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Unlocking the Potential of Palm Kernel Shell and Quarry Dust: A Cost-Driven Approach to Replacing Sand and Gravel in Concrete

Hassan Abdullahi MAIKANO[1], Toyin Yahaya AKANBI[2]

[1]*School of Civil Engineering, Linton University College 71700 Mantin, Malaysia*
Maikano07@yahoo.com

[2]*Civil and Environmental Engineering, Air Force Institute of Technology, Air Force Base Kaduna, Nigeria*
toyinsniper@yahoo.com

Corresponding Author: toyinsniper@yahoo.com, +2348142598209
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Abstract: *This research investigates the potential of palm kernel shells (PKS) and quarry dust (QD) as sustainable and cost-effective replacements for sand and gravel in concrete production. The study explores the impact of varying PKS and QD content on workability, density, water absorption, and mechanical properties. While increasing these alternative aggregates decreases workability and density, it improves water absorption and, in some cases, mechanical strength. Response Surface Methodology (RSM) identified a combination of 5% PKS and 20% QD (-1, -1) as the optimal replacement level for achieving a balance between cost and performance. This mix offers a significant cost reduction of 18.2% relative to concrete made with conventional aggregates. The study highlights the potential of PKS and QD as sustainable alternatives for conventional aggregates. Utilizing these readily available waste materials can reduce reliance on natural resources, promote waste management practices, and contribute to a more environmentally friendly construction industry. Additionally, the research suggests that quarry dust alone might be a more suitable replacement material than PKS due to its superior influence on concrete strength. This research provides valuable insights for optimizing concrete mix design with PKS and QD, promoting cost-effective and sustainable construction practices in regions with abundant palm oil production and quarrying activities.*

Keywords: *Palm Kernel Shell (PKS), Quarry Dust (QD), Lightweight Concrete, Workability, Solid Waste.*

1. INTRODUCTION

Construction activities have a substantial environmental footprint due to their high consumption of natural resources, with a significant demand for sand and gravel as primary aggregates in concrete. However, environmental concerns associated with sand mining, including depletion of natural resources and disruption of ecosystems, have prompted the search for sustainable alternatives. In this context, agricultural wastes like palm kernel shells (PKS) and industrial by-products like quarry dust (QD) emerge as promising candidates for replacing sand and gravel in concrete production.

Research has demonstrated the potential of PKS as a partial substitute for fine sand particles in concrete mixes. Due to its low bulk density and high porosity, PKS can contribute to lightweight and insulating concrete with improved thermal performance [1]. Additionally, studies have shown that PKS can enhance the workability of concrete mixtures while maintaining acceptable strength properties [2].

Meanwhile, QD, a finely crushed waste material produced during quarrying activities, has also shown promising results to partially replace both the sand and gravel in concrete. Replacing sand with QD can lead to denser concrete with improved compressive strength and durability [3]. Furthermore, QD can contribute to improved bond strength between concrete and steel reinforcement [4].

In developing countries like Nigeria, where affordable housing solutions are crucial for both rural and urban populations [5], [6], palm kernel shells (PKS) offer a promising alternative building material. PKS is readily available near palm oil production facilities [7], and its lightweight nature, boasting a unit weight of 500-600 kg/m³, presents a significant advantage. This translates to a substantial reduction (almost 60%) compared to traditional crushed stone aggregates [8], [9]. Furthermore, PKS exhibits varying thicknesses of 6, 8, or 12 mm depending on the palm species [7], offering some flexibility in selecting the most suitable size for specific construction applications.

Despite the encouraging results from these studies, the economic viability of utilizing PKS and QD as concrete aggregates remains a crucial factor for widespread adoption. This research aims to address this gap by conducting a comprehensive cost analysis comparing PKS and QD with conventional sand and gravel. The analysis will consider various factors, including material costs, transportation expenses, processing requirements, and potential environmental benefits.

This research is motivated by the author's commitment to sustainable construction practices and the commitment to incorporating sustainable practices by utilizing waste materials in the construction industry. By providing a comprehensive cost-benefit analysis, this research hopes to encourage the adoption of PKS and QD as sustainable and cost-effective alternatives to traditional concrete aggregates.

2. MATERIALS AND METHODS

2.1 Materials

The constituent materials used were all procured from local sources, and properly prepared to meet all requirements for further utilization in concrete production.

2.1.1 Fine sand

Well-graded river fine sand with a fine modulus of 3, 1.0% water absorption & specific gravity of 2.58 passing through 4.75mm was used. Details of the physical properties of fine sand are presented in Table 1.

Table 1: Physical properties of fine sand

Properties	Result
Specific gravity	2.58
Surface texture	Smooth
Particle shape	Rounded
Fineness modulus	2.33

2.1.2 Cement

OPC grade 53, 3.15 relative density conforming [10] and [11] were used. Details of the physical and mechanical properties are presented in Table 2.

Table 2: Physical and mechanical properties of cement

Physical Properties	Test Results
Fineness (retained on 90µm sieve)	9%
Specific gravity	3.15
Initial Vicat setting time	76
Final vicat setting time	214
Normal consistency	29%

2.1.3 Granite

The crushed granite (Coarse aggregate) with 2.65 specific gravity at SSD condition, 0.8% water absorption, and 2mm to 20mm size was utilized in the investigation. It was sourced from Negeri Road Stone SDN. BHD., Nilai, Malaysia. Details of the physical properties of gravel are presented in Table 3.

