

Utilization of Palm Kernel Shell in Concrete Mortar (PKSCM) for Sustainable Construction Material

Nur Shazliena Mohd Anuar¹, Wan Amizah Wan Jusoh^{1*}

¹ Department of Civil Engineering Technology, Faculty of Engineering Technology,
University Tun Hussein Onn Malaysia, 84600, Pagoh, Johor, MALAYSIA

*Corresponding Author: amizah@uthm.edu.my

DOI: <https://doi.org/10.30880/peat.2024.05.02.062>

Article Info

Received: 27 June 2024

Accepted: 17 July 2024

Available online: 25 November 2024

Keywords

Palm kernel shell, Concrete mortar,
Roof tiles, Water repellency, Strength

Abstract

The use of environmentally friendly materials like straw, sawdust, and palm kernel shell in construction contributes to sustainable building practices. Roofs, crucial for structural integrity and energy efficiency, are made from various materials, including concrete mortar. Concrete mortar, a popular building material, faces technical issues like cracking, durability concerns, and scaling. This study aims to determine the chemical and physical properties of palm kernel shell, to evaluation of optimum proportion based on mechanical properties of concrete mortar palm kernel shell and comparison effectiveness between normal concrete mortar and concrete mortar palm kernel shell. Experimental work consists of chemical, physical and mechanical testing which is, XRF, SEM, water absorption, compressive strength, sound absorption and water-phobic (hydrophobic) test. The percentage of PKS that added in concrete mortar mix design is 0%, 10%, 20%, 30%, 40%. The result of this study shows that the palm kernel shell can be as a replacement materials for aggregates because PKS contains silica in higher value. The optimum proportion of PKS was 5%. The more percent replacement of PKS, it will reduce the strength and increase the water repellency of concrete mortar compared to normal concrete mortar. This study contribute to establish the construction material such as for roof tiles and finishing from sustainable materials like palm kernel shell.

1. Introduction

Environmentally friendly materials like wood, cork, bamboo, straw, sawdust, and palm kernel shell are being used in building construction to contribute to sustainable construction [1]. These materials are durable, recyclable, and reusable, originating from nearby resources and containing components that allow for recycling. Roofs and coating mortar are essential for building structural integrity and energy efficiency. Research on covering mortar's strength has increased in recent years [2]. Palm kernel shell (PKS) is being explored as a sustainable alternative to traditional concrete, offering improved compressive strength and durability. This study focuses on developing hydrophobic materials for hot and humid climates like Malaysia. This study investigates the chemical and physical properties of palm kernel shell, evaluates optimal proportions based on mechanical properties, and compares the effectiveness of normal concrete mortar and palm kernel shell.

Concrete mortar, a widely used material in the construction sector, faces technical issues such as cracking, durability concerns, and scaling. Cracks can result from internal and external mechanisms, and can damage the surface appearance. Small surface defects and frost damage also contribute to deterioration [3]. The increasing consumption of river sand for concrete mortar production has led to environmental pollution and

destabilization of stream beds [4]. The palm oil processing industry in Malaysia produces waste, including oil palm trunks, fibers, shells, fronds, fruit bunches, mill effluents, and fuel ash. This study aims to replace sand with PKS to improve water repellency and reduce pollution from palm oil landfills.

The physical properties of concrete with palm kernel shells (PKS) influenced by mix design, curing conditions, and PKS percentage. The maximum raw material for concrete mortar is 5mm as same with sand size. Table 1 shows the physical properties of PKS. The table explain the properties of PKS by showing the color, thickness and void ratio (percentage).

Table 1 Physical properties of PKS [5]

An example of a column heading	Column B (t)
Colour	Dark grey to black
Shell thickness (mm)	0.15-8.0
Maximum shell Size (mm)	2-20
Voids ratio (%)	63 (Loose)

2. Methodology

The methodology is the guide that leads us through a network of question when we get into the complex process of studying. By using this methodological part, we guarantee the validity and accuracy of our findings in addition to gaining new perspectives.

2.1 Flow chart

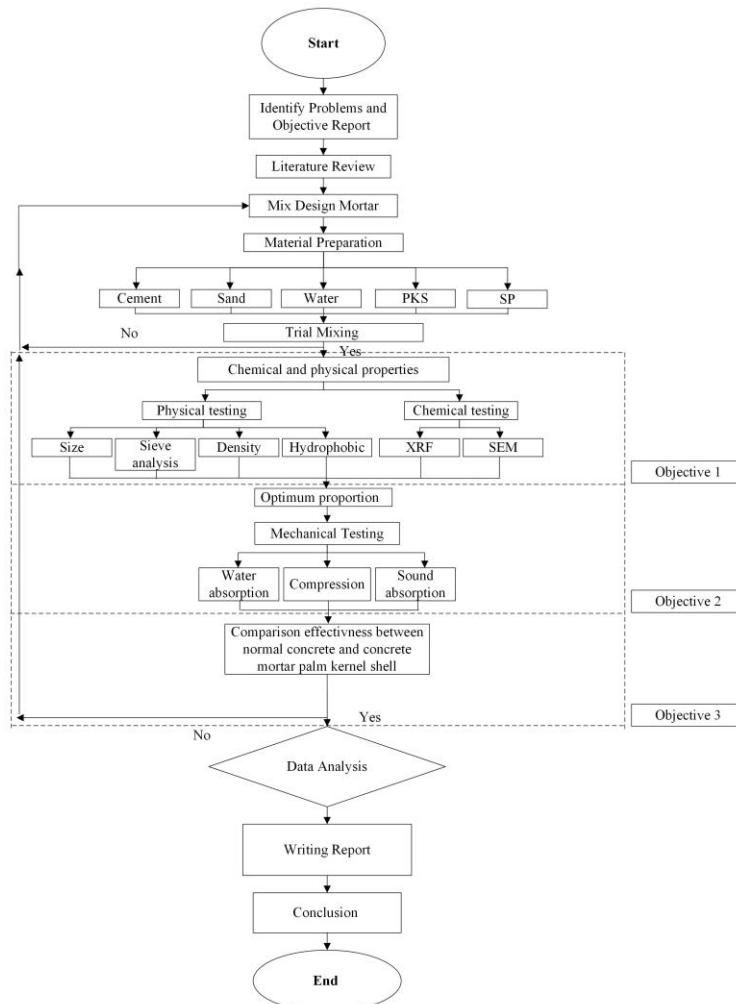


Fig. 2 Methodology flowchart

2.2 Reference Code

Table 2 Reference code

Testing	Standard Code
Concrete casting	BS 12390-1:2012
Curing	BS1881-113, 2011
Xrf	ASTM D5381 – 93 (2021)
Sem	ASTM-F1372-93-2020
Sieve analysis	ASTM C33/C33M-18
Hydrophobic	ASTM D7334 – 08
Density	BS EN 12390-7, 2009
Water absorption	EN-1015-18, 2002
Sound absorption	BS EN 10534-2:2001
Compression	ASTM I, 1999

