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# Deployment of Palmic Concrete Pavement Blocks in Light and Heavy Traffic Situations

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***Abstract:*** *The main objective of this research was to investigate the viability of deploying palmic concrete pavement blocks (PCPBs) in light and heavy traffic situations. The term "palmic concrete" refers to any concrete containing palm kernel shell and ordinary aggregates. In this study cement, fine aggregate, coarse aggregate and palm kernel shell (PKS) were used. It was observed that density and strengths of the PCPBs decreased as the PKS content increased. Although, the strengths of the PCPBs lowered as the percentage of PKS increased, compressive strengths of 30.00 N/mm$^2$ to 48.70 N/mm$^2$ which are satisfactory for light traffic and heavy traffic situations could be achieved if 0% to 30% PKS contents are used. A model was also developed to predict the density of PCPBs through laboratory analysis. The model is only capable of predicting the density of palmic concrete products if the water cement ratio, the curing age, the aggregates cement ratio and the curing condition used are within the tested range.*

***Keywords****: palmic concrete pavement blocks, water cement ratio, compressive strength, curing age.*

## I. INTRODUCTION

The controlling of agricultural by-products has become a momentous subject in the world due to the escalating rate at which such products are being generated. Several researchers have made a consequential attempt to deploy agro by-products (Nimityongskul and Daladar, 1995; Abdullah, 1996; Elinwa and Awari, 2001; Malhotra and Mehta, 2004; Olanipekun et al., 2006; Teo et. al, 2006a), which demonstrated the viability of utilizing gigantic amount of such materials in concrete products. Among the agro waste, palm kernel shell (PKS) is one of the most common environmental issues in the contemporary world. Palm kernel shell is produced during palm oil processing. It was estimated that over 4.56 million tonnes of PKS waste is produced annually (Teo et al., 2006b). A small fraction of these wastes are traditionally used as solid fuels for steam boilers to run turbines for the electricity production of a palm oil mill; and the best part of them ended up in landfills. The burning of these waste are associated with the emission of dark smoke and the carryover of partially carbonized fibrous particles due to incomplete combustion of the fuels (Sumiani, 2006). According to Ramli (2003), nearly 5 million hectares of palm oil trees are anticipated by the year 2020. In order to alleviate these difficulties, numerous researchers have made an indispensable endeavour to utilize PKS in concrete mixes. The density of PKS concrete is anticipated to be lowered than normal weight concrete by virtue of the low specific gravity of palm kernel shell. Research conducted by Okafor (1988), demonstrated that the density of PKS concrete was approximately 1758 kg/m$^3$, representing about 73% of that of ordinary concrete. Similarly, Basri et al. (1999) reported that the density of PKS concrete was reduced by about 20% as compared to that of ordinary crushed stone concrete. Also, Mannan and Ganapathy (2004) and Alengaram et al. (2008) experienced a reduction in density of PKS concrete of approximately 22% and 24% respectively as compared to that of normal weight concrete.

Various researches pertaining to the strengths of PKS concrete have also been conducted by renowned researchers in the world. It has been observed that the incorporation of PKS aggregates in concrete mix reduces its strengths. Basri et al. (1999) mentioned that the compressive strength of PKS concrete was about 50% lower than that of normal concrete. Shafigh et al. (2012) realized a slump in compressive strength of concrete when oil palm shell was used. Experimental studies conducted by (Okafor, 1988; Okpala, 1990; Abdullah, 1996; Basri et al., 1999; Mannan and Ganapathy, 2001; Mannan & Ganapathy, 2002; Mannan and Ganapathy, 2004; Teo et al., 2006a; Teo et al., 2007; Alengaram et al., 2008; Alengaram et al., 2011; Osei & Jackson, 2012; Yusuf & Jimoh, 2013; Ikponmwosa et al., 2014) clearly show that the inclusion of PKS in concrete reduces its mechanical properties. The literature review presented emphatically shows that studies relating to the use of PKS in concrete have been conducted. However, little attention has been given to the potential use of PKS as fine aggregate in concrete mixes, particularly for concrete pavement blocks (CPBs). Hence, the current research is aimed at investigating the feasibility of using PKS as partial replacement for fine aggregate in the production of CPBs. The use of PKS in CPBs will contribute to providing environmentally friendly solution for PKS disposal problem in the world.

## II. EXPERIMENTAL STUDIES

### 2.1 Materials

Ordinary Portland cement (OPC), fine aggregate (sand), coarse aggregate (stones), ground palm kernel shell (GPKS) and water were the materials used to develop the palmic concrete pavement blocks (PCPBs). Samples of the cement, sand, stones, and GPKS used are shown in Figure 1.


**Figure 1: Samples of the materials used to develop the PCPBs**

#### 2.1.1 Cement

Ordinary Portland cement (CEM I 42.5 N) produced by Ghana cement works (Ghacem) that conformed to EN 197-1 and labelled OPC was used. The mean particle size (µm) and specific gravity of the OPC were 4 and 3.14 respectively. Table 1 displays the chemical composition of the OPC.

