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EXPLORING THE USE OF PALM KERNEL SHELL AND PALM FIBRE AS SUSTAINABLE AGGREGATES IN CONCRETE

Ng Hock Seng[a], Ng Chiew Teng[a*], Abdullahi Muktar Bature[a], Mohd Khairi Abu Husain[b], Noor Irza Mohd Zaki[b], Mohamad Shazwan Ahmad Shah[a], Sarehati Umar[a], Nurul 'Azizah Mukhlas[a]

[a]Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia
[b]Faculty of Artificial Intelligence, Universiti Teknologi Malaysia, Jalan Sultan Yahya Petra, 54100 Kuala Lumpur, Malaysia

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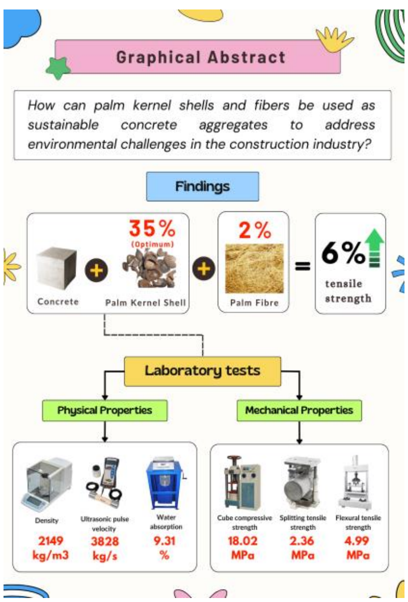
*Corresponding author
chiewteng.ng@utm.my

Graphical abstract



Abstract

Palm kernel shells and palm fibres are leftover materials from the palm oil industry. However, they are not fully utilized and encounter disposal issues, particularly in Malaysia where they are produced in large quantities. This research aims to enhance sustainability and reduce palm waste disposal in Malaysia by exploring the potential of substituting palm waste for conventional aggregates. Six experiments were carried out to assess both the physical properties (including density, UPV, and water absorption) and mechanical properties (such as compressive strength, flexural tensile strength, and splitting tensile strength). The results indicate that a 35% palm kernel shell substitution is optimal, and it was able to produce a concrete specimen of 18 MPa cube strength, approximately 40% lower than the control specimen's 30 MPa. Despite this reduction, the strength is adequate for structures such as driveways, footings, and footpaths. The flexural and splitting tensile strength were the highest, at 4.99 MPa and 2.36 MPa, respectively. This batch also exhibited the best physical properties with a density of 2149 kg/m³, UPV of 3828 km/s, and water absorption of 9.31%. Additionally, the research also concludes that the addition of palm fibre in concrete tends to increase tensile strength by about 6%.

Keywords: Palm Kernel Shell, Palm Fiber, Sustainability, Compressive Strength, Flexural Tensile Strength

Abstrak

Kulit kernel sawit dan serat sawit adalah produk sampingan dari industri minyak sawit tetapi pada masa ini tidak digunakan sepenuhnya dan menghadapi cabaran pelupusan, terutamanya di Malaysia di mana ia dihasilkan secara besar-besaran. Penyelidikan ini bertujuan untuk meningkatkan kelestarian dan mengurangkan pelupusan sisa sawit di Malaysia dengan meneroka potensi penggantian sisa sawit untuk agregat konvensional. Enam ujian dijalankan untuk menilai sifat fizikal (ketumpatan, UPV, dan penyerapan air) dan sifat mekanikal (kekuatan mampatan, kekuatan lenturan, dan kekuatan regangan belah). Keputusan menunjukkan bahawa penggantian 35% kulit kernel sawit adalah yang optimum, dan ia mampu menghasilkan spesimen konkrit dengan kekuatan kubus 18 MPa, kira-kira 40% lebih rendah daripada spesimen kawalan yang mempunyai 30 MPa. Walaupun terdapat pengurangan ini, kekuatan tersebut mencukupi untuk struktur seperti jalan masuk, tapak kaki, dan laluan pejalan kaki. Kekuatan lenturan dan regangan belah adalah yang tertinggi, masing-masing pada 4.99 MPa dan 2.36 MPa. Kumpulan ini juga menunjukkan sifat fizikal terbaik dengan ketumpatan 2149 kg/m³, UPV 3828 m/s, dan penyerapan air sebanyak 9.31%. Selain itu, penyelidikan ini juga menyimpulkan bahawa penambahan serat sawit dalam konkrit cenderung meningkatkan kekuatan regangan sekitar 6%.

