

The Feasibility of Palm Kernel Shell as a Replacement for Coarse Aggregate in Lightweight Concrete

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Abstract. Implementing sustainable materials into the construction industry is fast becoming a trend nowadays. Palm Kernel Shell is a by-product of Malaysia's palm oil industry, generating waste as much as 4 million tons per annum. As a means of producing a sustainable, environmental-friendly, and affordable alternative in the lightweight concrete industry, the exploration of the potential of Palm Kernel Shell to be used as an aggregate replacement was conducted which may give a positive impact to the Malaysian construction industry as well as worldwide concrete usage. This research investigates the feasibility of PKS as an aggregate replacement in lightweight concrete in terms of compressive strength, slump test, water absorption, and density. Results indicate that by using PKS for aggregate replacement, it increases the water absorption but decreases the concrete workability and strength. Results however, fall into the range acceptable for lightweight aggregates, hence it can be concluded that there is potential to use PKS as aggregate replacement for lightweight concrete.

1. Introduction

Palm Kernel Shell (PKS) is a waste material obtained during the crushing of palm nuts in the palm oil mills for palm oil extraction. In South East Asia, it is one of the most quantitative waste materials produced. Malaysia produces approximately 4 million tons of PKS annually [1]. Hence, utilizing PKS would impose lower construction costs compared to other waste materials like rubber crump, plastic waste, and others. With proper mix design, PKS can be utilized to develop normal strength concrete, which ranges from 20 to 30MPa [2]. Research has been conducted on PKS as lightweight aggregate to produce lightweight concrete since 1984 [3] which brought immense changes in the concrete industry. It was discovered by Imam et. al (2014) [4] that palm nut shell can be used as construction material in low cost buildings since it has attained a compressive strength of 18N/mm². This can indirectly facilitate in waste reduction. This research focuses on the contribution of PKS in the improvement of concrete performance in terms of workability, water absorption, density, and compressive strength.

2. Materials Characterization

2.1. Palm kernel shell (PKS)

The PKS used in this research was collected from a palm oil factory in Banting, Selangor. The PKS is air-dried naturally or in the oven, and then soaked for few days under ambient temperature to obtain Saturated Surface Dried (SSD) aggregates. The PKS grading size used was between 10.0 to 12.5mm to replace coarse aggregates at 25, 50, 75, and 100% of the total coarse aggregate value.



Table 1. Properties of aggregates and PKS.

Properties	PKS as coarse aggregate	Coarse aggregate	Fine aggregate
Specific gravity	1.21	2.72	2.6
Water absorption (%)	25.64	0.7	1.1
Bulk density (kg/m ³)	572	1445	-----
Fineness modulus	6.24	6.24	1.32
Maximum size (mm)	12.5	20	5
Aggregate impact value (%)	6.65	12.23	-----

2.2. Aggregates

Two types of aggregates; coarse aggregate and fine aggregate were used in this research. For the coarse aggregate, crushed granite rocks with a maximum size of 20mm according to the BS 812-103.2 1989 [5] was used. This coarse aggregate was prepared to be in Saturated Surface Dry (SSD) condition. For the fine aggregate, local natural sand with a maximum size of 5mm was used. The physical properties of PKS and aggregates are shown in Table 1.

2.3. Ordinary Portland cement (OPC)

In accordance to BS EN 197-1 2000 [6], OPC Type 1 was used in this research. OPC Type 1 with the specific gravity of 3.14g/cm³ was preferred because the observation of the concrete properties can be done in normal hydration process.

2.4. Silica fume

Silica fume was obtained from SIKKA-Kimia Materials in dry densified form Grade 920 conforming to the mandatory requirements of ASTM C1240 [7]. In this research, silica fume was used as cement replacement material with 15% replacement for all mixes.

2.5. Concrete mix design

The mix design was prepared based on the DOE method. The target 28 days strength was set to 30 to 40MPa. Five mixes were cast with fixed cement, silica fume, fine aggregate, and water content.

Table 2. Concrete mix proportion for PKS replacement with coarse aggregate.

Sample number	Percentage	Cement kg/m ³	w/c	Silica fume kg/m ³	Fine aggregate kg/m ³	Coarse aggregate kg/m ³	PKS kg/m ³	Design slump (mm)
CM	0%	382.5	0.45	67.5	540	1460	0	40-120
M25	25%	382.5	0.45	67.5	540	1095	365	40-120
M50	50%	382.5	0.45	67.5	540	730	730	40-120
M75	75%	382.5	0.45	67.5	540	365	1095	40-120
M100	100%	382.5	0.45	67.5	540	0	1460	40-120

3. Experimental set up

The specimens were cast according to BS1880 [8]. Slump test was conducted to determine the workability of concrete. Concrete density was determined according to BS EN 12390-7 [9]. For normal concrete, the density is approximately 2,400kg/m³. Modification of the concrete mix will result in concrete with higher or lower density, depending on the amount and density of the aggregate, cement concentration, and the maximum size of aggregate used. Lightweight concrete has a density of between 160 and 1920kg/m³. Water absorption test was conducted according to the British Standard [10] to determine the susceptibility

of an unsaturated concrete to water penetration. Compressive strength tests on the concrete was carried out conforming to BS 1881: Part 102: 1983 [11]. Concrete cubes of 100x100x100mm were then water-cured and its compressive strength monitored at ages 7, 14, and 28 days.