**Table 1: Chemical composition of ordinary Portland cement**

| Chemical composition | Content (%) |
|---|---|
| Silicon dioxide ($SiO_2$) | 19.70 |
| Aluminium oxide ($Al_2O_3$) | 5.00 |
| Ferric oxide ($Fe_2O_3$) | 3.16 |
| Calcium oxide (CaO) | 63.03 |
| Magnesium oxide (MgO) | 1.75 |
| Potassium oxide ($K_2O$) | 0.16 |
| Sodium oxide ($Na_2O$) | 0.20 |
| Sulphur oxide ($SO_3$) | 2.80 |
| Loss on ignition (LOI) | 2.58 |

#### 2.1.2 Fine aggregate, coarse aggregate, ground palm kernel shell and water

Natural river sand from Jacobu in the Ashanti Region of Ghana was used for the PCPBs. The sand was dried in an opened place to remove the moisture. The sand conformed to zone II as per IS: 383 – 1970. The GPKS used also conformed to zone II as per IS: 383 – 1970. The coarse aggregate used in this study were 10 mm nominal size, and were tested as per IS: 383 – 1970. Tables 2 and 3 show the physical properties and the sieve analysis of the sand, stones, and GPKS respectively. Potable water was used for the preparation and curing of the PCPBs.

**Table 2: Physical properties of sand, stones and ground palm kernel shell**

| Material | Specific gravity | Compacted bulk density (kg/m$^3$) | Fineness modulus | Moisture content (%) |
|---|---|---|---|---|
| Sand | 2.60 | 1695.00 | 2.53 | 2.04 |
| Stones | 2.63 | 1723.00 | 1.97 | 1.39 |
| GPKS | 1.21 | 864.5 | 2.52 | - |

**Table 3: Sieve analysis of sand, stones and GPKS**

| IS sieve size (mm) | Weight retained | | | % retained | | | % passing | | |
|---|---|---|---|---|---|---|---|---|---|
| | sand | stones | GPKS | sand | stones | GPKS | sand | stones | GPKS |
| 12.50 | 0.0 | 0.00 | 0.0 | 0.00 | 0.00 | 0.00 | 100.00 | 100.00 | 100.00 |
| 10.00 | 0.0 | 105.98 | 0.0 | 0.00 | 8.58 | 0.00 | 100.00 | 91.42 | 100.00 |
| 4.75 | 0.0 | 990.20 | 0.0 | 0.00 | 80.16 | 0.00 | 100.00 | 11.26 | 100.00 |
| 2.36 | 25.6 | 137.89 | 38.40 | 4.35 | 11.16 | 4.35 | 95.65 | 0.10 | 95.65 |
| 1.18 | 127.0 | - | 190.80 | 21.56 | - | 21.60 | 74.09 | - | 74.05 |
| 0.60 | 164.5 | - | 246.82 | 27.94 | - | 27.93 | 46.15 | - | 46.12 |
| 0.30 | 135.4 | - | 203.56 | 23.00 | - | 23.03 | 23.15 | - | 23.09 |
| 0.15 | 89.2 | - | 135.00 | 15.15 | - | 15.28 | 8.00 | - | 7.81 |
| pan | 47.1 | 1.20 | 69.05 | 8.00 | 0.10 | 7.81 | | | |

### 2.1.3 Preparation of the ground palm kernel shell

Palm kernel shells were collected from palm oil factory in Jacobu, a town in Ashanti Region of Ghana. The shells were washed in potable water and dried in an open place to remove the moisture. With the aid of metallic mortar and pestle, the palm kernel shells were ground into smaller particles.

## 2.2 Methods

### 2.2.1 Proportion of the mix

The mix proportion was 1: 1.5: 3 (cement: fine aggregate: coarse aggregate). The percentage weight of the GPKS was 0%, 10%, 20%, 30%, 40%, 50%, and 60% by volume of sand. Different water cement ratios (0.30, 0.35, 0.40, and 0.45) were used for the experiment. The plain concrete was used as a control test and denoted as Ay, where y is the water cement (w/c) ratio. The rest of the batches with GPKS were denoted as Bx/y. Where B is the batch with certain percentage (%) of GPKS, x is the volume percentage of GPKS and y is the w/c ratio. Table 4 exhibits the mix proportion of the aggregates used for the PCPBs.