1.0 INTRODUCTION

Concrete is one of the most significant building materials, revolutionising construction architecture and leading to innovations such as high-rise buildings and suspended bridges. With the rapid growth of industries and the increasing demand for materials to support the population, the earth is facing significant environmental challenges, and the way to mitigate them is through sustainability [19]. Globally, the construction industry is responsible for almost 40% of energy consumption, 30% of CO2 emissions, and 40% of solid waste generation [25]. Lightweight concrete is a blend of lightweight coarse particles, which leads to a reduced density compared to regular concrete. Structural lightweight concrete has an in-place density ranging from 1440 to 1840 kg/m^3 [27], whereas standard concrete has a density of 2400 kg/m^3. Two main lightweight aggregates are used in lightweight concrete: natural and artificial [11]. Artificial aggregates are usually formed by the process of granulation and hardening of raw materials such as sludge, fly ash, and clay [23]. Natural lightweight aggregates include agricultural by-products like coconut shells, palm kernel shells, date seeds, and periwinkle shells. These alternatives are preferred due to their low cost, environmental friendliness, and regional accessibility, where they are produced in large quantities [15].

Looking at aggregates, one of the main components of concrete, this research will focus on conducting tests and promoting sustainability within the concrete by substituting a certain percentage of the normal aggregates with palm kernel shells and adding palm fibre. Palm kernel shell and fibre are residual materials derived from extracting palm oil. These materials possess specific characteristics that make them well-suited for use as aggregates in concrete [24]. The oval-like structure of the kernel shell aids in the interlocking with cement, sand, and water, whereas palm fibre's high tensile strength (300 - 600 N/mm^2) enhances the workability and adhesion of the concrete mixture [16].

Part of the palm oil fruit, palm kernel shells serve as the outside of the seed and help to shield it from harm. They are can be useful in lightweight construction as a material filler and aggregate replacement [17]. The palm kernel shell concrete has a density that is typically 20% - 25% lower than normal-weight concrete, and its compressive strength normally falls within the range of 20 MPa to 35 MPa [10]. Nevertheless, many researchers have successfully attained impressive compressive strengths of up to 53 MPa after 28 days by including palm kernel shells as coarse aggregate in the concrete mixture. An optimum percentage of kernel shell must be introduced into the concrete mix to achieve these strengths [10]. Palm kernel shell also exhibits good structural, bonding, and flexural capacity behaviour.

In general, palm kernel shell concrete has a compressive strength between 20 and 35 MPa [22]. When substituted in lower percentages, compressive strength of more than 50 MPa has been reported in some cases. However, high incorporation levels of palm kernel shell reduce compressive strength, ranging between 13 and 22 MPa [13]. The uniform surface texture of palm kernel shell aggregates weakens the interfacial zone and decreases the mix's strength. Determining the optimum percentage of palm waste will provide the desired concrete strength. Palm waste is a viable substitute for traditional aggregates in the manufacturing of eco-friendly concrete because it requires minimal energy for collection. In contrast, the substantial energy needed to extract and process regular aggregates leads to excessive carbon emissions. [15].

The main issue within the construction industry today is the overuse of necessary materials, leading to the destruction of natural habitats, industrial expansion, and resource depletion faster than recovery. Obtaining coarse aggregates results in high energy consumption and is mostly non-environmentally friendly. The construction industry constantly looks for sustainable and renewable alternatives to traditional building materials [6]. However, scarcity and environmental concerns associated with traditional aggregates necessitate research into alternative materials. Palm kernel shells and palm fibres are by-products of the palm oil industry but are underutilised and face disposal challenges, especially in countries like Malaysia where they are mass-produced [29]. The process of extracting palm oil results in the creation of waste products such as palm kernel shells, empty fruit bunches, and palm fibre. If not disposed of properly, these by-products can have a detrimental effect on the environment and living organisms [15]. This research focuses on using palm kernel shells and palm fibre because they have the qualities to act as lightweight concrete aggregates based on their physical and mechanical attributes. Palm waste materials are abundant in Malaysia and can serve as an alternative source of concrete aggregates due to their availability and ease of access. The main objectives of this research are:

1) To investigate the physical and mechanical properties of concrete aggregates containing palm waste.
2) To determine the optimum aggregate substitution percentage for palm kernel shell concrete.
3) To identify the properties of the optimum palm kernel shell concrete containing palm fibre.

2.0 METHODOLOGY

The five main constituents utilised to form conventional concrete were cement, water, sand, crushed granite, and palm kernel shell. The palm kernel shells used in this research were obtained from a local palm mill in Johor. They replaced traditional coarse aggregate in substitution percentages of 35%, 45%, and 55%. Additionally, palm fibre was added to the palm kernel shell concrete with a 35% aggregate substitution; the weight of palm fibre added was 2% of the total volume of the concrete mix. Table 1 shows the densities used for different materials.

Table 1 Materials density

Materials	Density (kg/m3)
Ordinary Portland Cement (OPC)	3160
Sand	2441
Water	1000
Crushed stone	2700
Palm kernel shell	1800
Palm fibre	790

2.1 Laboratory Tests

Figure 1 shows the different properties to be studied in this research and their relevant tests.

