of pervious walkway was constructed using one of the mixes, capable of accommodating daily foot traffic.

Figure 2: PKS concrete mix

Figure 3: PKS pervious concrete walkway

IV. Results and Discussions

The specific gravity test was carried out on the fully dried aggregate before the addition of water. The results are shown in Table 3. According to British Standard BS 1330, Part 2 (1995), the test procedure and the specific gravity for fine aggregate should range between 2.5 and 3.0.

Table 1: Specific Gravity of the Aggregates

	GRANITE	PALM KERNEL SHELL
EMPTY PYCNOMETER(M1)	0.510KG	0.510KG
DRY SAMPLE(M2)	1.220KG	0.830KG
SAMPPLE + WATER (M3)	1.990KG	1.610KG

PYNOMETER +WATER(M4)	1.531KG	1.523KG
SPECIFIC GRAVITY	2.87	1.36

The results indicate that the specific gravity of granite is 2.87, which falls within the range specified by BS 1130: Part 2: 1995 and is normal for crushed aggregates. PKS, however, has a specific gravity of 1.36, which is lower than the specified range for aggregates according to BS 1130: Part 2: 1995, but aligns with the range for lightweight coarse aggregate, which varies between 1.17 and 1.37.

The aggregate size distribution analysis is conducted to determine the size of aggregates in a sample, in accordance with BS 812: Part 103 (1989). This is typically performed through a gradation process, which involves standard sieves arranged in a specific order to ensure a well-graded aggregate. The impact of particle size distribution cannot be overlooked, as well-graded materials significantly influence the workability of the concrete.