**Table 4: Mix proportion**

| Batch | Constituents of PCPBs (weight in kg) | | | | |
|---|---|---|---|---|---|
| | Water | Cement | Coarse aggregate | Sand | GPKS |
| A0.30 | 1.02 | 3.40 | 10.20 | 5.10 | 0.00 |
| A0.35 | 1.19 | 3.40 | 10.20 | 5.10 | 0.00 |
| A0.40 | 1.36 | 3.40 | 10.20 | 5.10 | 0.00 |
| A0.45 | 1.53 | 3.40 | 10.20 | 5.10 | 0.00 |
| B10/0.30 | 1.02 | 3.40 | 10.20 | 4.59 | 0.26 |
| B10/0.35 | 1.19 | 3.40 | 10.20 | 4.59 | 0.26 |
| B10/0.40 | 1.36 | 3.40 | 10.20 | 4.59 | 0.26 |
| B10/0.45 | 1.53 | 3.40 | 10.20 | 4.59 | 0.26 |
| B20/0.30 | 1.02 | 3.40 | 10.20 | 4.08 | 0.52 |
| B20/0.35 | 1.19 | 3.40 | 10.20 | 4.08 | 0.52 |
| B20/0.40 | 1.36 | 3.40 | 10.20 | 4.08 | 0.52 |
| B20/0.45 | 1.53 | 3.40 | 10.20 | 4.08 | 0.52 |
| B30/0.30 | 1.02 | 3.40 | 10.20 | 3.57 | 0.78 |
| B30/0.35 | 1.19 | 3.40 | 10.20 | 3.57 | 0.78 |
| B30/0.40 | 1.36 | 3.40 | 10.20 | 3.57 | 0.78 |
| B30/0.45 | 1.53 | 3.40 | 10.20 | 3.57 | 0.78 |
| B40/0.30 | 1.02 | 3.40 | 10.20 | 3.06 | 1.04 |
| B40/0.35 | 1.19 | 3.40 | 10.20 | 3.06 | 1.04 |
| B40/0.40 | 1.36 | 3.40 | 10.20 | 3.06 | 1.04 |
| B40/0.45 | 1.53 | 3.40 | 10.20 | 3.06 | 1.04 |
| B50/0.30 | 1.02 | 3.40 | 10.20 | 2.55 | 1.30 |
| B50/0.35 | 1.19 | 3.40 | 10.20 | 2.55 | 1.30 |
| B50/0.40 | 1.36 | 3.40 | 10.20 | 2.55 | 1.30 |
| B50/0.45 | 1.53 | 3.40 | 10.20 | 2.55 | 1.30 |
| B60/0.30 | 1.02 | 3.40 | 10.20 | 2.04 | 1.56 |
| B60/0.35 | 1.19 | 3.40 | 10.20 | 2.04 | 1.56 |
| B60/0.40 | 1.36 | 3.40 | 10.20 | 2.04 | 1.56 |
| B60/0.45 | 1.53 | 3.40 | 10.20 | 2.04 | 1.56 |

*Note: Density of sand = 1695.0 Kg/m$^3$ and density of GPKS = 864.5 Kg/m$^3$. Therefore, weight of GPKS for an equivalent volume of sand (conversion factor) = 864.5/1695.0 = 0.51

**2.2.2 Preparation and curing of PCPBs**

Mixing of concrete and compaction of the blocks were done mechanically. Steel mould with internal dimensions of 200mm in length, 100mm in width and 60mm in depth was used to mould the PCPBs. The prepared PCPBs were packed on boards and covered with polythene sheets for 24 hours before curing started. The specimens were then placed in a curing tank for specific number of days (i.e. 7 days, 14 days and 28 days).

**2.2.3 Testing of specimens**

The density and compressive strength of the PCPBs were determined in accordance with BS 1881 – Part 114 (1983) and BS 6717 – Part 1 (1986) respectively. The water absorption was tested in conformity with ASTM C 642 (2006). To test the flexural strength, a centre line was marked at the top of the specimen perpendicular to its length. The PCPBs were tested under the centre line load while simply supported over supporting span of 150 mm. The flexural strength was then calculated from the formula; $\sigma = 3/2\ (LF / BD^2)$, where σ is the flexural strength ($N/mm^2$), L is the span length (mm), F is the maximum applied load (N), B is the average width of the specimen (mm), and D is the average thickness (mm). For the splitting tensile test, line loads were applied to the top and bottom of the PCPB using two steel bars. Plywood strips were inserted between the bars and the blocks to ensure even load distribution. Upon failure, the maximum applied load was recorded and the splitting tensile strength was calculated from the formula; $T = (0.868 \times K \times F) / (L \times D)$. Where T is the splitting tensile strength ($N/mm^2$), F is the load at failure (N), L is the length of the failure plane (mm), D is the thickness of the specimen at the failure plane (mm), and K is the correction factor for the thickness, calculated from the equation, $K = 1.3 - 30\ (0.18 - t/1000)^2$, t is the thickness of specimen.

## III. RESULTS AND DISCUSSION

**3.1 Effect of w/c ratio and palm kernel shell content on strengths of PCPBs**

The results of the strengths of PCPBs for various w/c ratios and PKS contents are summarized in Table 5. It can be noticed that several strengths were obtained when different w/c ratios were used. Water cement ratio of 0.40 was found to be the optimum. By comparing the optimum w/c ratio to the other w/c ratios, the compressive strength was decreased by about 20%, 14% and 6% when w/c ratios of 0.30. 0.35 and 0.45 were applied irrespective of the percentage of PKS aggregate used. Study conducted by Okpala (1990) revealed that the quantity of water used for the preparation of PKS concrete has significant effect on its compressive strength. For PKS concrete mix of 1:1:2, w/c ratio of 0.5 was found to be the optimum. The compressive strength was reduced by about 10.8%, 25.7% and 32.9% when w/c ratios of 0.60, 0.70 and 0.80 were used respectively. In the same study, when a mix of 1:2:4 was used and the same range of w/c ratio was applied, the compressive strength was lowered by approximately 12.7%, 31.2% and 39.1% when w/c ratios of 0.60, 0.70 and 0.80 were applied respectively. In this study, the flexural strength was also affected when different w/c ratios were used. A slump of about 15%, 10% and 5% were observed when w/c ratios of 0.30, 0.35 and 0.45 were used. Okpala (1990) noticed the impact of w/c ratio on flexural strength of PKS concrete. For concrete mix of 1:1:2, w/c ratio of 0.5 was the optimal. The flexural strength was declined by about 10.0%, 18.1% and 24.2% when w/c ratios of 0.60, 0.70 and 0.80 were used respectively. In the current study, the splitting tensile strength experienced a reduction of approximately 19%, 13% and 7% when w/c ratios of 0.30, 0.35 and 0.45 were used notwithstanding the amount of PKS aggregate applied. Okafor (1988) showed that the splitting tensile strength of PKS concrete varied in the range of 2.0 $N/mm^2$ to 2.4 $N/mm^2$ with varying w/c ratio of 0.48 to 0.65. This indicates that the splitting tensile strength was reduced by about 17% when w/c ratio of 0.65 was used. In the present investigation, the differences in mechanical properties may be due to the different quantities of water used for the preparation of the PCPBs. Mixes produced from w/c ratios of 0.30 and 0.35 may be little dry causing insufficient compaction and hence leading to decrease in strengths. Mixes made from w/c ratio of 0.45 may be quite wet and this might have created voids in the concrete as the results of the evaporation of excess water from the PCPBs after hydration reaction.