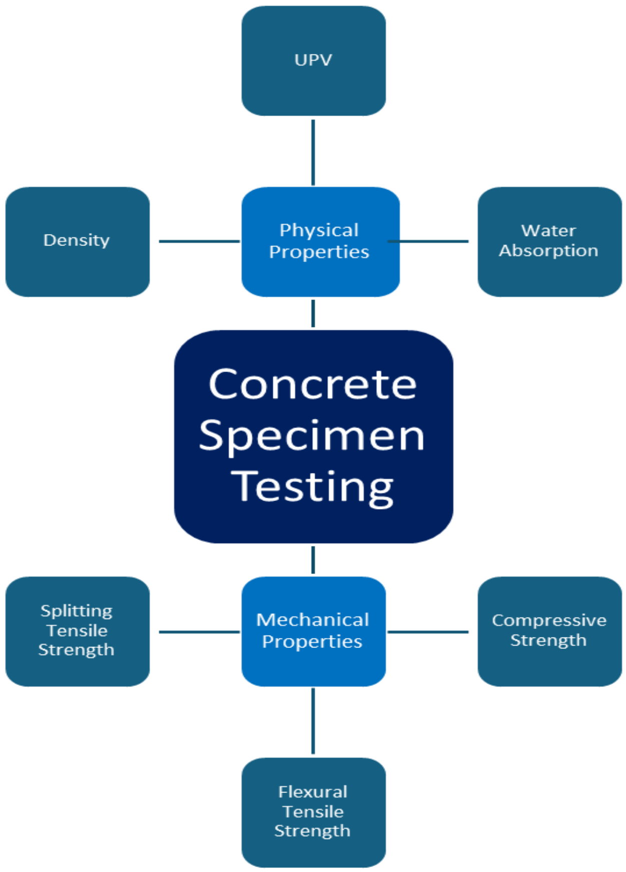


Figure 1 Various laboratory tests

2.2 Concrete Mix Constituents

The concrete mix ratios were determined based on the British DOE Method of Mix Design, and all physical and mechanical properties tests were conducted in accordance with ASTM standards. The type of cement used was OPC of grade 52.5N, aimed at achieving high-quality concrete. Fine grain sand and crushed coarse aggregates of 10 mm size were used, along with tap water for the mixture. The palm kernel shells and palm fibre were acquired from a nearby mill in Johor. There were a total of 45 specimens made. These included 15 cube specimens that measured 100 x 100 x 100 mm, 15 prism specimens that measured 100 x 100 x 500 mm, and 15 cylinder specimens with a diameter of 100 mm and a length of 200 mm. The water-cement ratio employed was 0.55, determined based on the correlation between compressive strength and the free water/cement ratio table in the British DOE Method of Mix Design. Table 2 displays the components of various batches of concrete mix.

2.3 Palm Kernel Shell Percentage Substitution

Using batch 2 as an example (Table 2), the method for determining the weight of palm kernel shell based on volumetric substitution is shown below. Figure 2 illustrates the differences in appearance among the various batches of specimens. The same procedure is carried out to substitute palm fibre.

- Density = mass/volume
- Density of crushed granite = 2700 kg/m^3
- Density of palm kernel shell = 1800 kg/m^3

1) The coarse aggregate weight before substitution should be 720 kg/m^3.
2) Multiply the above weight by the batch's total volume of 0.023 m^3.
3) A coarse aggregate weight of 16.61 kg is obtained for this mix.
4) Volume of coarse aggregate = 16.61(1000)/2700 = 6.152 L
5) 35% of the volume = 0.35*6.152 L = 2.152 L
6) Weight of palm kernel shell = 1800(2.152/1000) = 3.9 kg
7) Weight of coarse aggregate = (6.152-2.152)/1000*2700 = 10.8 kg

Table 2 Concrete mix constituents

Batch	Description	Volume (m^3)	Cement (kg)	Water (kg)	Fine Aggregate (kg)	Coarse Aggregate (kg)	Palm Kernel Shell (kg)	Palm Fibre (kg)	Slump (mm)
1	Control	0.0253	10.8	5.9	25.2	16.61	-	-	90
2	35% PKS	0.0253	10.8	5.9	25.2	10.8	3.9	-	65
3	45% PKS	0.0253	10.8	5.9	25.2	10.0	5.5	-	70
4	55% PKS	0.0253	10.8	5.9	25.2	8.3	6.7	-	60
5	35% PKS + 2% Fibre	0.0253	10.8	5.9	25.2	10.8	3.9	0.4	85