2.3 Material Preparation

The concrete mix will use Ordinary Portland Cement (OPC), water and sand as fine aggregates, with sand being the preferred choice. Palm oil clinker-based (POCA) added to all mixes to enhance workability as superplasticizer. The dosage should be 500-2000 ml per 100 kg of cement. The experiment also involved the production of palm kernel shell (PKS) as a replacement material for fine aggregate, with varying percentages used. Waste PKS was collected from a palm oil mill factory in Muar, Johor. Size of PKS used was passing sieve 2.36 mm as shown in Fig 1.

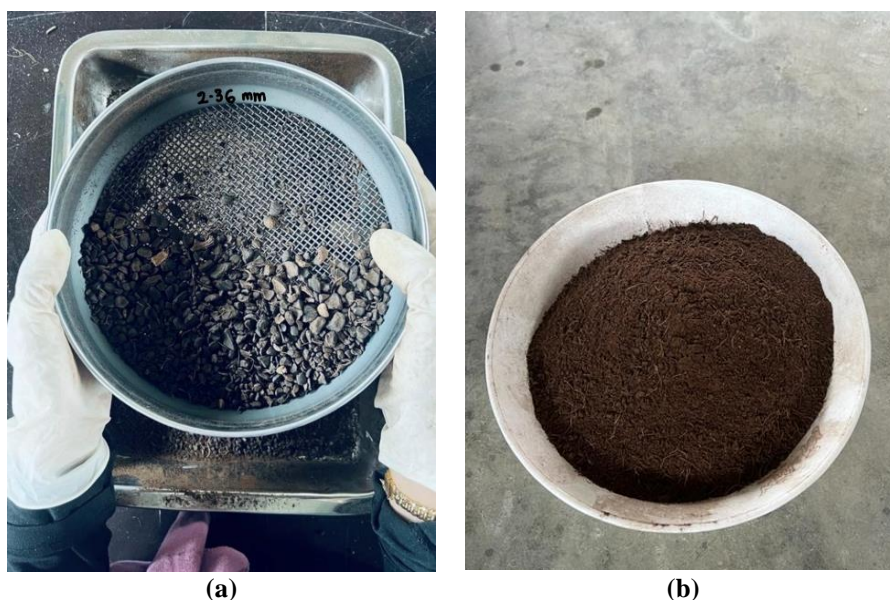


Fig. 1 PKS preparation (a) PKS passing sieve 2.36 mm; (b) PKS

2.4 Mixed Design

The ratio mixture between cement, fine aggregate, and PKS and water 1:3:0.6. The percentage of PKS that mixed with concrete mortar is 0.00%, 0.05%, 0.10%, 0.15% and 0.20%. The sample consists of 60 sample; 45 cube sample (50mm x 50mm x 50mm) and 15 cylinder (25 mm diameter, 100 mm length).

Table 3 Mass material and volume fraction (percentage) for cube

Code	Percentage of Replacement (%)	Cement (kg)	Water (kg)	Fine aggregate (kg)	Palm kernel shell (kg)	SP (ml)
CM	0	0.55	0.33	1.66	0	11.09
PKSCM5	5	0.55	0.33	1.58	0.08	11.09
PKSCM10	10	0.55	0.33	1.50	0.17	11.09
PKSCM15	15	0.55	0.33	1.41	0.25	11.09
PKSCM20	20	0.55	0.33	1.33	0.33	11.09

Table 4 Mass material and volume fraction (percentage) for cylinder

Code	Percentage of Replacement (%)	Cement (kg)	Water (kg)	Fine aggregate (kg)	Palm kernel shell (kg)	SP (ml)
CM	0	0.08	0.05	0.25	0	1.66
PKSCM5	5	0.08	0.05	0.24	0.01	1.66
PKSCM10	10	0.08	0.05	0.22	0.02	1.66
PKSCM15	15	0.08	0.05	0.21	0.04	1.66
PKSCM20	20	0.08	0.05	0.20	0.05	1.66

2.5 Laboratory Work

2.5.1 Preparation of Concrete Cube and Cylinder

The preparation of concrete was performed after mixing was done. The list of apparatus, material and procedure of concrete based on BS 12390-1: 2012. Apparatus used is tamping rod, shovel, cylinder, cube mold (50mm x 50mm x 50mm) mold, cylinder mold (25 mm diameter, 100 mm length), and materials used is sand (fine aggregate), palm kernel shell (PKS), ordinary Portland cement (OPC), water and superplasticizer (SP).

After concrete mortar opened, the concrete mortar immersed in curing tank at 7 and 28 days before concrete test start. Method standard for curing test based on BS1881-113:2001. The water for testing curing should be at 27±2°C.

2.5.2 XRF test

XRF analyzers may determine a sample's chemistry by identifying the fluorescence (or secondary) X-ray that is released when a primary X-ray source activates the sample.

2.5.3 SEM test

Scanning Electron Microscopy (SEM) is a test process that scans a sample with an electron beam to produce a magnified image for analysis.

2.5.4 Sieve analysis test

Sieve analysis is a laboratory testing procedure used to determine the particle size distribution of a granular material. This analysis performed on sand and PKS. The results of a sieve analysis are crucial for assessing the quality and suitability of materials for concrete mortar mix.