It can also be observed that the strengths of the PCPBs reduced as the palm kernel shell content increased (Table 5). The decrease pattern of the strengths is similar for the four different w/c ratios. The compressive strength lowered from 39.26 $N/mm^2$ to 15.14 $N/mm^2$, 42.90 $N/mm^2$ to 16.58 $N/mm^2$, 48.70 $N/mm^2$ to 19.37 $N/mm^2$, and 45.83 $N/mm^2$ to 17.81 $N/mm^2$ at 0.30, 0.35, 0.40, and 0.45 w/c ratios respectively. The test results of Basri et al. (1999) showed that PKS concrete have lower compressive strength than ordinary concrete by 42% to 55% and 41% to 50% at 28 days and 56 days respectively depending on the curing environment. Mannan et al. (2002) reported that PKS concrete have approximately 52% lower compressive strength than crushed stone concrete. Similarly, Shafigh et al. (2012) mentioned that on average, the compressive strength of PKS concrete in their study was about 21% lighter than normal weight concrete. The present investigation also shows that the incorporation of PKS as fine aggregate in concrete reduces its compressive strength as compared to the normal concrete. For this study, the splitting tensile strength was lessened from 4.09 $N/mm^2$ to 1.86 $N/mm^2$, 4.43 $N/mm^2$ to 2.11 $N/mm^2$, 5.10 $N/mm^2$ to 2.34 $N/mm^2$, and 4.76 $N/mm^2$ to 2.24 $N/mm^2$ at 0.30, 0.35, 0.40, and 0.45 w/c ratios in order. The measured 28-day splitting tensile strength is in the range of 1.86 $N/mm^2$ to 5.10 $N/mm^2$. Previous studies (Abdullah, 1996; Mannan and Ganapathy, 2002; Teo et al., 2006a; Alengaram et al., 2008; Shafigh et al., 2012) showed that the 28-day splitting tensile strength of PKS concrete in moist curing is in the range of 1.10 $N/mm^2$ to 3.54 $N/mm^2$. It can be observed that the splitting tensile strength obtained in this study is significantly higher than previous studies. Generally, the splitting tensile strength of normal weight concrete is 8% to 14% of compressive strength (Skosmatka et al., 2002). It can be concluded that the splitting tensile strength of the PCPBs tested in this study is within the range. In the current research, the flexural strength declined from 5.11 $N/mm^2$ to 2.65 $N/mm^2$, 5.43 $N/mm^2$ to 2.91 $N/mm^2$, 6.01 $N/mm^2$ to 3.13 $N/mm^2$, and 5.73 $N/mm^2$ to 3.05 $N/mm^2$ at 0.30, 0.35, 0.40, and 0.45 w/c ratios respectively. The 28-day flexural strength of the PCPBs in this study ranged from 2.65 $N/mm^2$ to 6.01 $N/mm^2$. Previous studies (Okpala, 1990; Mannan &Ganapathy, 2002; Teo et al., 2006a; Alengaram et al., 2008; Alengaram et al., 2011, Shafigh et al. 2012) revealed that PKS concrete have flexural strength in the range of 2.13 $N/mm^2$ to 6.99 $N/mm^2$. The 28-day flexural strength of the current study is on average 14% of the 28-day compressive strength. Research conducted by Shafigh et al. (2012) showed that flexural strength of PKS concrete with compressive strength of 34 $N/mm^2$ to 54 $N/mm^2$ is in the range of 4.42 $N/mm^2$ to 6.99 $N/mm^2$. They further stated that the flexural strength / compressive strength ratio was in the range of 12.9% to 14.8%, with an average of 13.7%. By comparing, it can be observed that this study has a similar average flexural / compressive strength ratio with that of (Shafigh et al. 2012). From the analysis, it is obvious that the inclusion of PKS in concrete mix as fine or coarse aggregate reduces its strengths. However, the rate of reduction is likely to be reduced if the PKS aggregate is used as partial replacement for the normal aggregate. The reason for the decline in strengths in the current research could be attributed to the smooth surface of the palm kernel shell aggregates which might have weakened the adhesion between the boundaries of the palm kernel particles and the cement paste.