Table 3: Physical properties of gravel

Properties	Result
Specific gravity	2.65
Surface texture	Rough
Particle shape	Angular
Fineness modulus	7.75

2.1.4 Palm kernel shell

Thoroughly flushed with water to remove impurities that could affect the strength of the concrete. Dried under open air for 3 to four weeks to remove moisture and then kept in waterproof bags in batches. With water absorption of less than 10% and a specific gravity of 1.17 at SSD conditions. It was sourced from Sime Derby SDN. BHD., Nilai, Malaysia.

2.1.5 Quarry Dust

To achieve a cost-effective and sustainable concrete mix design, locally available quarry dust, sieved to a 1.18 mm maximum size, was used as a partial replacement for fine aggregate. Table 4 shows the physical properties of quarry dust.

2.1.6 Water

Standard tap water, free of contaminants like oil, alkali, acid, silt, sugar, salt, or organic compounds, was deemed suitable for mixing and curing the concrete. Since the potable tap water is drinkable, it is therefore considered a suitable hydrating element for the production of PKS-QD concrete.

Table 4: Physical properties of quarry dust

Physical Properties	Test Result
Colour	Grey
Specific gravity	2.54

2.2 Mix Proportion

The 1:1.5:2.6 mix ratios for cement to fine to coarse aggregate were adopted for:

i. Water Cement Ratio: - 0.48
ii. Mass of Cement in Kg/m^3: - 437.5
iii. Mass of Water in Kg/m^3: - 210
iv. Mass of Fine Aggregate in Kg/m^3: - 613.4
v. Mass of Coarse Aggregate (Approximate) in Kg/m^3: - 1139

Therefore, the summation of masses above is given by: -
=> 210 + 437.5 + 613.4 + 1139 = 2400Kg/m^3.
$f'_{ck} = f_{ck} + 1.64.S = 20 + 1.64(4) = 26.58 N/mm^2$. (M20 Grade Concrete)
The application of the Response Surface Method (RSM) in the Minitab Software where three different levels for the replacement materials are produced for PKS, QD, and CD as shown in Table 5 was involved in obtaining the different mix types.

Table 5: Replacement levels/percentages and selected curing periods

Material	Minimum Replacement	Medium Replacement	Maximum
Palm kernel shell (PKS)	5%	10%	15%
Quarry Dust (QD)	20%	40%	60%
Curing Periods	7days	18days	28days

The used levels are a set of variable possible combinations of the parameters as individual functions based on the mathematical permutation and combination. The interpretation of each of -1, 0, and +1 for minimum level, medium level, and maximum level substitution of materials at curing periods was clearly shown as denoted in Table 5. Having known the mix types, the mixing proportions for each are shown in Tables, 6, 7, and 8 were used for knowing the mix type to be cast for the batching processes when casting specimens.

Table 6: Mix proportions for PKS-QD concrete (cube samples)

Mix type/sub. level	Water (kg)	Cement (kg)	Fine aggregate (kg)		Coarse aggregate (kg)	
Per 1m^3	210	437.5	613.38		1139.13	
	Water (kg)	Cement (kg)	QD (kg)	SAND (kg)	PKS (kg)	GRAVEL(kg)
Minimum level 20% QD 5% PKS	0.78	1.62	0.46	1.82	0.21	4.02
Medium level 40% QD 10% PKS	0.78	1.62	0.92	1.36	0.42	3.81
Maximum level 60% QD 15% PKS	0.78	1.62	1.38	0.9	0.63	3.6

Table 7: Mix proportions for PKS-QD concrete (beam samples)

Mix type/sub. level	**Water (kg)**	**Cement (kg)**	**Fine aggregate (kg)**		**Coarse aggregate (kg)**	
Per $1m^3$	210	437.5	613.38		1139.13	
	Water (kg)	Cement (kg)	QD (kg)	SAND (kg)	PKS (kg)	GRAVEL (kg)
Minimum level 20% QD 5% PKS	1.155	2.406	0.675	2.699	0.313	5.952
Medium level 40% QD 10% PKS	1.155	2.406	1.35	2.024	0.627	5.639
Maximum level 60% QD 15% PKS	1.155	2.406	2.024	1.35	0.94	5.325

Table 8: Mix proportions for PKS-QD concrete (cylindrical samples)

Mix type/sub. level	**Water (kg)**	**Cement (kg)**	**Fine aggregate (kg)**		**Coarse aggregate (kg)**	
Per $1m^3$	210	437.5	613.38		1139.13	
	Water (kg)	Cement (kg)	QD (kg)	SAND (kg)	PKS (kg)	GRAVEL (kg)
Minimum level 20% QD 5% PKS	0.363	0.756	0.212	0.848	0.0985	1.872
Medium level 40% QD 10% PKS	0.363	0.756	0.424	0.636	0.197	1.773
Maximum level 60% QD 15% PKS	0.363	0.756	0.636	0.424	0.296	1.675

3. RESULT AND DISCUSSION

3.1 Sieve Analysis

The sieve analysis was done using 500 g of dry sand and 500 g of quarry dust for fine aggregate. The standard sieve sizes used were 5 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm, and 0.15 mm. From the results, we can see that the percentage of fine aggregate passing the 0.6 mm sieve was 59.82 %. Table 9 and Figure 1 show the results obtained. To confirm that all the aggregates that were used are within the specifications according to BS 882, the sieve analysis was conducted.