2.5.5 Hydrophobic Test

This practice covers the measurement of the angle of contact when a drop of liquid applied to a coated surface, substrate, or preformed disk of pigment.

2.5.6 Density Test

The standard used was BS 12390-7:2000 the mass of the samples measured by using the weight balance with a sensitivity of 0.01g, while its dimension is measured using a ruler or measuring tape.

2.5.7 Water absorption Test

The water absorption test is carried out is to determine the quantity of water that is absorbed in a given time. The lower rate of absorption, the better concrete. The water absorption test procedure is being carried out based on ASTM C1403 – 13. This test done after the samples cured for 7 and 28 days.

2.5.8 Compression Test

The compression test will done to take the compressive strength for each composition of the cube using the compression test machine. The compressive strength test is to determine the maximum load a material can with sand before fracturing. This test method is following based on ASTM C109 – 19.

2.5.9 Sound absorption Test

This test technique aims to determine the sound absorption coefficient of sound absorbers for normal sound incidence using an impedance tube, two microphone sites, and digital frequency analysis equipment.

3. Result and Discussion

The result of this study conducted and discussed based on result get and previous study about concrete mortar using palm kernel shell. The data and result that was discuss based on chemical, physical and mechanical testing.

3.1 Chemical Composition

The chemical analysis of PKS revealed that it contains several oxide, chemical compounds and elements as shown in Table 5. The percentage of SiO₂ one of the highest percent, which is 10.9%, and the total of Al₂O₃, MgO and Fe₂O₃ was 4.33% which means less than 30. Based on Sarania et al., (2022), with high percentage of SiO₂ in PKS proves that the material can, with high percentage of SiO₂ in PKS proves that the material can be as replacement material with total Al₂O₃, MgO and Fe₂O₃ less than 30% is practical to replacement fine aggregates.

PKS can be stated as replacement for fine aggregates in concrete mortar. With high content of Al₂O₃ is responsible for the higher water absorption rate of PKS while lower MgO is responsible for its lower crushing value than the normal concrete mortar. The result shows that the value of Al₂O₃ and MgO was 1.33% and not detected (ND) indicates the water absorption less and lower crushing.

Table 5 Chemical composition in PKS

Composition	Weight percent, % Palm kernel shell
Magnesium Oxide (MgO)	ND
Aluminum Oxide (Al ₂ O ₃)	1.33
Silicon Dioxide (SiO ₂)	10.9
Phosphorus Pentoxide (P ₂ O ₅)	1.12
Sulphur Trioxide (SO ₃)	1.07
Chlorine (Cl)	0.53
Potassium Oxide (K ₂ O)	2.92
Calcium Oxide (CaO)	79.1
Manganese (II) Oxide (MnO)	ND
Iron (III) Oxide (Fe ₂ O ₃)	3.00
Zinc Oxide (ZnO)	ND
Rubidium Oxide (Rb ₂ O)	ND
Loss On Ignition (LOI)	96.4

3.2 Scan Electron Magnifier (SEM)

Fig 3 shows the SEM image of PKS at 500x and 1000-x magnification. From the image, the surface of PKS is rough and non-uniform shaped with a non-porous, with comparison to the results of [6]. PKS is heterogeneous in nature and consists of micro-pores at the smooth outer surface as illustrated in the scanning electron microscope image in Fig 3. However, the pores in PKS could be of significant benefit in the production of pervious concrete with better acoustic and insulation properties as that from [5].

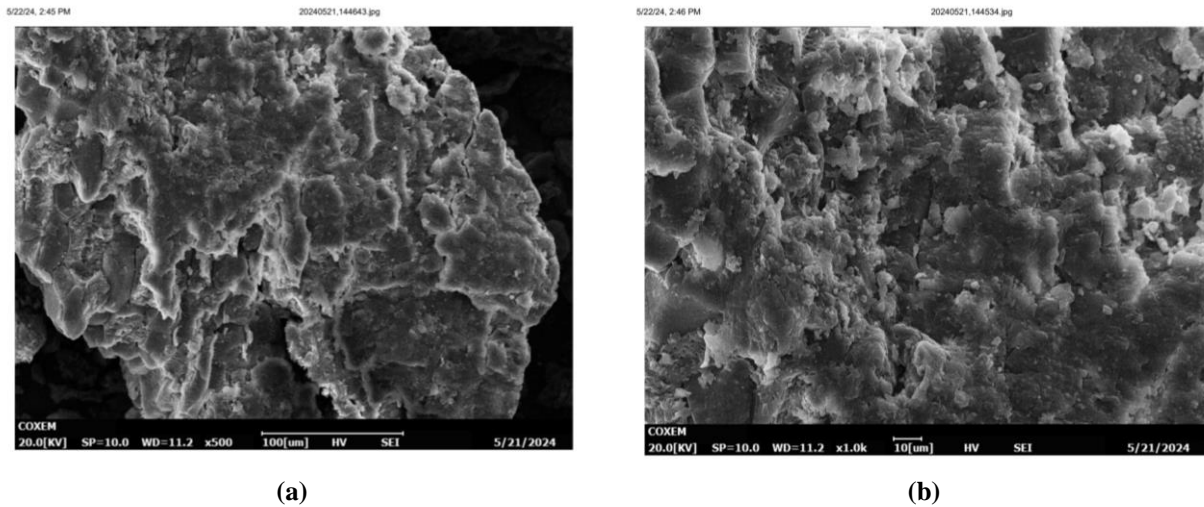


Fig. 3 SEM image of PKS (a) x500 magnification; (b) x1000 magnification

3.3 Sieve Analysis Test

Sieve analysis is a method used in physical testing to determine the particle size distribution of granular materials for sand and palm kernel shells (PKS). Mass of sand and PKS is equal to 500g used for this test. Sieve analysis performed according to (ASTM C33/C33M-18, 2023) in order to obtain the grading of fine aggregate used in this study. Average of particle size distribution curves of sand and PKS was obtained by performing as shown in Fig 4 and 5.