**Table 5: 28 day strengths tests results**

| Water cement ratio | PKS content (%) | Compressive strength ($N/mm^2$) | Splitting tensile strength ($N/mm^2$) | Flexural strength ($N/mm^2$) |
|---|---|---|---|---|
| 0.30 | 0 | 39.26 | 4.09 | 5.11 |
| | 10 | 36.29 | 3.82 | 4.84 |
| | 20 | 32.07 | 3.41 | 4.43 |
| | 30 | 26.94 | 3.04 | 3.95 |
| | 40 | 23.19 | 2.71 | 3.60 |
| | 50 | 18.07 | 2.23 | 2.97 |
| | 60 | 15.14 | 1.86 | 2.65 |
| 0.35 | 0 | 42.90 | 4.43 | 5.43 |
| | 10 | 38.25 | 4.02 | 5.03 |
| | 20 | 34.41 | 3.58 | 4.59 |
| | 30 | 28.69 | 3.30 | 4.29 |
| | 40 | 24.83 | 2.75 | 3.62 |
| | 50 | 20.44 | 2.55 | 3.41 |
| | 60 | 16.58 | 2.11 | 2.91 |
| 0.40 | 0 | 48.70 | 5.10 | 6.01 |
| | 10 | 44.88 | 4.65 | 5.59 |
| | 20 | 41.02 | 3.97 | 5.12 |
| | 30 | 32.90 | 3.64 | 4.71 |
| | 40 | 27.99 | 3.07 | 4.02 |
| | 50 | 22.54 | 2.76 | 3.63 |
| | 60 | 19.37 | 2.34 | 3.13 |
| 0.45 | 0 | 45.83 | 4.76 | 5.73 |
| | 10 | 42.68 | 4.43 | 5.43 |
| | 20 | 39.92 | 3.70 | 4.99 |
| | 30 | 31.42 | 3.41 | 4.43 |
| | 40 | 26.05 | 2.87 | 3.76 |
| | 50 | 21.45 | 2.57 | 3.42 |
| | 60 | 17.81 | 2.24 | 3.05 |

### 3.2 Impact of curing age on strengths of PCPBs

The influence of curing age on strengths of PCPBs is exhibited in Figures 2, 3, and 4. Critical examination of Figure 2 shows that the compressive strength was increased by about 32% when the curing age moved from 7 days to 28 days irrespective of the PKS content used. Experimental study carried out by Olanipekun et al. (2006) clearly demonstrates the effect of curing age on PKS concrete. For concrete mix of 1:1:2, compressive strengths of 15 $N/mm^2$ to 24 $N/mm^2$ were obtained within curing age range of 7 days to 28 days. This suggests that at 25% PKS replacement, the compressive strength was increased by approximately

60% when the curing period moved from 7 days to 28 days. Yusuf and Jimoh (2013) also experienced similar trend in their research. For PKS concrete mix of 1:2:4, the compressive strength moved from 10.21 N/mm$^2$ to 15.8 N/mm$^2$, indicating an increase of about 55% when the curing age rose from 14 days to 56 days. Osei and Jackson (2012) also noticed the influence of curing period on PKS concrete. A compressive strength of 9.34 N/mm$^2$ to 15.00 N/mm$^2$, representing an upsurge of about 61% was observed. This indicates that at 50% replacement of the coarse aggregate by PKS, the compressive strength was increased by about 61% when the curing age moved from 7 days to 28 days. Similarly, Ikponmwosa et. al (2014) reported that at 20% substitution of coarse aggregate with PKS, the compressive strength was increased from 13.53 N/mm$^2$ to 19.77 N/mm$^2$ for a curing age range of 7 days to 56 days, representing an increase of approximately 46%.

Figure 3 displays the impact of curing period on splitting tensile strength of the developed PCPBs. Careful study of the figure shows that the splitting tensile strength was increased by approximately 33% when the curing age moved from 7 days to 28 days regardless of the PKS content applied. Yusuf and Jimoh (2013) also noticed a similar direction in their experimental study. For PKS concrete mix of 1:1:2, the splitting tensile strength increased from 0.23 N/mm$^2$ to 1.25 N/mm$^2$. This implies that the splitting tensile strength was increased by about 81.6% when the curing period moved from 3 days to 56 days.

The influence of curing age on flexural strength is shown in Figure 4. It is obvious that the flexural strength increases as the curing age increased. A rise of about 31% in flexural strength was noticed when the curing period moved from 7 days to 28 days. Ikponmwosa et. al (2014) noticed that at 30% replacement of coarse aggregate by PKS, the flexural strength was moved from 1.03 N/mm$^2$ to 1.51 N/mm$^2$ for a curing age range of 7 days to 28 days, representing an upsurge of about 47%. Also, Yusuf and Jimoh (2013) observed an increase in flexural strength of PKS concrete when the curing age increased. For PKS concrete mix of 1:2:4, the flexural strength was moved from 1.12 N/mm$^2$ to 1.78 N/mm$^2$, indicating an increase of approximately 59% when the curing period moved from 7 days to 28 days. The increase in strengths as a result of change in curing age may be due to the hydration reaction of the cement paste which increases the strengths of concrete as curing age increases.