Table 9: Sieve analysis result

Sieve Size (mm)	Weight Retained (g)	Passing (g)	(%) Weight retained	Cumulative (%) weight retained	(%) Finer
5	4.5	495.5	0.9	0.9	99.1
2.36	45.7	449.8	9.14	10.04	89.96
1.18	56.4	393.4	11.28	21.32	78.68
0.6	94.3	299.1	18.86	40.18	59.82
0.3	152.5	146.6	30.5	70.68	29.32
0.15	95.5	51.4	19.1	89.78	10.22
Pan	51.1	0.3	10.22	100	0
Total	500			232.9	

$$\text{Fineness modulus, Fm} = \frac{\textit{sum of cummulative \% weight retained}}{100} \quad (1)$$

$$\text{Fm} = \frac{232.9}{100} = 2.329$$

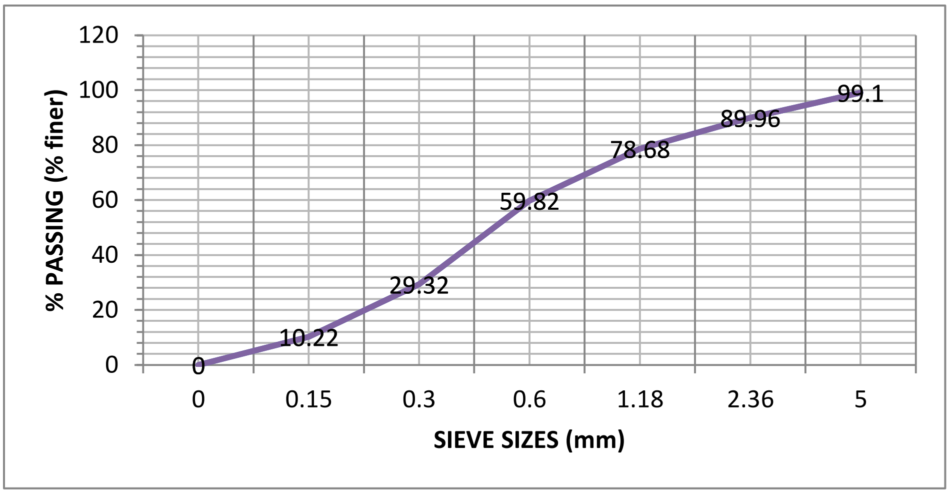

Figure 1: Sieve analysis graph

From the Table 9, the fineness modulus of the sand is 2.329 which falls between acceptable values of fineness modulus which is 2 to 3. The smaller value of fineness modulus indicates the presence of a larger proportion of finer particles. Also, note that pan value is not included while summing the cumulative % in finding the fineness modulus of the sand.

3.2 Properties of Fresh Concrete

3.2.1 Slump test

Workability was measured using the standard slump test. The test involves filling a cone-shaped mold (100 mm top diameter, 200 mm bottom diameter, 300 mm high) with fresh concrete and measuring the vertical settlement after the mold is lifted. It should be noted that the failures of bleeding and segregation at this stage were nullified by ensuring a compactable homogeneous concrete. At the lowest replacement levels of PKS and QD (5%, 20%), the altered concrete has its best workability though not as the control mix compared to the other mix types of (0, 0), (-1, 1), (1, -1) and (1, 1) which had the lowest workability measure in slump values.

From Table 10 and Figure 2, We observe that as the percentage of PKS increases from (5% to 10%) and from (10% to 15%), the mix becomes harder, hence the slump height declines. This is due to the natural fiber in PKS and the water absorption of the shell. Another reason for this reduction is that a control concrete is denser than the PKS aggregate and since the replacement is by weight, the specific surface increases as the PKS content increases which results in more cement paste required for the lubrication of the aggregate, therefore decreasing the entire fluidity on the mix, which results in decrease of the slump [12].