According to standard specification for concrete mortar aggregate (ASTM C33/C33M-18, 2023), for concrete mortar not subject to abrasion the limit for material finer than the 75- μ m sieve shall be 5.0 % maximum. For manufactured fine or other recycled aggregate, if the material finer than the 75- μ m sieve consists of the dust of fracture, essentially free of clay or shale, this limit shall be 5.0% for concrete mortar subject to abrasion, and 7% maximum for concrete mortar not subject to abrasion.

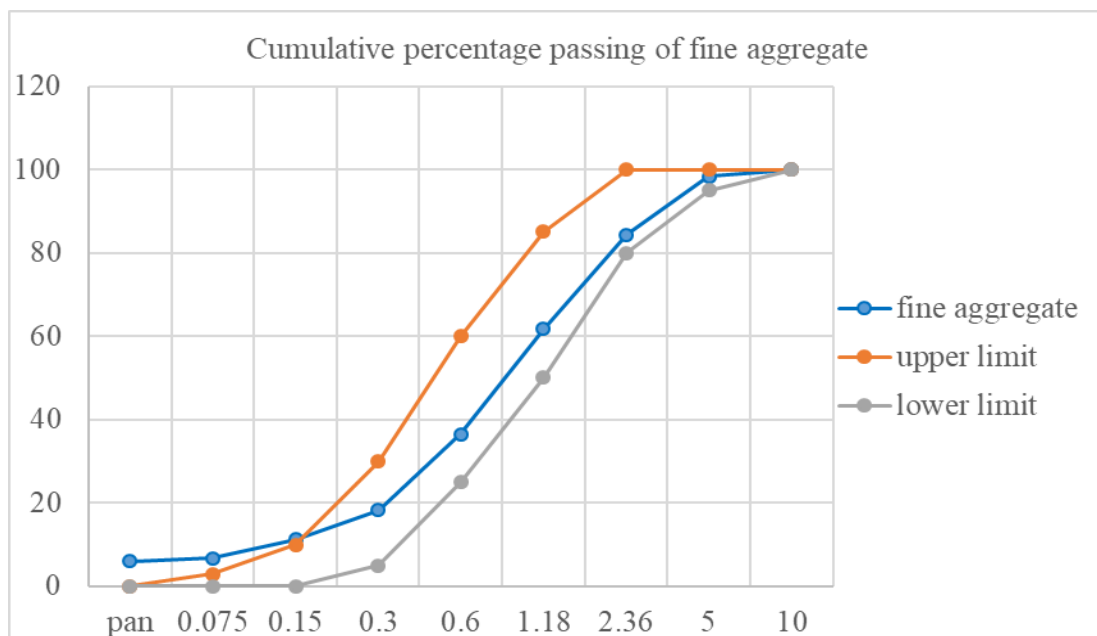


Fig. 4 Sieve analysis of sand

According to Fig 4, the orange line and grey lines show the upper limit and lower limit of the fine aggregate sieve analysis. The blue line show the percentage passing of sand as shown in Fig 4. The percentage passing of sand through opening 0.075mm are 6.81%, which mean that the particle size of sand below the limit maximum for concrete mortar not subject to abrasion compared to the standard sand. The percentage passing of the sand were in range between upper and lower limit which are acceptable to be used as fine aggregate in concrete mortar.

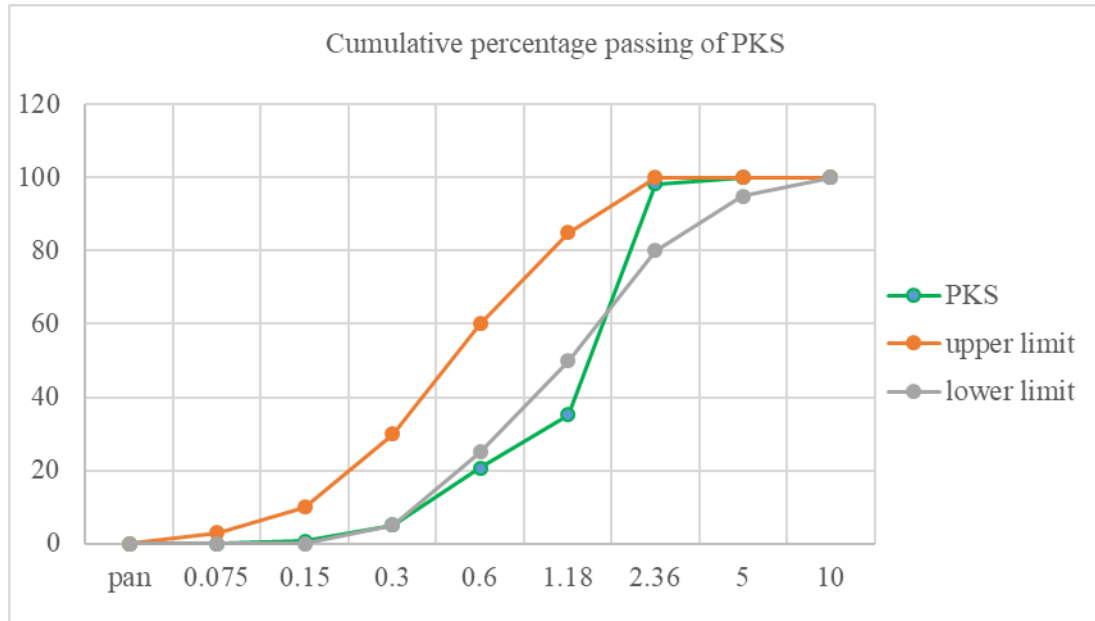


Fig. 5 Sieve analysis of PKS

According to Fig 5, the orange line and grey lines show the upper limit and lower limit of the fine aggregate sieve analysis. The green line show the percentage passing of PKS as shown in Fig 5. The percentage passing of the PKS were in range between upper and lower limit but below the lower limit at 1.18 mm sieve which still acceptable to be used as fine aggregate in concrete mortar.

3.4 Hydrophobic Test

Concrete mortar with 0%, 5%, 10%, 15% and 20% shows the contact angle of 68.49°, 67.29°, 62.24°, 70.87° and 57.49°, which is lower than 90°. Concrete mortar with 15% of PKS proves to be the practical combination with contact angle 70.87 while the lowest is 20% of PKS, which is 57.49 only as shown in Fig 6.