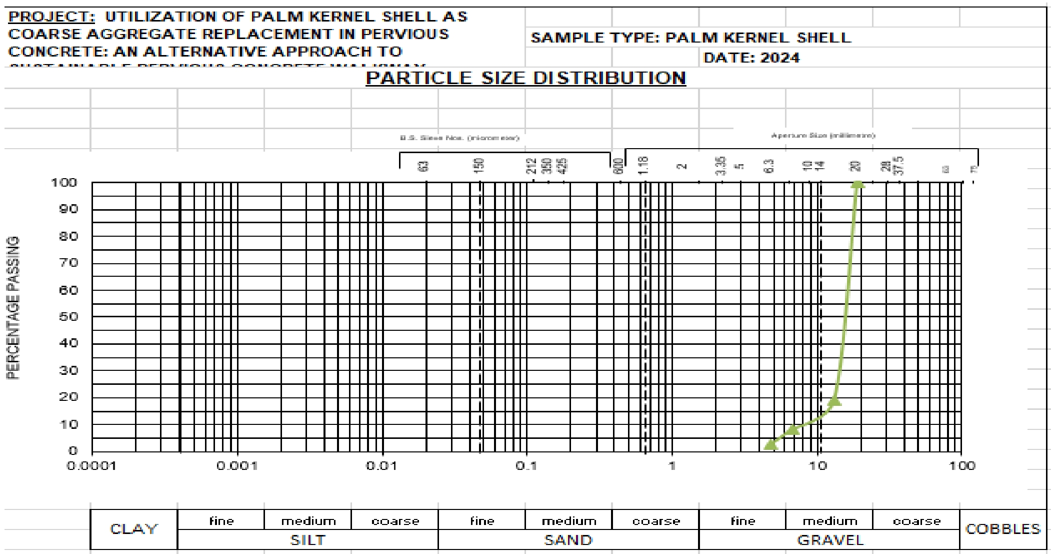

Figure 4: Palm kernel shell distribution

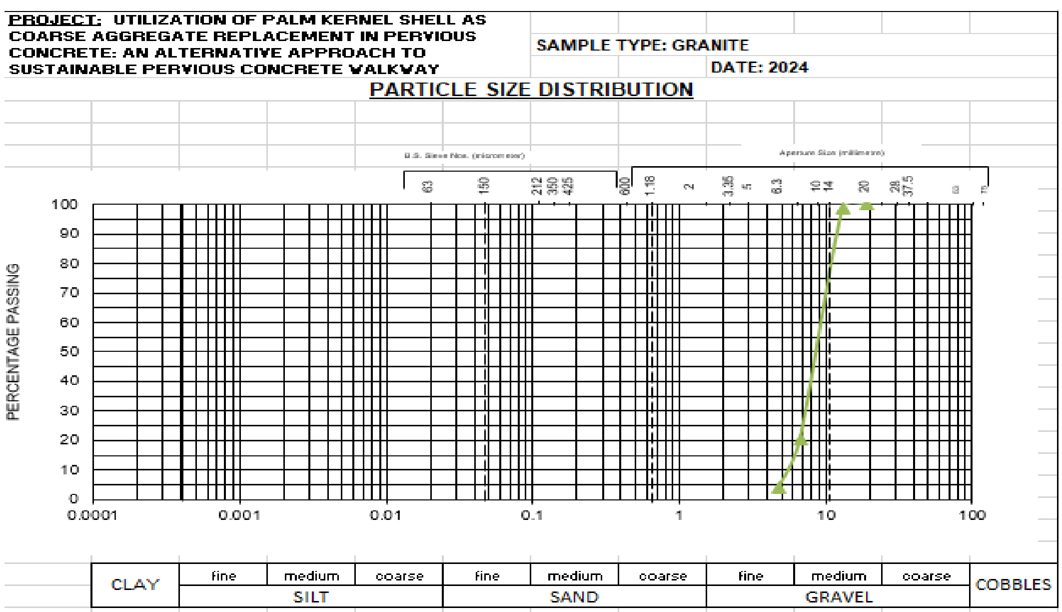

Figure 5: Granite distribution

The results from Figures 4 and 5 indicate similarities in the distribution patterns.

The water absorption rate was assessed on 28-day cubes after they were fully cured and dried. The cubes were entirely immersed in a curing tank for a designated period, and measurements were taken before and after curing. Table 6 presents the water absorption results for each cube.

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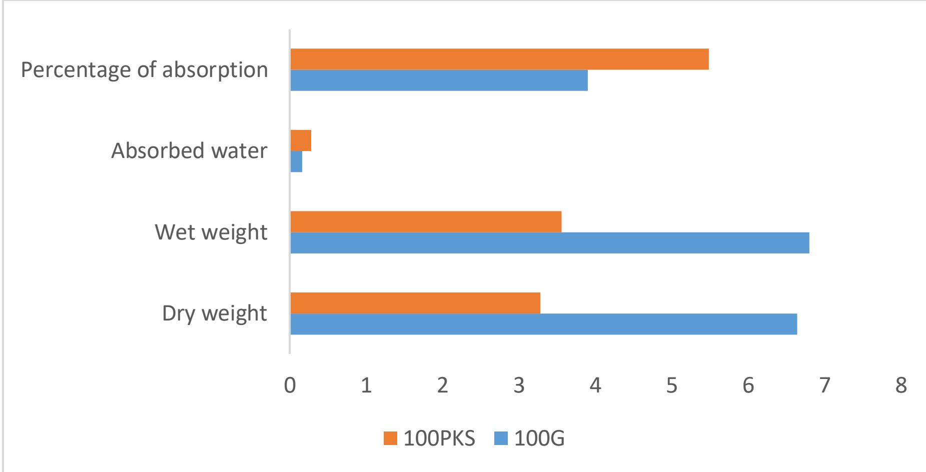

Figure 6: Absorption percentage of control mixes

Figure 6 shows that the water absorption rate for 100% granite is the lowest, while 100% palm kernel shell has a higher absorption rate, as palm kernel shell absorbs more water than granite.

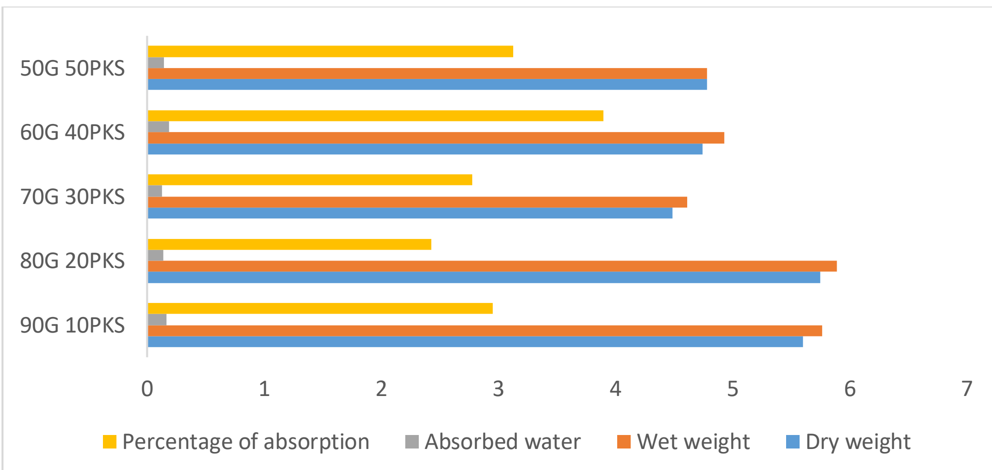

Figure 7: Water absorption rate of pervious concrete with partial replacement of granite with palm kernel shell

Figure 7 indicates that increasing the replacement of granite with PKS leads to greater water absorption, which confirms the perviousness of concrete made with PKS. After establishing the mix ratio of 1:5 and identifying possible replacement ratios for palm kernel shell, an experiment was conducted to evaluate the strength of the cubes. The control mixes used were 100% granite (100G), 90% granite and 10% sand (90G 10S), 100% PKS (100PKS), and 90% PKS and 10% sand (90PKS 10S)