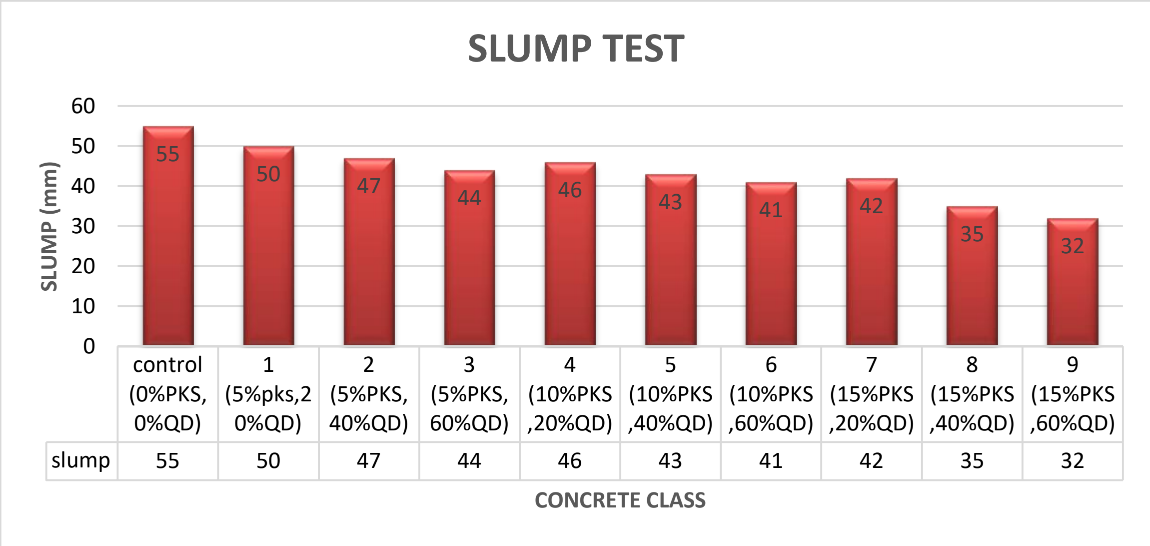

Figure 2: Slump test graph

The control concrete has a 55 mm slump, which is followed by the specimen with the least replacement 50 mm at 5%PKS and 20% CS. The maximum-maximum level replacement (15%PKS, 60%QD) is identified to have the lowest workability. The slump decreases with an increase in replacements which may be due to the water absorption capacity of both PKS and QD concrete but none completely collapsed which is an indication of cohesiveness in the mix.

3.2.2 Compacting factor test

Figure 3 shows the Compacting Factor Test Graph. In this test, the hoppers were cleaned thoroughly and the hinged door was ensured to be closed. The upper hopper was filled up with concrete to the brim before releasing the door to let the concrete fall into the lower hopper. When the concrete is in the second hopper, the door of the second hopper is released to let the concrete fall into the cylinder. Excess concrete was cut off from the top of the cylinder. The weight of partially compacted concrete is the net weight of the concrete while the concrete that is refilled and compacted in three layers is the fully compacted concrete.

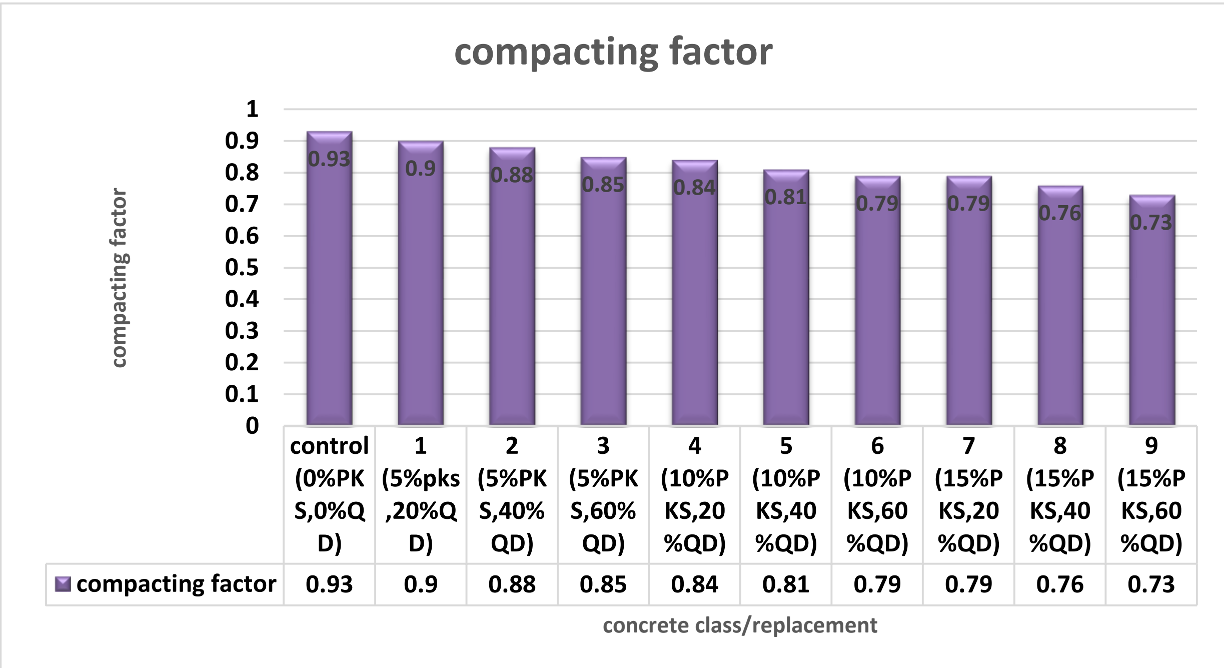

Figure 3: Compacting factor test graph

By merely examining the results of the test, the compacting factor decreases with an increase in the percentage of both palm kernel shell (PKS) and quarry dust (QD). Evidence of this can be seen from the compacting factors obtained at

(5%PKS, 20%QD), (10%PKS, 40%QD), and (15%PKS, 60%QD) which were 0.90, 0.81, and 0.73 respectively. This decrease is due to the water absorption of the PKS and QD which makes the mix firmer.