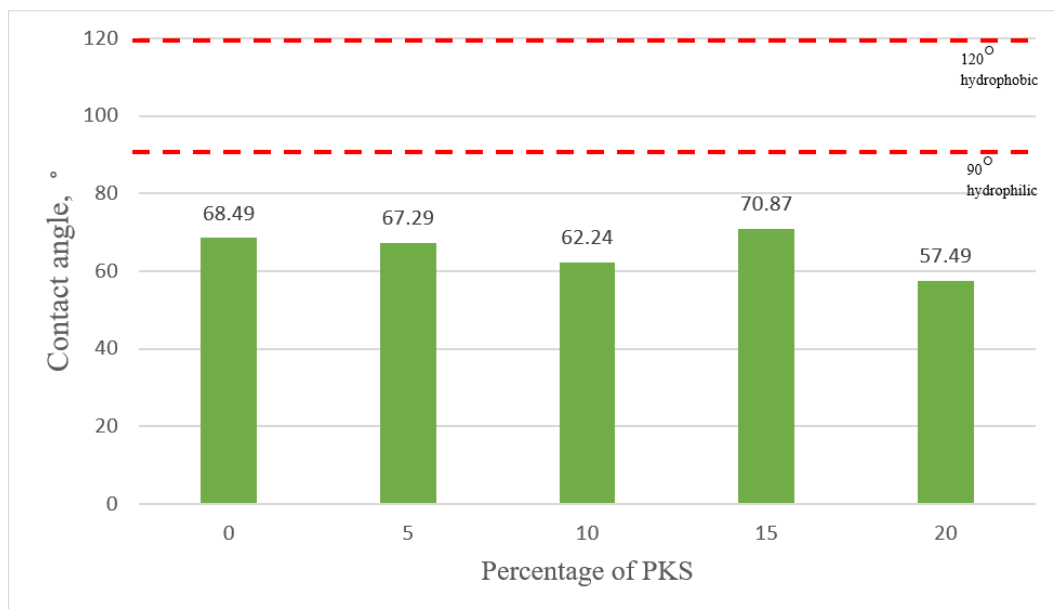


Fig. 6 Contact angle vs percentage of PKS

Fig 7 indicates the angle of CM and PKSCM result. It is proven that contact angle of PKSCM was higher than CM. With mix of PKS proven, the concrete mortar was defined as water repellency effectiveness. At 10% and 20% of PKS indicates the contact angle is low because there is a bunch of small cracks.

The result showed that the surface is defined as hydrophilic coating because the contact angle is 90° below and not strongly correlate with the surface's ability to reject water. If the contact angle in between 90° – 120° (150°) indicates hydrophobic (super-hydrophobic) behavior, which is strongly correlate with the surface's ability to reject water while hydrophilic shows contact angle of 90° below.

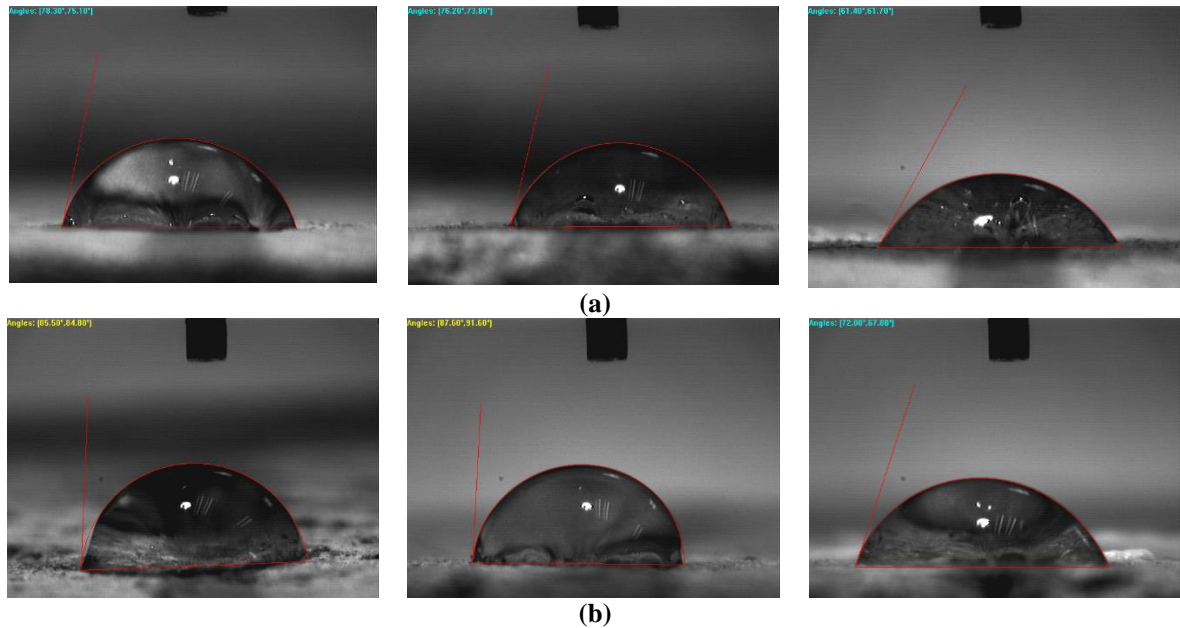


Fig. 7 Contact angle of PKS (a) normal concrete mortar; (b) normal concrete mortar with PKS

3.5 Density of PKSCM

Density is defined as the number of particles that are squeezed into a given volume. It is an important parameter to classify the categories of concrete mortar as either light-, medium-, or normal-weight. The density of concrete mortar normally found in the range of 1900 kg/m^3 to 1800 kg/m^3 . Density data and result has been present in Table 6 and Fig 8 below that obtained from this study.