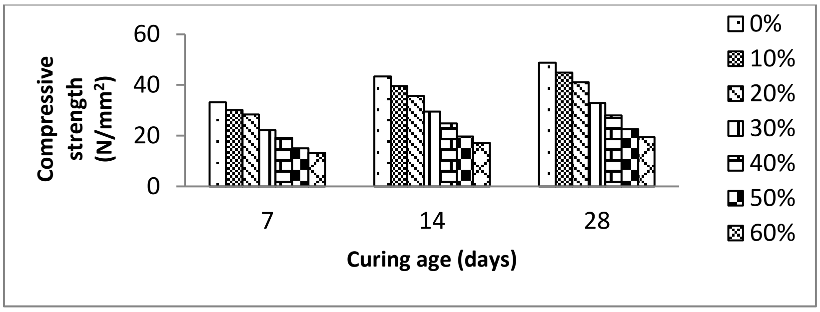


**Figure 2: Compressive strength of different curing ages for w/c ratio of 0.40**

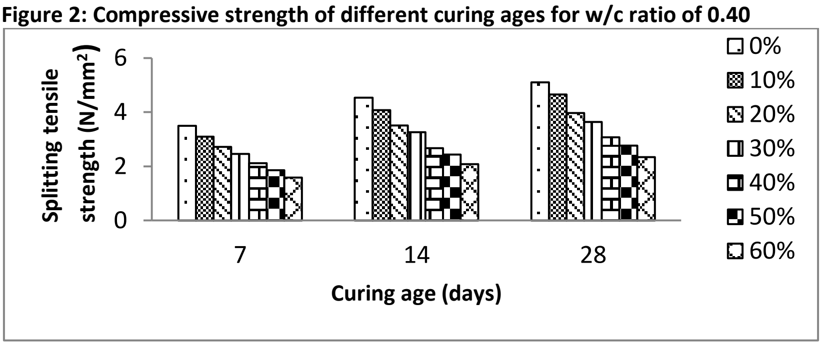


**Figure 3: Splitting tensile strength of different curing ages for w/c ratio of 0.40**

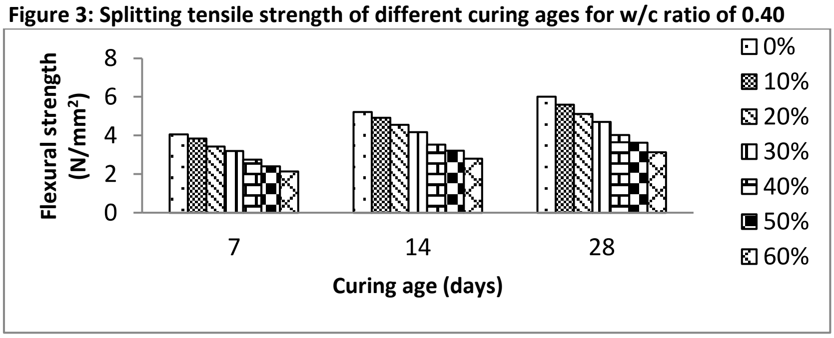


**Figure 4: Flexural strength of different curing ages for w/c ratio of 0.40**

### 3.3 Influence of palm kernel shell content on water absorption

The effect of palm kernel shell content on water absorption of the PCPBs is demonstrated in Table 6. It is noticeable that the water absorption increases as the percentage of the palm kernel aggregate rises. The water absorption moved from 1.46% to 1.77%, indicating a rise of about 21% when 60% of the sand was substituted with PKS aggregates. Olanipekun et al. (2006) noticed the effect of PKS on water absorption of concrete. They reported that the percentage water absorption increases with increase in the percentage replacement level of coarse aggregate with PKS. For mix ratio 1:1:2, the value range from 0.41% to 5.88% for PKS concrete (10% to 100% replacement levels).The water absorption of PKS concrete under air drying curing and full water curing were 11.23% and 10.64% respectively (Teo et al., 2007). And these values are higher than that of normal weight concrete (Newman & Choo, 2003). It can be noticed that the water absorption values found in this study are within that of normal weight concrete. The upsurge in water absorption may be attributed to the increase of voids in the PCPBs as a result of the poor bond between the palm kernel particles and the cement paste in the mix. It may also be due to the difference between the water absorption of fine aggregate and that of palm kernel shell. The relationship between palm kernel content and percentage increase in water absorption was found to be linear (Figure 5). The $R^2 = 0.9962$ indicates that 99.62% of the variation in water absorption can be explained by palm kernel shell content.

**Table 6: Effect of PKS content on water absorption**

| Water cement ratio | PKS content (%) | Water absorption (%) | % rise in water absorption |
|---|---|---|---|
| | 0 | 1.46 | 0.00 |
| | 10 | 1.51 | 3.42 |
| | 20 | 1.56 | 6.85 |
| 0.40 | 30 | 1.60 | 9.59 |
| | 40 | 1.65 | 13.01 |
| | 50 | 1.71 | 17.12 |
| | 60 | 1.77 | 21.23 |