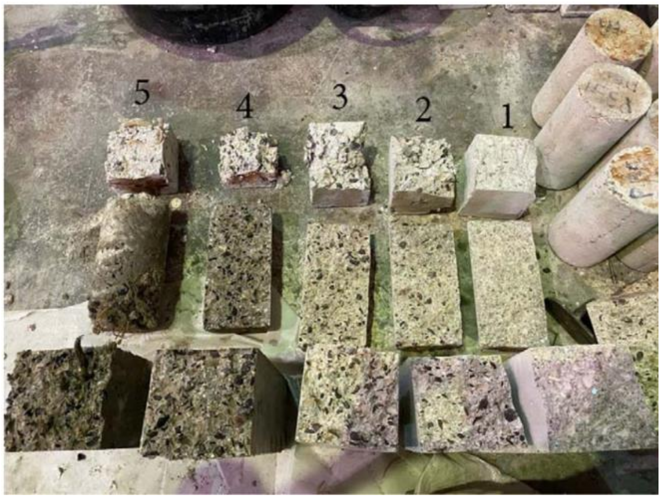


Figure 2 Concrete specimens of batches 1-5

2.4 Preparation of Palm Kernel Shell

Cleaning the palm kernel shell thoroughly is necessary before mixing it with the concrete and adding the remaining ingredients. Preparing the palm kernel shell is important because it removes organic contaminants, dust, fibres, oil, and dirt. To prepare palm kernel shells, they are often washed with detergent and allowed to air dry after being cleaned on their surface naturally [15]. It is essential to properly prepare the palm kernel shell before adding it to the concrete since improper preparation can have a major negative impact on the final product's quality. The amount of water required for hydration might rise when surface coatings such as oil, silt, clay, or fine dust obstruct the bonding between cement paste and palm kernel shell. to counteract the high water absorption property of palm kernel shell, it is also imperative to pre-soak the aggregates for 45 minutes to 1 hour [20]. Pre-treatment of the palm kernel shell shields it against water infiltration and enhances adhesion to the cement matrix. This process safeguards organic polymer substances and the cement matrix [20]. The palm kernel shell is cleaned to remove impurities like dirt or dust as well as harmful materials [3].

2.5 Batching and Specimens

There were five batches of specimens with different palm kernel shell cast proportions. Except for batch 5, which contained palm fibre and was cured for a duration of 7 days because it is easier to test the early strength development and evaluate the impact of palm fibre on the concrete's mechanical properties with limited curing time. All batches were demolished 24 hours subsequent to casting and transferred to the water curing tank for a total of 28 days of curing. The casting process for each batch was consistent throughout the research period. Initially, it was necessary to prepare the materials and ready the steel moulds before beginning the casting. The materials were weighed on a scale based on the volume of concrete to be cast. After gathering the materials, the moulds were tightened well to prevent them from falling apart during vibration. Once the moulds were secured in the vibration chamber, they were greased with oil to prevent the concrete from sticking. The palm kernel shell and coarse and fine aggregates were combined in a concrete mixer and left to solidify for a specified duration prior to the addition of water. The cement was then carefully poured into the mixer as it spun until proper consistency was achieved. Once the concrete looked well mixed, a slump test was performed, and the concrete was placed into the moulds. With the help of the vibration chamber, the concrete was deposited into the moulds, and then the chamber was activated to eliminate trapped air and ensure the absence of voids in the specimens. After casting, the specimens were left to dry for 24 hours and then weighed on a scale to determine the day-one density. Subsequently, they were transferred to the curing tank and left to cure for 28 days, except for batch 5, which was cured for only 7 days. Figure 3 shows the wet mix concrete and the process of placing it into the moulds.

(a) (b)

Figure 3 (a) Wet mix concrete (b) Placement into moulds

2.6 Curing of Concrete

The research focused on examining the compressive strength of samples after 28 days The specified parameters are as follows: The specimens were immersed in water for a duration of 28 days at a temperature of 28°C. The concrete specimens underwent a complete curing process underwater for a total of 28 days. During this period, the compressive, flexural tensile, and splitting tensile strength of the specimens were evaluated. Nevertheless, concrete batch five was subjected to a curing process lasting only 7 days.

2.7 Physical Properties

Three tests were conducted to evaluate physical properties: density, ultrasonic pulse velocity (UPV), and water absorption. Each batch included 9 samples, consisting of 3 cubes, 3 cylinders, and 3 prisms, for both the density and UPV tests to calculate the average values for each property. For the water absorption test, 3 cube samples per batch were used to provide standardised and consistent measurements.

The characteristics of palm kernel shells have been previously studied by [9] with average values based on various data collected from other studies. The palm kernel shell exhibited an average water absorption percentage of 19.6% over a 24-hour period. Additionally, it had a loose bulk density of 530 kg/m3, a compacted bulk density of 600 kg/m3, and an average specific gravity of 1.3.