Table 6 Result of density

Percentage of PKS	Mass (kg)	Volume (m^3)	Density (kg/m^3)
0	0.24	0.0001	1952.13
5	0.23	0.0001	1853.07
10	0.23	0.0001	1874.43
15	0.24	0.0001	1893.84
20	0.23	0.0001	1814.11

The normal concrete mortar density was 1952.13 as normal density of concrete mortar. Test results showed that PKSCM is lighter than conventional concrete mortar. Based on Table 6, percent PKS of 5% and 20% showed the lowest density with value 1853.07 and 1814.11. Therefore, the partial substitution of PKS in conventional concrete mortar should significantly reduce the density.

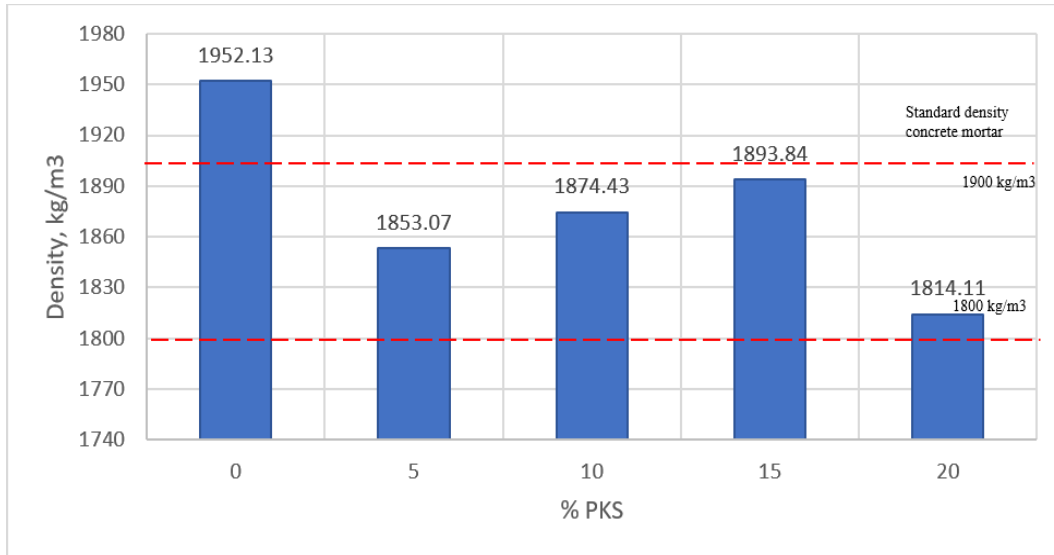


Fig. 8 Density of PKSCM

It was observed that by the incorporation the density was reduced by observed the Fig 8. It was observed that the density of all concretes mortar decreased with the increasing amount of PKS as the replacement of natural fine aggregate due to the lower density of PKS aggregates compared to normal fine aggregates. This proven that if the percentage replacement of PKS higher, then the density decrease.

3.6 Water Absorption Test

Water absorption data and result has been present in Table 7. The water absorption test was carried out for all concrete mortar mixes at age 7 days and 28 days for 30 minutes (final water absorption).

Table 7 Result of water absorption

Percentage of PKS	Water absorption, % (7 days)	Water absorption, % (28 days)
0	11.39	0.58
5	6.57	2.98
10	10.02	2.78
15	4.57	6.84
20	4.22	2.18

Based on Table 7, the normal concrete mortar indicates as good water absorption while the moderate was 5%, 10%, 20% of PKS and the poor was 15% of PKS which is 0.58%, 2.98%, 2.78%, 2.18% and 6.84% respectively for 28 days. Aslam et al., (2016), categorized the quality of concrete mortar based on initial water absorption as poor, average, and good with a water absorption of 5% and above, 3-5% and 0-3% respectively.

The contribution of PKS aggregates in concrete mortar increased the water absorption of the concrete mortar. It has proven from subtopic 2.6 that said high content of Al₂O₃ is responsible for the higher water absorption rate of PKS and the content of Al₂O₃ is quite higher. Previous studies [8] have also observed the same pattern whereby the absorption of water absorption of the concrete mortar increased as more waste material was used to replace sand. It was also noted that a high percentage of sand removal would affect the bonds between the agricultural wastes and cement, leading to high porosity and subsequently increased water absorption [8].

On the other hand, all ratios of PKS resulted in higher water absorption than control. This might be due to the existence of micropores that generate greater antiparticle-voids. Therefore, the water could easily be absorbed inside the matrix of palm kernel shell concrete mortar.

3.7 Compressive Strength Test

Compressive strength data and result has been present in Table 8 and Fig 9 below. The highest strength was 5% of PKS in concrete mortar with value 5.806 Mpa for 28 days and 15% of PKS with value 3.558 Mpa for 7 days while the lowest was 20% of PKS with value 2.524 Mpa for 28 days and 10% of PKS with value 1.093 Mpa for 7 days.

Table 8 Result of compressive strength

Percentage of PKS	Compressive strength, Mpa, 7 days	Compressive strength, Mpa, 28 days
0%	1.328	5.339
5%	2.537	5.806
10%	1.093	4.232
15%	3.558	3.038
20%	1.667	2.524

According to [9], the lower compressive strength of 20% PKS concrete mortar might be due to certain reasons; one of the major problem in PKS concrete mortar is due to the smooth surface texture of PKS grain for both concave and convex faces which causes weak bond between the aggregate and cement matrix. [9] also reported that failure of PKS concrete mortar at 28 days was due to the breakdown of the bond between aggregate and the cement paste.