It was also observed that the control mix has the higher compacting factor while the mix with 15% PKS and 60%QD have the lowest compacting value of 0.73 and it may be due to the non-uniform, non-cohesive mix that is good from the uppermost, but weak downwardly with less performance, durability, strength as well as the total efficiency of the mix.

3.3 Hardened Concrete Properties

3.3.1 Dry density test

Table 10 shows the density of PKS-QD concrete by weight of cubes. It's quite reasonable to say that the densities reduce with an increase in contents of PKS and QD which may be attributed to the direct influence the differences in specific gravities have. The first approach was when the respective weights were measured with a fixed cube volume for each mix and then determined the ratio of mass to volume for densities. Whereas, the other was to verify if the values obtained were close to the values obtained which are supposed to consider the amounts of the specific gravities and content of each constituent.

Table 10: Densities of PKS-QD concrete by weight of cubes

Minitab Output		**Replacements**		**Mass (Kg)**	**Volume (M^3)**	**Density (Kg/M^3)**
		PKS	QD			
Control		0%	0%	8.14	0.003375	2412
-1	-1	5%	20%	7.79	0.003375	2308
0	0	10%	40%	7.6	0.003375	2251
1	1	15%	60%	7.44	0.003375	2204
-1	1	5%	60%	7.73	0.003375	2290
1	-1	15%	20%	7.34	0.003375	2174
			Average density			$2245Kg/m^3$

When the latter is checked for all mix types, an average of $2245Kg/m^3$ would be recorded for combined weights irrespective of mix types when PKS and QD are combined making it fall within the range of a structural normal weight as presented in Table 12 and Figure 4. Therefore, it is evident that the incorporation of PKS and QD does not guarantee lightweight concrete. Although lightweight concrete can be achieved only when a higher percentage of PKS is used.

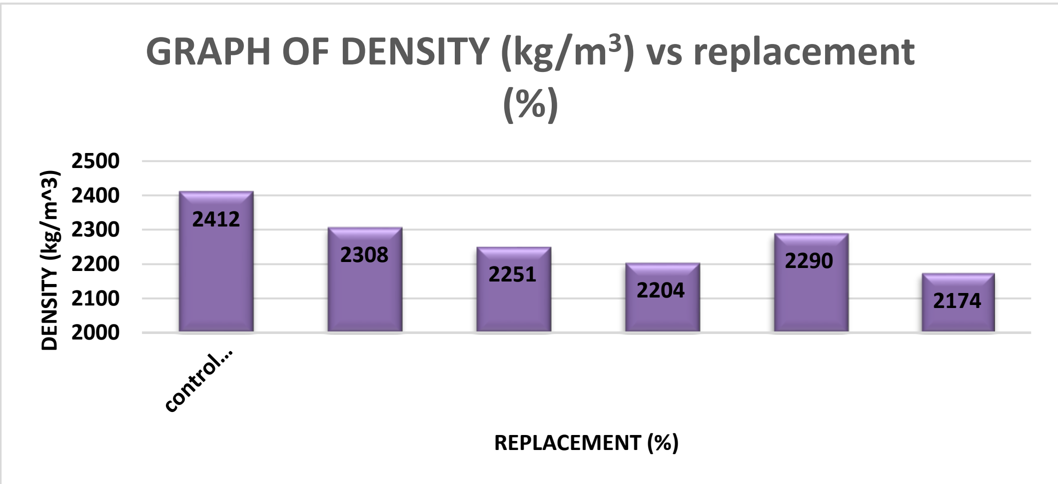

Figure 4: Graph of density test

3.3.2 Water Absorption Test

Table 11 shows the absorption of water at 28 days. As the PKS and QD quantities increase, a porous void is created within the molecular structures of these materials that give rise to mixing water to occupy which in turn makes the replaced aggregate specimen absorb more water as shown in Figure 5. The literature revealed higher water absorption percentages as the work of and revealed.

Table 11: Absorbed water content at 28 days

Minitab values			Dry density, M_d	Weight saturated, M_w (kg)	Water content (kg)	% of water absorption
	PKS (%)	QD (%)	(Kg)			
control	0	0	7.99	8.14	0.15	1.88%
(-1, -1)	5	20	7.42	7.84	0.42	5.60%
(0, 0)	10	40	7.2	7.74	0.54	7.50%
(1, 1)	15	60	6.94	7.62	0.68	9.80%
(-1, 1)	5	60	7.2	7.65	0.45	7%
(1, -1)	15	20	6.92	7.34	0.42	6.80%