2.7.1 Density Test

Figure 4 shows a sample being weighed to determine its density. The density of the specimens can be calculated using Equation 1 [14].

$$\text{Density (kg/m}^3) = \text{Mass (kg) / Volume (m}^3) \quad (1)$$

Figure 4 Determining the weight of the specimen

2.7.2 Ultrasonic Pulse Velocity Test

The UPV value is determined by measuring the distance between the frequency transducers and dividing it by the time taken for the sound waves to pass through the specimen. This can be calculated using Equation 2 [12].

$$\text{UPV (m/s)} = \text{Length (m) / Time (s)} \quad (2)$$

The first step in conducting the test is calibrating the machine by passing the sound waves through a material with a pre-determined UPV value (Figure 5). After calibration, grease is applied to the specimens, and the transducers are held at the far ends of the specimens. The time taken for the sound waves to travel through the specimens is then recorded in microseconds (Figure 6).

(a) (b)

Figure 5 (a) Calibrating specimen (b) UPV testing machine

(a) (b)

Figure 6 (a) Grease (b) Machine time readings

2.7.3 Water Absorption Test

The water absorption testing procedure for concrete blocks was performed by ASTM C642 - Standard Test Method for Density, Absorption, and Voids in Hardened Concrete [5]. Equation 3 [7] is used for calculating the water absorption percentage over 48 hours. Figure 7 shows the cubic specimens after ongoing oven drying.

$$\text{Water absorption ratio (\%)} = ((M_A - M_B)/M_A)*100 \quad (3)$$

Where M_A represents the initial mass of the sample before it is dried in an oven, and M_B represents the final mass of the sample after it has been dried in an oven.

Figure 7 Cubic specimens undergoing oven-drying

2.8 Mechanical Properties

Three tests were conducted to evaluate mechanical properties: compressive strength, flexural tensile strength, and splitting tensile strength. For the compressive strength test, each batch utilised 3 cube samples to determine the concrete's resistance to axial loads. The flexural tensile strength test required the use of 3 cylinder samples for each batch to evaluate the concrete's capacity to resist bending forces. Lastly, the splitting tensile strength test used 3 prism samples per batch to determine the tensile capacity of the concrete.

Depending on the physical qualities of palm kernel shell, the mechanical properties of palm kernel shell concrete tend to fluctuate. Palm fibre often has different physical and chemical characteristics depending on the plant species. It is long and stiff, and its physical characteristics allow it to be incorporated into cement or concrete mixes to enhance tensile strength and reduce shrinkage and cracking. Due to its strength, durability, and porous surface shape, palm fibre can mechanically interlock with matrix resin more effectively to create composite materials such as concrete. It behaves like natural fibre reinforcement and improves the mechanical properties of concrete composite. The study conducted by [18], the addition of 1% palm fibre to concrete resulted in a 13.22% increase in compressive strength and an 18.35% increase in flexural tensile strength.

2.8.1 Compressive Strength Test

The cube compressive strength test was conducted following the guidelines of MS EN 12390 [26]. The load was increased at a rate of 6 kN/s ± 2 kN/s until the point of failure. Equation 4 [2] is used to determine the cube compressive strength of the specimens. Figure 8 shows the cubes under compression.

$$\text{Mean Compressive Strength (N/mm}^2\text{) = Load at failure (N) / Surface area (mm}^2\text{)} \quad (4)$$


(a) (b)

Figure 8 (a) Compression before failure (b) Compression after failure

2.8.2 Flexural Tensile Strength Test

The flexural tensile strength was measured in accordance with the MS EN 12390 standard [26] and expressed as the Modulus of Rupture in units of MPa. The load was applied at a rate of 4.7 kN/s ± 1.57 kN/s until failure (Figure 9). Equations 5 [1] and 6 [28] are used to obtain the flexural tensile strength of the prism specimens.

$$\text{Modulus of rupture} = PL/bd^2 \text{ if } a > L/3 \quad (5)$$

$$\text{Modulus of rupture} = 3PL/bd^2 \text{ if } a < L/3 \quad (6)$$

Where P is the maximum applied load (kN), L is the span of the prism (mm), b is the width of the prism (mm), d is the depth of the prism (mm), and a is the position of fracture from near support.

Figure 9 Specimen after failure

2.8.3 Splitting Tensile Strength Test

The splitting tensile strength test was performed by ASTM C496, which is the standard test method for determining the splitting tensile strength of cylindrical concrete specimens [4]. The load was applied at a rate of 0.09 – 0.18 kN/s (Figure 10). Equation 7 [8] is used to obtain the splitting tensile strength of the cylinder specimens.

$$\text{Indirect tensile strength} = 2P / (\pi D \times L) \quad (7)$$

Where P is the maximum load at failure (kN), D is the diameter of the specimen (mm) and L is the length of the specimen (mm).