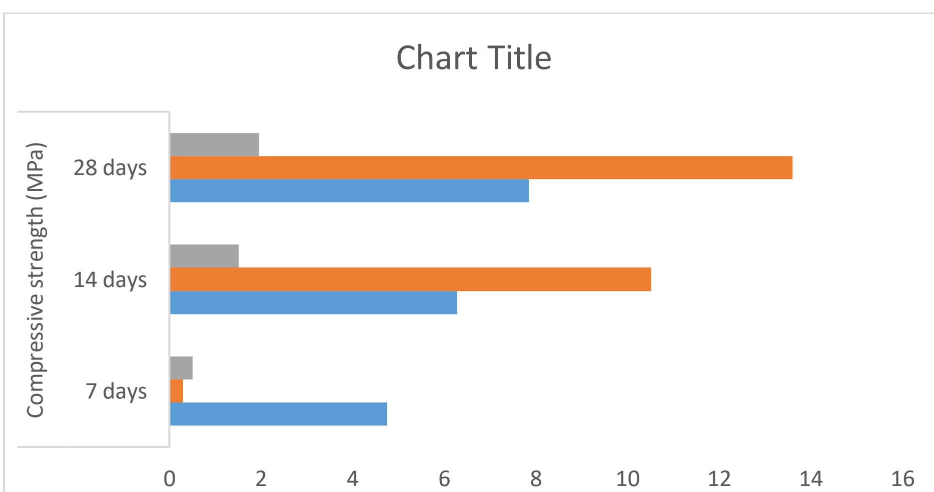

Figure 8: Compressive strength of the control

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In analyzing the compressive strength from Figure 8, the control mixes' strength increased with the number of curing days. Since pervious concrete is known to gradually reach its maximum strength, it is likely that it can achieve greater strength with extended curing periods. The graph illustrates the compressive strength of pervious concrete produced from the control mixes, including partial replacements with palm kernel shell and sand (fine aggregate). These mixes were cured for 7, 14, and 28 days. The peak strength for the control mix was observed with 90% granite and 10% PKS. While granite alone has good strength, it was enhanced by the addition of palm kernel shell. Although the initial strength of the palm kernel shell mixture was low, adding sand to the palm kernel shell increased its strength and load-bearing capacity.

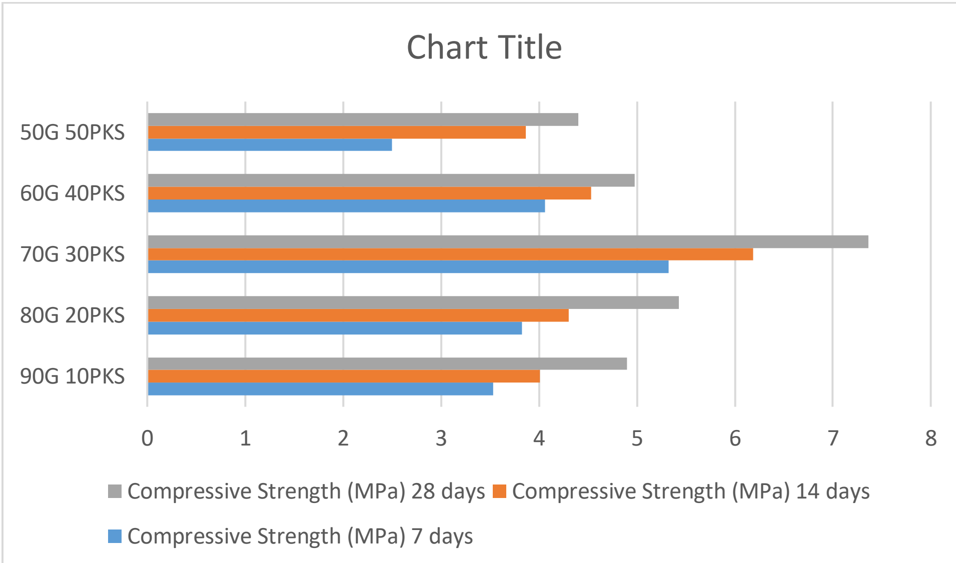

Figure 9: Compressive strength of pervious concrete partial replacement of granite with palm kernel shell

Figure 9 shows that the strength of the pervious concrete increased for each column representing different curing days, with the highest strength observed at 28 days. However, the rows of different mixes indicate that while strength initially increased to a maximum at 70% granite and 30% PKS, further increases in the percentage of PKS led to a decrease in strength.

V. Conclusion

The experiment, analysis, and discussion on the impact of aggregate on pervious concrete have been presented in this paper. The study concluded that palm kernel shell has potential as a partial replacement in pervious concrete without fine aggregate. The compressive strength peaked with a partial replacement of 70% granite and 30% palm kernel shell, achieving values of 5.33 MPa at 7 days, 6.19 MPa at 14 days, and 7.36 MPa at 28 days.

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