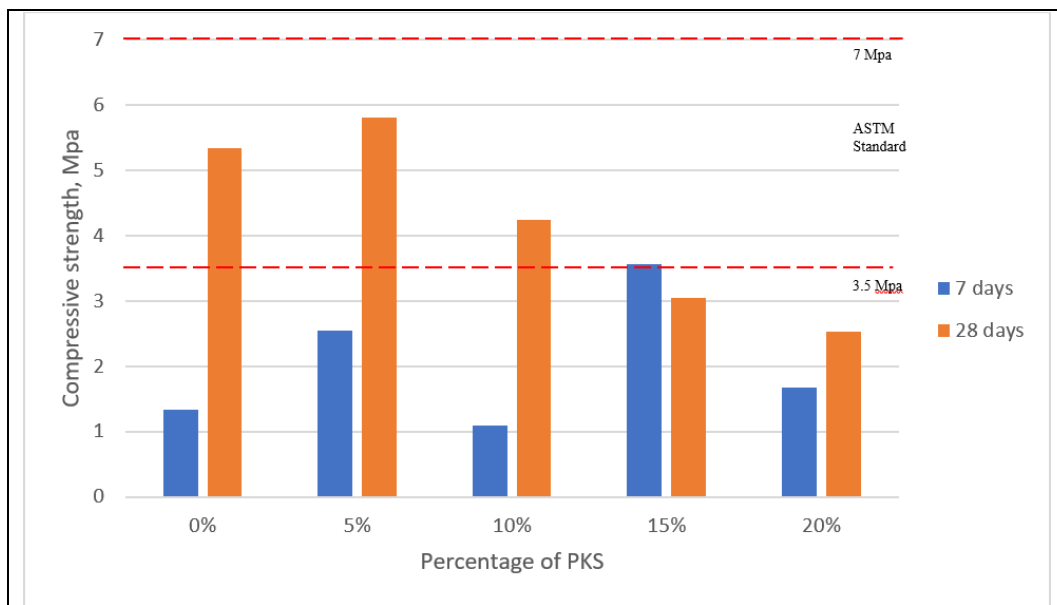


Fig. 9 Compressive strength of PKSCM

The graph showed the increased and decrease line for compressive strength 7 days and decrease for 28 days as shown in Fig 9. When the relationship is shown in figure, it may be concluded that higher PKS aggregate will produce low strength. At 15% of replacement PKS in concrete mortar, the strength at 28 days is lower than 7 days.

The presence of amorphous silica in PKS, the particles are a good pozzolanic material that improves the performance of concrete mortar mixtures. But in this case was observed the strength at 28 days is lower than 7 days for 15% of PKS that maybe caused by the human errors in terms of not properly compacted the concrete mortar and not mixing and adding the material properly.

In addition, lower content of MgO is responsible for its lower crushing value than the normal concrete mortar and the results of MgO in PKS in ND proven the replacement of PKS was due to decreased strength as mentioned in subtopic 2.6.2. In other words, compressive strength values changed significantly depending on PKS content amount. In all mix, the strength gained was due to higher fine aggregate and lower PKS content.

3.8 Sound Absorption Test

According [10], noise reduction coefficient (NRC) is a rating to measure the effectiveness of material at sound absorption. It defines as the percentage of sound that a surface absorbs. The average of the acoustic experiment results plotted in Fig 10. It can observed from this Fig that NRC decreased with increasing the percent of PKS and got the negative value. The most practical sound insulation was at normal concrete mortar with value -0.241 and 5% of PKS replacement with value -0.294. Based on [11], better good sound insulation with the highest value.

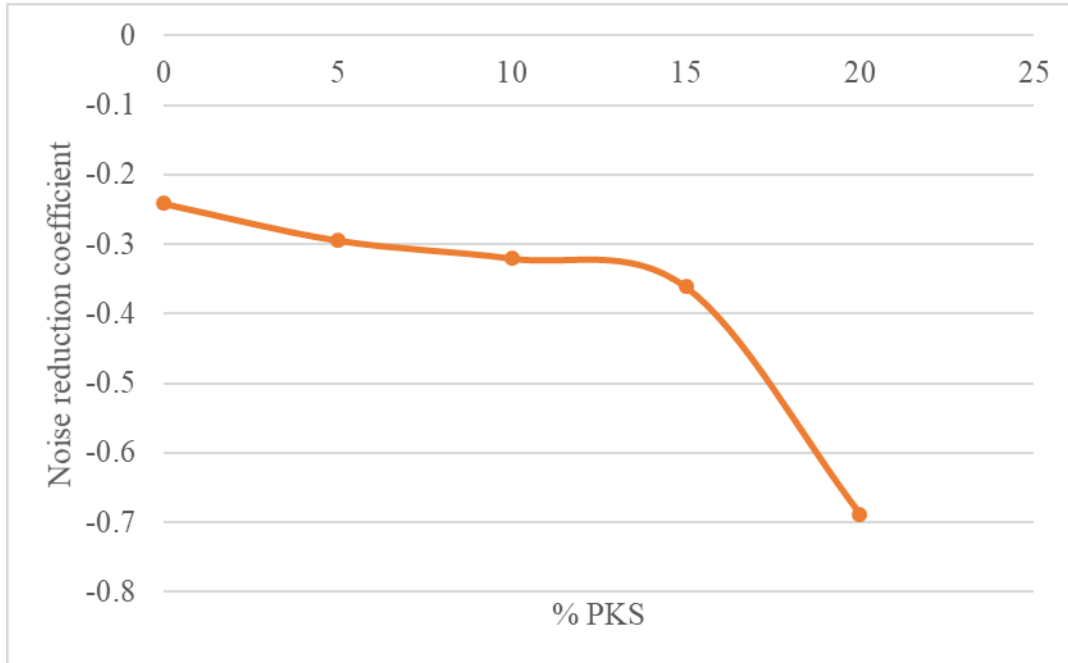


Fig. 10 Sound absorption of PKSCM

In sound absorption coefficient (SAC), a negative number indicates that more sound is being reflected towards a microphone than is being produced by a speaker. One and zero represent the total quantity of sound absorbed and the total amount of sound reflected, respectively. Previous investigations have also revealed SAC values that are negative. [12].

A positive sound absorption coefficient indicates that the material absorbs sound energy, which mean it does not reflect it back into the environment. On the other hand, a negative sound absorption coefficient suggests that the material reflects more sound energy than it absorbs. In conclusion, the result showed the noise reduction coefficient was negative and relatable with suggests the material reflects more sound energy than it absorbs.

3.9 Effectiveness Result of PKSCM

Table 9 indicates the effectiveness data for all testing for PKSCM. The effectiveness mixture was determined based on the testing given to identify the practical effectiveness in all aspect. For result SAC, WA, the lower value is the more effective because the sound absorption is higher, while for water absorption is lower.