Figure 10 Splitting tensile strength of cylinder specimen

3.0 RESULTS AND DISCUSSION

3.1 Physical Properties

3.1.1 Density Test

Table 3 shows the changes in density as the curing of concrete specimens occurs. There is a slight constant increase in the density of the specimens after curing, with a consistent increase of 1.5% in the density of the specimens by the end of the curing period. The reduction in density, especially with greater percentage replacements, is anticipated because of the lower density of palm kernel shells compared to crushed aggregates. The control specimen produced a density of 2286 kg/m^3, while the batch 2 specimen came in close second with a density of 2149 kg/m^3. Batches 3 and 4 had density values of 2022 kg/m^3 and 2041 kg/m^3, respectively. Batch 5 achieved a much lower density than batch 2 by about 12%, indicating that adding palm fibre to concrete significantly reduces its density. The projected density for palm kernel shell concrete was in the range of 1750 to 1850 kg/m^3 [27]. However, the specimens produced had much higher densities than expected, with the lowest density obtained being well above 1850 kg/m3.

Table 3 Density test results

Batch	Average 1-day density (kg/m^3)	Average 7-day density (kg/m^3)	Average 28-day density (kg/m^3)
1	2260	-	2286
2	2116	-	2149
3	1993	-	2022
4	2009	-	2041
5	1975	2003	-

3.1.2 Ultrasonic Pulse Velocity Test

Table 4 shows the values obtained for the UPV testing of specimens. Contrary to the expectation of lower UPV value, the specimens showcased positive results, lying within the same range as good quality concrete (3500 - 4500 m/s) [10]. Compared to the control specimens (4343 m/s), these positive results are likely due to the usage of a concrete mixer and vibration chamber during the casting process. The results indicate the absence of voids in the specimens, deeming the test specimens acceptable. Compared to the control batch, batches 2, 3, and 4 had UPV values of 3828 m/s, 3726 m/s, and 3632 m/s, respectively. These values are well within the good range, so the palm kernel shell percentage substitution within the researched range produces concrete with well-distributed aggregates. Batch 5 showed a significantly lower value (3356 m/s) than batch 2 (3838 m/s), suggesting that the inclusion of fibre in the mix resulted in the formation of voids. The quality of concrete in batch 5 is considered fair (3000 - 3500 m/s) [10].

Table 4 Ultrasonic pulse velocity test results

Batch	Average UPV Value (km/s)	Quality of Concrete
1	4343	Good
2	3828	Good
3	3726	Good
4	3632	Good
5	3356	Fair

3.1.3 Water Absorption Test

The results obtained from this test were within the predicted range, as shown in Table 5. Batch 1 had the lowest water absorption ratio of 7.69% as expected. However, it was surprising that batch 3 had a lower water absorption ratio (8.89%) than batch 2 (9.31%), despite containing more palm kernel shells. Another interesting observation is that batch 5 had a water absorption ratio of 8.89% which was lower than batch 2's 9.31%, even though batch 5 contained palm fibre. This indicates that including palm fibre resulted in less water absorption, contrary to the initial belief that its fibrous nature would lead to higher absorption.

Table 5 Water absorption test results

Batch	Average Water Absorption in 48 hours (%)
1	7.69
2	9.31
3	8.89
4	10.99
5	8.89

3.2 Mechanical Properties

3.2.1 Compressive Strength Test

Table 6 displays the compressive strength of cubes for various batches at 7 and 28 days. The findings suggest that as the proportion of palm kernel shells in the concrete increases, there is a gradual reduction in compressive strength. The obtained results lie within the expected range of 15 - 20 MPa [21], making them suitable for non-structural elements. Batch 2 attained the maximum cube compressive strength of 18 MPa and demonstrated the most favourable outcomes during the substitution process. Therefore, batch 2 is declared the optimum substitution percentage for this research. Batches 3 and 4 achieved cube compressive strength values of 14.31 MPa and 13.62 MPa, respectively, with the rate of strength decrement decreasing as higher percentages of palm kernel shell were substituted. For the concrete containing fibre, it achieved a 7-day mean compressive strength value of 11.09 MPa which is about 12% lower compared to batch 2, which achieved a 7-day mean compressive strength of 12.61 MPa. Thus, it can be concluded that adding fibre did not result in positive outcomes concerning cube compressive strength.

Table 6 Cube compressive strength test results

Batch	Cube Compressive Strength at 7 Days (MPa)	Cube Compressive Strength at 28 Days (MPa)
1	-	29.38
2	12.61	18.02
3	-	14.31
4	-	13.62
5	11.09	-

3.2.2 Flexural Tensile Strength Test

Table 7 shows the flexural tensile strength for different batches at 7 and 28 days. The flexural tensile strength was expected to exceed at least 3.0 MPa, which is clearly met as no tensile strength values are less than 3.0 MPa. Batches 2, 3, and 4 achieved flexural tensile strengths of 4.99 MPa, 3.79 MPa and 3.81 MPa, respectively. Batch 2 obtained the highest result even in the tensile strength category, while batches 3 and 4 showed almost the same flexural tensile strengths. This situation indicates there is no significant reduction in tensile stress with higher percentages of palm kernel shell substitution. The batch with palm fibre achieved a flexural tensile strength of 3.72 MPa, which is about 6% higher than batch 2 (3.49 MPa) without palm fibre. This supports the theory that palm fibre aids in better bonding of the aggregates, resulting in slightly higher tensile strength.