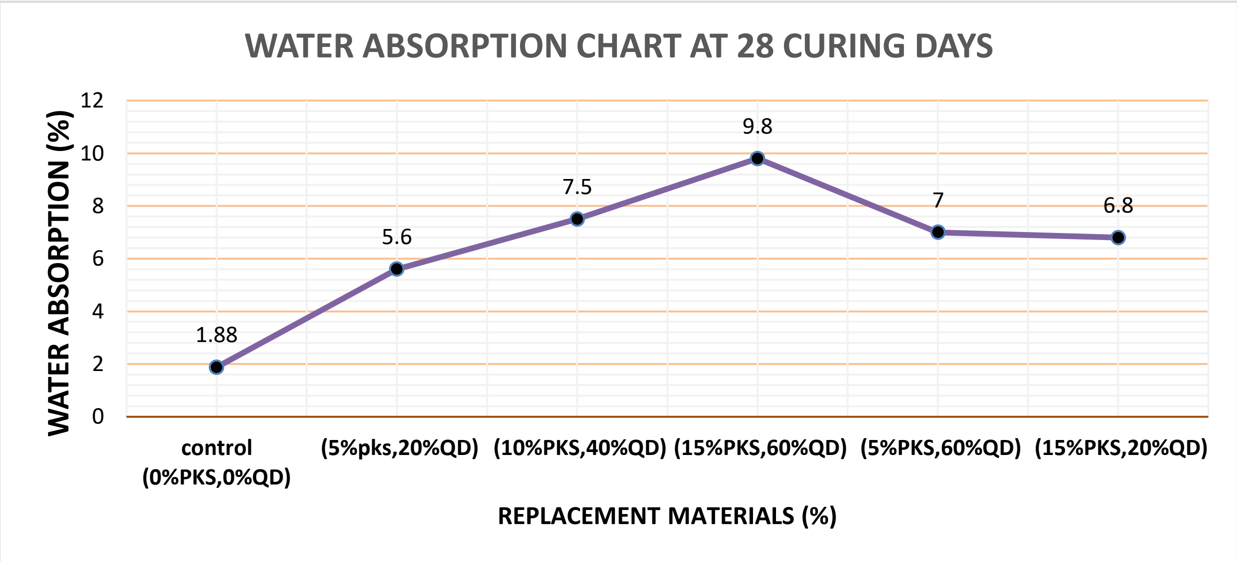

Figure 5: Water absorption graph at 18 days

The figure above shows the percentage water absorption of cube samples at 28 curing days under different mix proportions. The table and graph above show that the control mix whose materials are not replaced has 1.88% water absorption which is the least among all other mix types under 28 curing days.

The figure above also indicates that there is a uniform increase in water absorption percentages as percentages of replacement of PKS and QD increase. The absorption of water by samples in the curing water is a sign of the open pore volume within the concrete sample [13].

3.3.3 Compressive test

For all the curing periods, the control sample was recorded to have a loading resistance value less than that of the minimum-minimum (-1, -1) replacement sample. As the replacement is increased, a decrease in resistance to exerting force in compression was observed and recorded. This may be due to the lack of bonding ability of PKS and QD with other constituents. The high specific gravity of QD as the Minitab surface plot indicated made it more actively involved in this test. From the graph below, the (-1, -1) replacement has a strength of 25.11 MPa at 28 days while the control sample has 22.26 Mpa as recorded and presented in Figure 6.

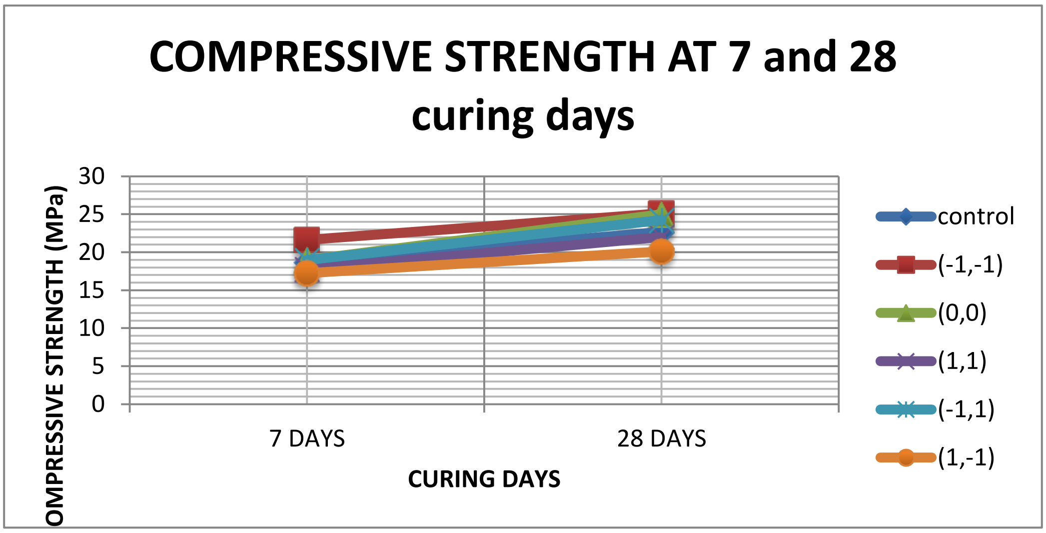

Figure 6: Compressive strength of concrete

3.3.4 Flexural test

From Figure 7 below, the flexure strength represents the highest stress experienced by a sample at the moment of its rupture. The resistance to deformation under load increases with a decrease in replacements of CF and CS. The surface plot of the compressive is a reflection of this test as only magnitude changes but the major role is played by the coconut shell.