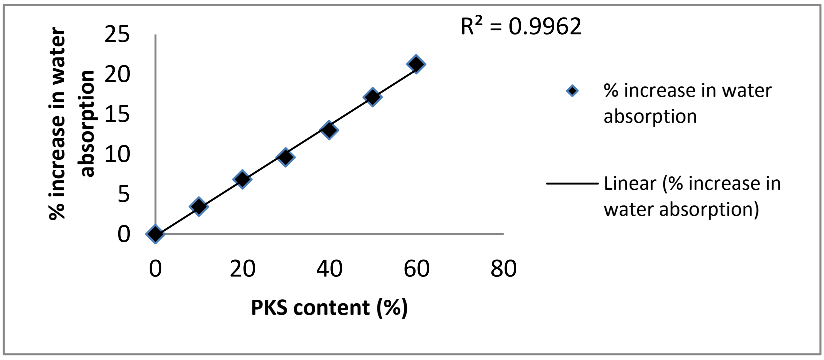


**Figure 5: Relationship between PKS content and % increase in water absorption**

### 3. 4 Effect of PKS aggregates and w/c ratio on density of PCPBs

The density of the developed PCPBs obtained from the experiment is displayed in Table 7. It is observable that the rate of reduction in density increases as the PKS content increases. The density was lowered by about 11% when 60% of the fine aggregate was substituted with PKS irrespective of the w/c ratio used. Research conducted by Okafor (1988) showed that the density of PKS concrete was approximately 1758 $kg/mm^3$, representing about 73% of that of normal concrete. Likewise, Basri et al. (1999) noticed that the density of PKS concrete was declined by approximately 20% as compared to that of ordinary crushed stone concrete. Alengaram et al. (2008) also experienced a reduction in density of PKS concrete by about 24% as compared to that of normal weight concrete. The slump in density may be due to the low specific gravity of palm kernel shell (1.21) as compare to that of sand (2.60). Partially replacing volume of the sand by PKS would certainly reduce the masses of the PCPBs.

The influence of w/c ratios on density of PKS concrete is demonstrated in Table 7. It can be noticed that different densities were obtained when different w/c ratios were applied. By comparing the optimal w/c ratio to the other w/c ratios, the density was decreased by approximately 12%, 7% and 2% when w/c ratios of 0.30. 0.35 and 0.45 were applied regardless of the percentage of PKS aggregate used. Okpala (1990) had similar experience when different w/c ratios were used in his study. A density range of 1630 $kg/mm^3$ to 1780 $kg/mm^3$ were obtained for 1:1:2 concrete mix. This shows that the density of the PKS concrete was lowered by about 8% when w/c ratio of 0.80 was used. For concrete mix of 1:2:4, the density was reduced from 1700 $kg/mm^3$ to 1600 kg/mm$^3$, representing approximately 6% reduction in density when w/c ratio of 0.80 was applied. For the current study, the differences in densities may be influenced by the different quantities of water used for the preparation of the PCPBs. Mixes produced from w/c ratios of 0.30 and 0.35 may be little dry causing insufficient compaction and hence leading to decrease in masses. Mixes made from w/c ratio 0.45 may be quite wet and this might have created voids in the concrete as the results of the evaporation of excess water from the PCPBs after hydration reaction and these voids are likely to affect the masses of the PCPBs.

**Table 7: Experimental testing results of density**

| Water cement ratio | PKS content | Density (kg/m$^3$) | | |
|---|---|---|---|---|
| | (%) | 7 days | 14 days | 28 days |
| 0.30 | 0 | 2342.92 | 2348.27 | 2353.57 |
| | 10 | 2326.98 | 2333.01 | 2336.34 |
| | 20 | 2250.79 | 2257.83 | 2266.46 |
| | 30 | 2200.26 | 2203.49 | 2209.79 |
| | 40 | 2110.30 | 2116.31 | 2123.90 |
| | 50 | 2094.69 | 2099.16 | 2105.51 |
| | 60 | 2078.65 | 2082.13 | 2087.69 |
| 0.35 | 0 | 2478.41 | 2481.02 | 2488.17 |
| | 10 | 2411.17 | 2416.63 | 2426.11 |
| | 20 | 2368.09 | 2373.26 | 2377.01 |
| | 30 | 2319.17 | 2327.20 | 2334.32 |
| | 40 | 2287.56 | 2288.33 | 2298.78 |
| | 50 | 2242.17 | 2245.92 | 2251.42 |
| | 60 | 2200.91 | 2208.46 | 2216.41 |
| 0.40 | 0 | 2615.11 | 2622.81 | 2633.17 |
| | 10 | 2577.24 | 2584.17 | 2589.44 |
| | 20 | 2532.72 | 2537.65 | 2543.92 |
| | 30 | 2505.83 | 2514.07 | 2519.07 |
| | 40 | 2468.11 | 2474.82 | 2478.35 |
| | 50 | 2424.79 | 2431.05 | 2437.61 |
| | 60 | 2365.25 | 2371.45 | 2375.99 |
| 0.45 | 0 | 2568.37 | 2586.17 | 2594.17 |
| | 10 | 2532.53 | 2536.31 | 2544.75 |
| | 20 | 2495.54 | 2498.91 | 2502.46 |
| | 30 | 2456.37 | 2457.11 | 2462.35 |
| | 40 | 2413.11 | 2419.72 | 2425.72 |
| | 50 | 2358.42 | 2363.54 | 2369.17 |
| | 60 | 2310.79 | 2317.62 | 2324.08 |

### 3.5 Development of model for predicting the density of the developed PCPBs

The model was developed based on the experimental results presented in Table 7. Multiple regression analysis was used to develop the predictive equation with the help of Statistical Analysis System (SAS). Multiple regressions give the opportunity to establish the evidence that one or more independent variables cause another dependent variable to change (Blaikie, 2003). In so doing, the analysis establishes the relative magnitude of the contribution of each predictor variable. It also offers the opportunity to examine what proportion of the variance in the outcome variable is explained by each predictor variable and or / their combined effect (Brace et al., 2003). In this case the predictor variables (independent variables) were represented by water cement ratio, curing age and PKS content while the criterion variable (dependent variable) was density of PCPBs.