Table 7 Flexural tensile strength test results

Batch	Modulus of Rupture at 7 Days (MPa)	Modulus of Rupture at 28 Days (MPa)
1	-	7.02
2	3.49	4.99
3	-	3.79
4	-	3.81
5	3.72	-

3.2.3 Splitting Tensile Strength Test

Table 8 illustrates the splitting tensile strength for various batches at 7 and 28 days. Typically, the splitting tensile strength is estimated to be approximately 10 - 15% of the concrete compressive strength. Batches 1, 2, 3, and 4 showed percentages of 10%, 13%, 13%, and 16%, respectively, when compared with their compressive strength values. Batch 5 had a splitting tensile strength that was 17% of its compressive strength, performing better in tensile strength compared to the concrete with the same percentage of palm kernel shell but no fibre. Batch 2 obtained the highest splitting tensile strength of 2.36 MPa after the control specimen (2.94 MPa), followed by batch 4 (2.15 MPa) and batch 3 (1.91 MPa). Batch 5 obtained a splitting tensile strength value 11% higher than its counterpart with no fibre. Like the flexural tensile strength results, adding fiber in this case also showed an increase in the concrete's ability to resist tensile forces.

Table 8 Splitting tensile strength test results

Batch	Indirect Tensile Strength at 7 Days (MPa)	Indirect Tensile Strength at 28 Days (MPa)
1	-	2.94
2	1.65	2.36
3	-	1.91
4	-	2.15
5	1.86	-

Figure 11 shows the increase or decrease in strength based on percentage substitution. Figure 12 demonstrates the distinction between palm kernel shell concrete with and without the addition of palm fibre. The concrete containing palm fibre exhibited higher flexural and splitting tensile strengths by around 6% and 11%, respectively while displaying a cube compressive strength approximately 12% lower than that of the concrete lacking palm fibre.

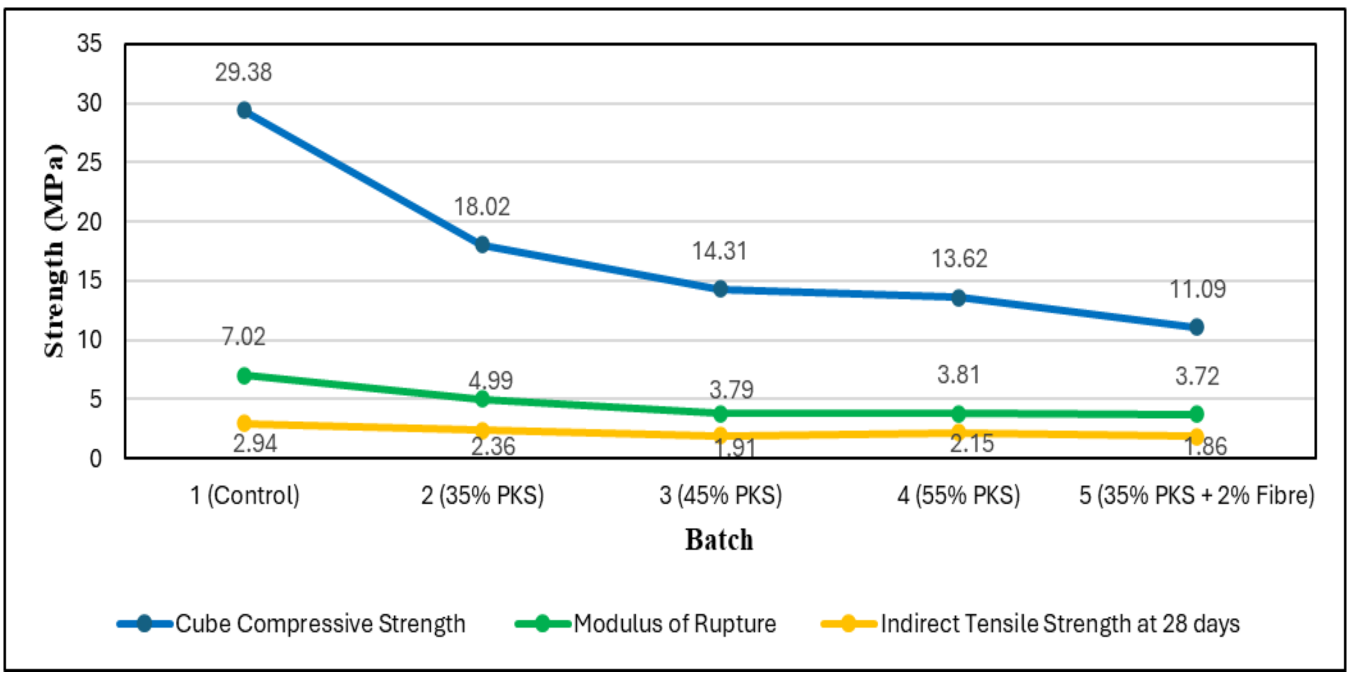


Figure 11 A linear view of the increase/decrease in strength based on percentage substitution