Table 9 Result of effectiveness

PKS%	Sound Absorption Coefficient	Contact angle, °	Fcu, 7 days	Fcu, 28 days	WA % 7 days	WA % 28 days	Density, kg/m
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	18.03	-1.78	47.65	8.04	-73.36	80.54	-5.35
10	24.69	-10.04	-21.50	-26.16	-13.67	79.14	-4.15
15	33.24	3.36	62.68	-75.74	-149.23	91.52	-3.08
20	64.97	-19.13	20.34	-111.53	-169.91	73.39	-7.61

Based on Table 9, the result for effectiveness was in 15% of PKS replacement in concrete mortar based on the all data testing involved in this study. The effectiveness result based on three repeated data from all testing involved in this study, which is contact angle, Fcu 7 days and density. The percentage of effectiveness result concrete mortar mix PKS based on original percentage of concrete mortar (100%) for each testing involved which is contact angle, Fcu 7 days and density was 118.03%, 162.68% and 103.08%.

4. Conclusion

In summary, the first objective of this study is to determine the chemical and physical properties of palm kernel shell. Based on the result, was founded that palm kernel shell can be as a replacement materials because PKS contains silica in higher value as mentioned in subtopic 2.6 and 4.2.1. With below 30% addition of three content which is Al₂O₃, MgO and Fe₂O₃ proven to be as replacement fine aggregates. The size of PKS used is same as fine aggregate, which need to passing by 2.36-millimetre sieve.

Next, the second objective is to evaluation of optimum proportion for concrete mortar production. The optimum proportion of PKS based on mechanical testing was 5% as discuss in chapter 4. The more percent replacement of PKS, when compared to regular concrete mortar, it will weaken the concrete mortar.

Lastly, the third objective is to comparison effectiveness between normal concrete mortar and palm kernel shell concrete mortar. The most effective result was 15% of PKS in concrete mortar as proven from subtopic 4.3. It has been compare from mechanical testing with three times repeated. The percentage of effectiveness result concrete mortar mix PKS based on original percentage of concrete mortar (100%) for each testing involved which is contact angle, Fcu 7 days and density was 118.03%, 162.68% and 103.08%. Thus, the 15% of replacement PKS in concrete mortar will be the effective material for application on top structure, which is roof tile.

Based on the findings of this study on mortar incorporating palm kernel shell (PKS), the following recommendations are proposed to future study:

1. Compaction of concrete mortar should be more carefully and perfectly to avoid honeycomb.
2. Add epoxy in concrete mortar mix to provide more strength.
3. Mix hydrophobic agent such as silica in concrete mortar to provide more hydrophobic surface.

Acknowledgement

The author expresses gratitude for the opportunity to pursue engineering studies at UTHM's Faculty of Civil Engineering Technology, expressing gratitude for the knowledge gained throughout the program and for the UTHM's support.

This section is compulsory. Acknowledgements and Reference heading should be left justified, bold, with the

References

- [1] D. A. Suhamad and S. P. Martana, "Sustainable Building Materials," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 879, no. 1, 2020, doi: 10.1088/1757-899X/879/1/012146.
- [2] G. Baptista Junior *et al.*, "Durability for coating mortars: Review of methodologies," *J. Mater. Res. Technol.*, vol. 30, no. March, pp. 657–671, 2024, doi: 10.1016/j.jmrt.2024.03.020.
- [3] J. Kwasny, M. Sonebi, S. Amziane, and J. Plasse, "Effect of Mix Composition on Rheology and Surface Finish of Cement-Based Mortars," no. October, pp. 1–8, 2013.
- [4] K. Muthusamy, N. Tukimat, N. N. Sarbini, and N. Zamri, "Exploratory study on the use of crushed cockle shell as partial sand replacement in concrete," *Int. J. Res. Eng. Sci. ISSN*, vol. 4, no. 2, pp. 67–71, 2016, [Online]. Available: www.ijres.org.
- [5] M. A. Kareem, A. A. Raheem, K. O. Oriola, and R. Abdulwahab, "A review on application of oil palm shell as aggregate in concrete - Towards realising a pollution-free environment and sustainable concrete," *Environ. Challenges*, vol. 8, no. August 2021, p. 100531, 2022, doi: 10.1016/j.envc.2022.100531.
- [6] N. A. Sarania *et al.*, "Physical-Mechanical Properties and Thermogravimetric Analysis of Fired Clay Brick Incorporating Palm Kernel Shell for Alternative Raw Materials," 2022.
- [7] ASTM, "Standard Specification for Concrete Aggregates. (ASTM C33/C33M-18)," vol. i, 2023, doi: 10.1520/C0033.
- [8] M. S. M. Zaini and M. A. B. M. Za'aim, "Fibreglass Reinforcement Integrated with Palm Kernel Shell as Partial Replacement of Sand for Brick Production," *Kem. u Ind.*, vol. 71, no. 5–6, 2022, doi: 10.15255/kui.2021.067.
- [9] M. Aslam, P. Shafiqh, and M. Z. Jumaat, "Effect of replacement of oil-palm-boiler clinker with oil palm shell on the properties of concrete," in *AIP Conference Proceedings*, 2016, vol. 1774, doi: 10.1063/1.4965060.
- [10] Z. C. Yong, M. K. Yew, X. W. Sieng, J. H. Beh, M. C. Yew, and F. W. Lee, "Strength and Acoustics Properties of

Lightweight Foamed Concrete Incorporating of Bio-Based Aggregate," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1216, no. 1, 2023, doi: 10.1088/1755-1315/1216/1/012014.

- [11] J. Zanariah *et al.*, "Preliminary Investigation of Acoustical Properties of Concrete Containing Oil Palm Shell as an Aggregate Replacement," *E3S Web Conf.*, vol. 34, pp. 1–8, 2018, doi: 10.1051/e3sconf/20183401015.
- [12] S. Park, K. A. Moges, and S. Pyo, "Experimental study on the sound absorption performance of surface-perforated mortar," *Constr. Build. Mater.*, vol. 307, no. November, 2021, doi: 10.1016/j.conbuildmat.2021.124824.