### 3.5.1 Predicting the density of the developed PCPBs

With the application of SAS, the necessary outputs required for predicting the density are shown in Tables 8, 9 and 10. Table 8 presents the model summary of the results for the regression analysis. The R-square ($R^2$ = 0.857) which is the coefficient of determination shows that there is strong correlation between the criterion variable (density) and the predictor variables (water cement ratio, curing age and PKS content). The table also demonstrates that the adjusted $R^2$ = 0.852. Using the analysis of variance (Table 9) and the adjusted $R^2$, the following conventional statistical report was extracted (adjusted $R^2$ = 0.852, $F_{3, 80}$ = 160.117, $P < 0.0001$). As $P < 0.0001$, it implies that the model is statistically significant. The parameter estimate column (Table 10), gives the coefficients of the predictor variables in the regression equation. Subsequently, the following equation for predicting the density was derived:

**Density of PCPBs = 1814.539 + 1827.581 w/c ratio + 0.560 curing age – 4.464 PKS content (Adjusted $R^2$ = 0.852).**

The 1814.539 is a constant value for predicting the density of the developed PCPBs. The 1827.581 means if water cement ratio is increased by one unit, density of the developed PCPBs will on average increase by 1827.581. The 0.560 indicates that if curing age is increased by one unit, density of the PCPBs will on average increase by 0.560. The – 4.464 suggests that if PKS content is increased by one unit, density of the developed PCPBs will on average decrease by 4.464. The adjusted $R^2 = 0.852$ indicates that 85.2% of the variation in density can be explained by water cement ratio, curing age and PKS content. The t-values and the respective P – values reported in Table 10 indicate the significant contribution of w/c ratio, curing age and PKS content in predicting the density of the PCPBs. The t-values measure how strongly each variable influence the prediction of the density. Table 10 also demonstrates that the contribution of water cement ratio and PKS content in determining the density of PCPBs is statistically significant ($P < 0.0001$) whilst that of the curing age is statistically insignificant ($P > 0.05$).

### 3.5.2 Test of Goodness of fit

The adjusted $R^2$ of 85.2% is very high and this suggests that the equation is relatively good. Analysis of variance (Table 9) also indicates that the regression equation is statistically significant ($P < 0.0001$). These parameters are indications of the goodness of fit of the equation.

**Table 8: Model summary of the regression analysis**

| Root MSE | Dependent mean | Coefficient of variance | R-square | Adjusted R-square |
|---|---|---|---|---|
| 56.77641 | 2352.51889 | 1.09778 | 0.857 | 0.852 |

**Table 9: Analysis of variance table showing the significance of the regression model**

| Analysis of Variance | | | | | |
|---|---|---|---|---|---|
| Source | DF | Sum of squares | Mean square | F-value | Pr > F |
| Model | 3 | 1548442.695 | 516147.565 | 160.117 | <.0001 |
| Error | 80 | 257884.822 | 3223.560 | | |
| Corrected Total | 83 | 1806327.517 | | | |

**Table 10: Parameter estimates table showing the coefficients of the independent variables in the regression equation**

| Parameter Estimates | | | | | |
|---|---|---|---|---|---|
| Variable | DF | Parameter Estimates | Standard Error | t-value | Pr > \|t\| |
| Intercept | 1 | 1814.539 | 44.564 | 40.718 | <.0001 |
| Water cement ratio | 1 | 1827.581 | 110.816 | 16.492 | <.0001 |
| Curing age | 1 | 0.560 | 0.710 | 0.790 | <.432 |
| PKS content | 1 | - 4.464 | 0.310 | - 14.413 | <.0001 |

## IV. CONCLUSIONS

Based on the experimental results of this study, the following conclusions can be drawn.

- Both physical and mechanical properties of the concrete pavement blocks were affected when palm kernel shell was used as a partial replacement for sand. Decrease in density, compressive strength, splitting tensile strength and flexural strength was observed when part of the sand was substituted with PKS. But the water absorption of the PCPBs increased as the PKS content increased. Comparison between the current study and the previous studies shows that both physical and mechanical properties of PKS concrete reduced, whether the PKS aggregate is used as coarse or fine aggregate in the concrete mix. However, the rate of reduction is declined if the PKS aggregate is used as partial replacement in the mix.
- Although, the strength of PCPBs decreased as the PKS content increased, compressive strength of 30.00 $N/mm^2$ to 48.70 $N/mm^2$ which are satisfactory for light and heavy traffic situations could be achieved if 0% to 30% PKS contents are used.
- A model was developed to predict the density of the PCPBs. The effect of PKS content and w/c ratio on the prediction was statistically significant ($p < 0.0001$) whilst that of curing age was statistically insignificant ($p > 0.05$). The model is only capable of predicting the density of palmic concrete products if the w/c ratio, the curing age, the aggregate cement ratio and the curing condition used are within the tested ranged.
- The model shows that increase in w/c ratio results in increase in density. This does not mean that whenever w/c ratio is increased, density of PCPBs would be increased. This is happening as a result of the range of w/c ratios used. From the experiment, it was realized that after the optimum w/c ratio (0.40) was used, the density started declining when w/c ratio of 0.45 was employed. This presupposes

that if a different range of w/c ratios of say 0.40 to 0.75 is used, the effect of w/c ratio on the prediction of density may probably be the reverse. Hence, the model should not be applied outside the range of w/c ratios used in this study.

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