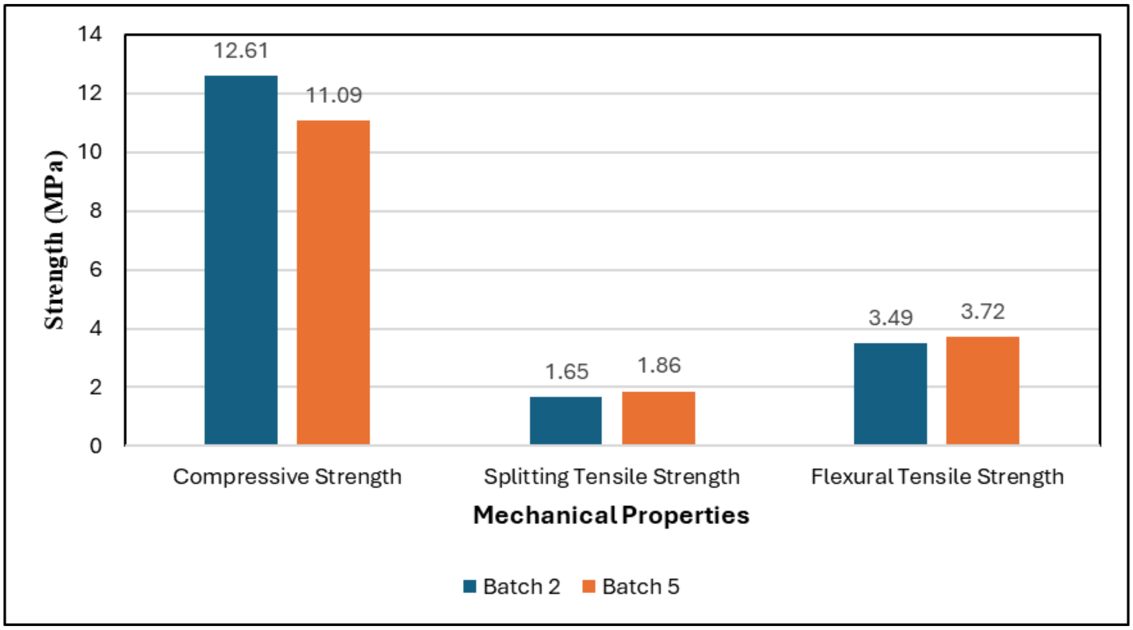


Figure 12 A comparison of the mechanical properties of palm kernel shell concrete with and without palm fibre

4.0 CONCLUSION

This research involved conducting multiple tests to examine the characteristics of concrete made from palm kernel shells and assess its appropriateness as a substitute for regular aggregates. The findings imply that as the proportion of palm kernel shells used in the concrete increases, there is a consistent decrease in both the density and compressive strength of the material. After analysis, it has been shown that the ideal replacement percentage is 35%. This leads to concrete with a cube compressive strength of 18 MPa, which is 40% lower than the control specimen's strength of 29 MPa. However, it is still considered suitable for non-structural elements. The physical properties of the optimum palm kernel shell concrete include a density of 2149 kg/m³, an ultrasonic pulse velocity (UPV) test value of 3828 km/s, and water absorption value of 9.31%. These physical properties are also lower than the control specimen by about 6%, 12%, and 17% for density, UPV, and water absorption, respectively. In terms of mechanical properties, the palm kernel shell concrete showed flexural and splitting tensile strength values of 4.99 MPa and 2.36 MPa, correspondingly. These values are approximately 29% and 20% lower than the control specimen's strengths of 7.02 MPa and 2.94 MPa, respectively.

Additionally, adding palm fibre has no positive impact on the concrete's compressive strength. The compressive strength of the cube was measured at 11.09 MPa, which is around 12% lower compared to the 7-day compressive strength of 12.61 MPa in batch 2. However, the addition of palm fibre significantly influences the tensile strength, yielding a 6% higher flexural tensile strength (3.72 MPa) and 11% higher splitting tensile strength (1.86 MPa) compared to concrete without palm fibre, which achieved 3.49 MPa and 1.65 MPa for flexural tensile strength and splitting tensile strength, respectively. Finally, this research concluded that adding palm kernel shell reduces the physical qualities of the concrete while greatly improving its mechanical properties, making this type of concrete more acceptable for usage in non-structural elements. Regarding the inclusion of palm fibre, this material has a beneficial effect on the tensile strength of the concrete, leading to an overall rise in its ability to withstand tension. However, it does result in a decrease in its ability to withstand compression.

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Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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