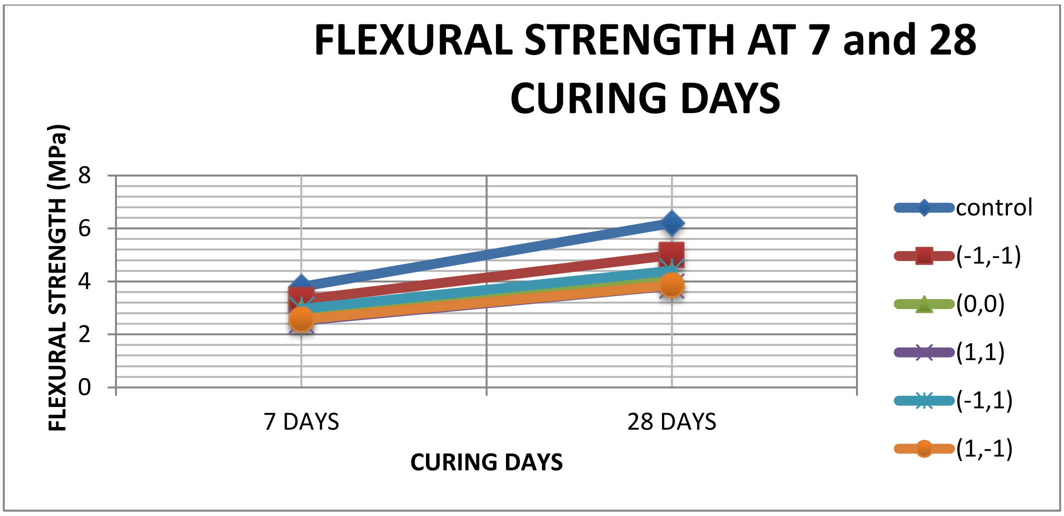

Figure 7: Flexural strength of concrete

By merely looking at the flexural and curing days comparison graph above, a strong relationship is developed when the two variables are correlated to each other. The graph demonstrates that increased curing days lead to a corresponding increase in the concrete's flexural strength. This is a clear indication and also proves that the flexural strength of concrete is directly proportional to curing days as seen in the graph above. It can be observed that the movement of the line graph is almost the same for both strength tests with variation only at some certain replacement level where the concrete yielded a very high strength.

3.3.5 Splitting tensile test

Figure 8 shows the splitting tensile strength at 7 and 28 curing days. The load at which PKS-QD concrete failed was recorded. The resistance of a concrete slab or beam to a failure due to bending is its measure of flexural strength. It can be seen from the table that the concrete whose contents are replaced at a minimum level at 28 curing days developed strength of 3.82 MPa which is higher than all other concrete specimens at the same curing days. The strength obtained at this level is less than that of the control concrete whose strength was found to be 2.6 Mpa.

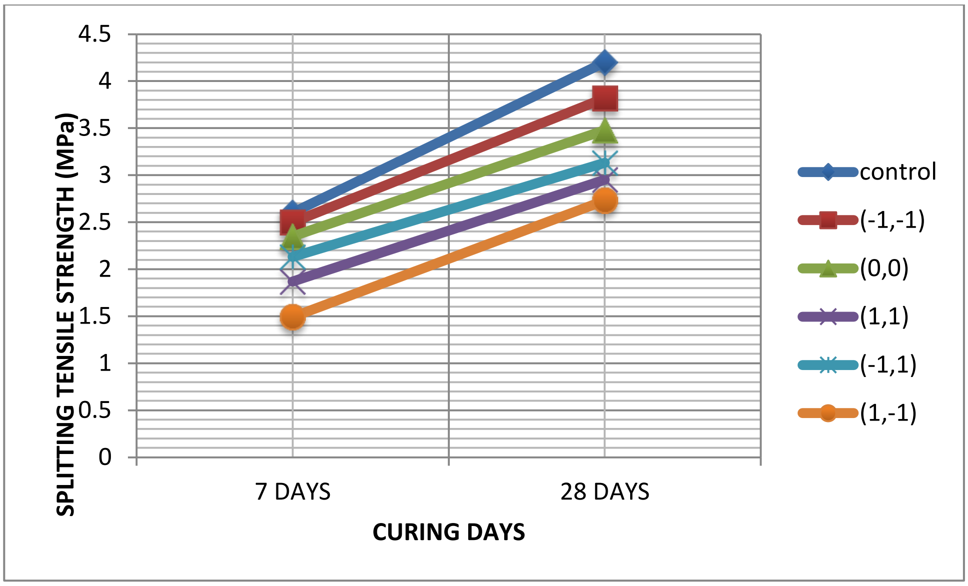

Figure 8: Concrete's splitting tensile strength at 7 and 28 days

Increased curing days lead to a corresponding increase in the concrete's splitting tensile strength, as shown in the graph. The graph also indicates that the minimum-minimum (-1, -1) replacement has the highest resistance to splitting force exerted on the sample.

3.4 Cost Comparison

At present, cost reduction plays a vital role, especially in the construction industry. The cost reduction or the cost of the constituents obtained for the thesis might vary from one location to the other depending on the need, demand, and purpose of construction. Table 12 shows a comparison of normal and Pks-QD concrete costs.

Table 12: Comparison of normal and PKS-QD concrete cost

Conc Type/Curing Days	7 Days	18 Days	28 Days	Total
NORMAL AGG. CONCRETE (RM)	21.66	43.35	23.02	88.03
PKS-QD CONCRETE (RM)	18.03	36.01	18.02	72.03

Table 12 and Figure 9 show the comparative cost analysis between normal aggregate concrete and concrete whose coarse and fine aggregate are partially substituted by palm kernel shell (PKS) and quarry dust (QD).