4. Results and discussion

4.1. Properties of fresh concrete

4.1.1. Slump test

Results show that the slump for CM and M25 are 120 mm and 100 mm respectively, reflecting high workability concrete. The value of slump for M50 is 50 mm, reflecting medium workability. The value of slump for M75 and M100 are 45 mm and 40 mm respectively, reflecting low workability. It can be concluded that the workability of concrete reduces linearly as the amount of PKS percentage increases. This can be that since normal aggregate is denser than PKS aggregate, and the replacement is by weight, the specific surface increases as the PKS content increases. This implies that more cement paste is required for the lubrication of the aggregate, hence reducing the entire fluidity of the mix, thereby reducing the height of the slump. Similar findings have been obtained by Daneshmand and Saadatin (2011) [12], agreeing with the fact that the workability of concrete decreases with the increment of PKS replacement percentage, causing the reduction of height of slump.

4.2. Properties of hardened concrete

4.2.1. Water absorption

Table 3. Results of water absorption test.

Sample number	Wet mass (g)	Dry mass (g)	Water absorption (%)
CM	2198 g	2068 g	6.28
M25	1960 g	1798 g	9.01
M50	1849 g	1693 g	9.21
M75	1790 g	1627 g	10.01
M100	1672 g	1460 g	14.52

Table 3 shows the wet mass for all concrete mixes. Three samples from each mix designs were oven-dried for 24 hours at a temperature of 115°C. The dry mass was then measured. Complying to the British Standard [14], the water absorption of concrete using PKS replacement should fall between the range of 9 to 33%, of which all mixes containing PKS (M25 to M75) abide to.

4.2.2. Compressive strength

Results show that compressive strength of concrete tends to decrease with the increment of PKS. CM gave the highest strength of 33.01 MPa at 28 days of curing compared to other mixes. Mixes M25, M50, M75, and M100 resulted in compressive strengths of 30.2MPa, 25.7MPa, 20.1MPa, and 10.9MPa respectively. This indicates that the amount of PKS affects concrete strength. The reduction of strength could be due to PKS having lower strength when compared to normal aggregate. This is reflected from the impact value for normal aggregate which is double that of PKS (see Table 1). Another factor that may cause the decrease could be attributed to the highly irregular shapes of the PKS, which could prevent full compaction with normal coarse aggregate, thereby affecting the concrete strength. This theory is supported by Daneshmand and Saadatin (2011) [16]. The bonding between PKS and cement paste will also decrease with the inclusion of higher percentage of PKS due to the smooth surface of PKS as mentioned by Mannan [17].

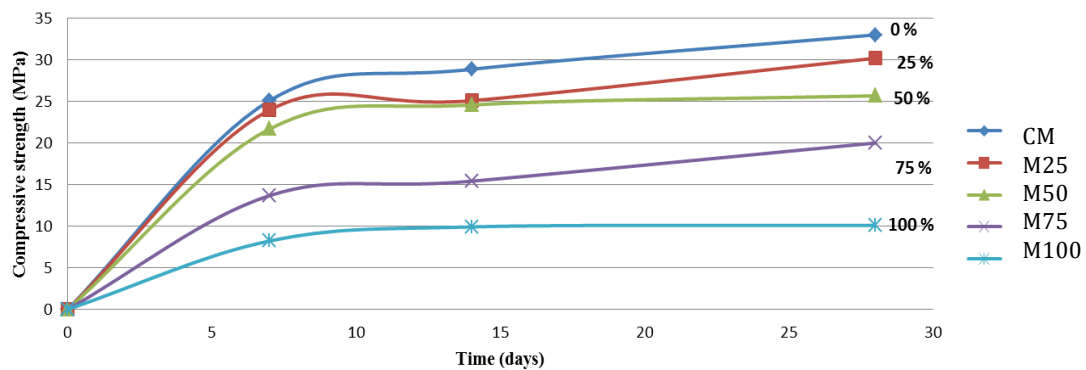


Figure 1. Comparison of compressive strength (MPa) at 7, 14, and 28 days of curing.

4.2.3. Density test

Similar to the compressive strength analysis, it was found that concrete density decreases with the increment of PKS. Starting from CM with the density of 2000kg/m^3 , the value decreases linearly with the increment of PKS. Mixes M25 to M100 can be considered as lightweight concrete judging from their densities which are 1960kg/m^3 , 1848kg/m^3 , 1790kg/m^3 , and 1672kg/m^3 respectively.

5. Conclusion

The following conclusions can be derived from the experimental results:

- The workability of fresh concrete mix decreases with the inclusion of PKS.
- Water absorption for concrete containing PKS increases but is still within standard ranges.
- The inclusion of PKS reduces the concrete strength, but the replacement of 50% PKS gives acceptable values as it falls within the range of requirement for structural LWC components.

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