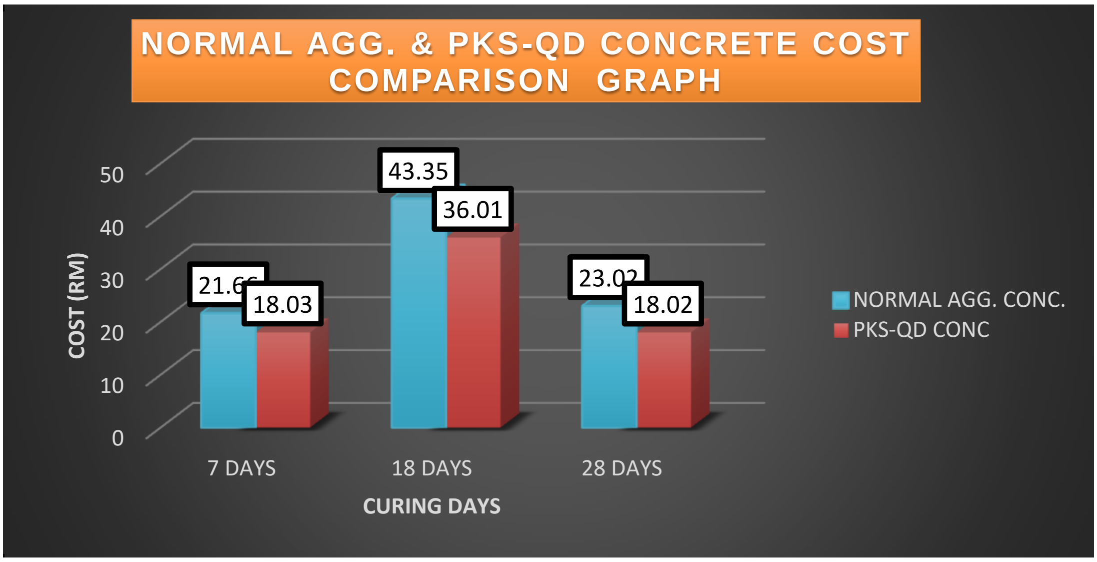

Figure 9: Cost comparison graph

The compared cost is based on the casted concrete samples excluding the control samples and also based on the substituted materials. Figure 9 indicates that the cost of the concrete is reduced as more and more the percentage of PKS and QD increases. The total amount of normal aggregate concrete was found to be RM88.03 while RM72.03 for the PKS-QD concrete (based on the casted samples). There is a total of 18.2% cost reduction of the casted concrete samples under all curing days (7, 18, and 28 days) though the cost reduction depends on the percentage replacement of the substituting materials. There may be up to 30% cost reduction when palm kernel shell and quarry dust replace gravel and sand at a higher percentage but it may also reduce the strength of the concrete.

4. CONCLUSION

This study explored palm kernel shells (PKS) and quarry dust (QD) as replacements for sand and gravel in concrete, focusing on cost reduction and environmental benefits. While increasing PKS and QD content reduced workability and slightly lowered density, it offered a total cost reduction of 18.2%. PKS-QD concrete exhibited good water absorption properties, and strength generally increased with more QD and less PKS. Response Surface Methodology proved valuable for optimizing mix design. The optimal replacement for cost-effectiveness was 5% PKS and 20% QD, but a mix with 5% PKS and 40% QD showed the potential for the highest strength. The readily available and low-cost PKS and QD offer a promising approach to reducing construction costs and environmental impact by utilizing waste materials, offering valuable direction for future research and eco-friendly construction practices.

RECOMMENDATIONS

To improve the accuracy and generalizability of the findings, future research should:

i. Increase sample size: Utilize a larger number of casted concrete samples to ensure more precise and representative results.
ii. Extend testing duration: Conduct a long-term investigation to assess the mechanical properties of the concrete over an extended period. This will provide valuable insights into the long-term performance of PKS-QD concrete.
iii. Evaluate peak strength potential: Extend the curing period for the 18-day mix types to 28 days. This will determine if their strength continues to increase, potentially revealing even higher peak strength capabilities.
iv. Incorporate superplasticizers: Investigate the use of superplasticizers in the mix design. These admixtures can improve the workability of the concrete while potentially enhancing its strength.
v. Develop automation software: Consider creating a computer program for industrial automation purposes. This could streamline the production process and optimize mix design for PKS-QD concrete in real-world applications.
vi. Durability and permeability: Conduct tests to evaluate the concrete's durability, permeability, and thermal conductivity under various PKS-QD replacement levels. This will provide a broader picture of its suitability for different construction applications.
vii. Chemical resistance: Investigate the concrete's resistance to chemical attack by subjecting it to relevant chemical exposure tests.
viii. Refine PKS-QD ratios: Explore different PKS and QD replacement ratios to identify the optimal balance between cost-effectiveness and maintaining desired strength properties. This will allow for the creation of cost-efficient PKS-QD concrete with the necessary strength for specific construction needs.

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