

SHRINKAGE AND CREEP CHARACTERISTICS OF PALM KERNEL SHELL CONCRETE

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Abstract: This research work evaluates the shrinkage and creep characteristics of concrete containing Palm Kernel Shell (PKS) as partial replacement of natural coarse aggregate. Concrete was mixed at 0.55 water-cement ratio, mix proportion of 1:1:2 and percentage replacement of natural aggregate with PKS at 0%, 25% and 50%. The creep and shrinkage results of Palm Kernel Shell Concrete (PKSC), increased as the percentage content of PKS increased in the concrete. The maximum creep strain observed for normal concrete, 25% and 50% PKS content were 0.00018 mm/m, 0.00057 mm/m and 0.00094 mm/m respectively. The maximum total shrinkage strain recorded for 0%, 25% and 50% PKS content was 0.00102 mm/m, 0.00183 mm/m and 0.00247 mm/m respectively.

Keywords: Concrete, Palm Kernel Shell, Aggregates, Creep and Shrinkage.

1. INTRODUCTION

The need to research other materials that can be used to replace natural aggregate used in concrete cannot be overemphasized. The breaking of rocks to produce natural aggregates for concrete is not sustainable, and it impacts its environment negatively [1]. Palm Kernel Shell (PKS) is a waste product of the oil palm tree usually disposed on open land areas in very large quantities. The use of palm kernel shell in concrete could resolve this challenge with some other advantages; reduction in the need to crush more rocks for natural coarse aggregate and reduced land areas used as dump sites. Shrinkage in concrete is defined as reduction in volume of concrete usually over a period. Concrete is subjected to changes in volume either autogenous or induced. Volume change is one of the most detrimental properties of concrete, which affects the long term strength and durability. Aggregate size and shape have been reported to be key factors affecting the shrinkage of hardened concrete. The study by Bisschop et al [2] indicated that larger aggregate sizes increase the depth and length of cracks caused by shrinkage of concrete. It has been reported that the degree of restraint of a concrete matrix is affected largely by the elastic property of its aggregate [3]. Natural aggregates usually do not shrink. However, aggregate's physical property determines the extent of shrinkage strain of its concrete [4]. For example, concrete made with steel aggregate will shrink less than the one made with natural aggregate. Similarly, concrete made with expanded shale aggregate will restrain shrinkage less than the one made with a natural aggregate. In other words, a stiffer coarse aggregate produces concrete with less shrinkage strain. The elastic modulus of the aggregate determines the extent of restraining action of the concrete to shrinkage.

Studies by Kim et al [5] show that at a constant concrete mix proportion, a significant difference was observed in the shrinkage strain of concretes made with different types of coarse aggregate. This phenomenon is very likely due to the varying modulus of elasticity measured from the different aggregate types. Teo et al. [6] carried out drying shrinkage test on PKSC and compared it with normal concrete on 7, 28, 56 and 90 days. They reported that the drying shrinkage of both the PKSC and normal concrete increased with age but PKSC showed higher

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increment. At the age of 28 and 90 days, PKSC showed 64 and 182 microstrain respectively. This was 6% and 14% higher than the drying shrinkage of normal concrete, for the ages indicated respectively.

Concrete creep is defined as deformation under constant load. This deformation often takes place in the direction of the applied force. Basically, concrete shape can be affected over time by long term stress. Creep does not necessarily cause failure or breaking apart of concrete. Aggregates usually record very little creep, the paste in the concrete is responsible for creep. However, the aggregate influences the creep of concrete through a restraining effect on the magnitude of creep. The paste which is creeping under load is restrained by the aggregate which do not creep. The restraining effect of concrete on creep increases as aggregate strength increases. The modulus of elasticity of aggregate is an important property that determines the extent of concrete creep. It can easily be imagined that aggregates with higher modulus of elasticity produces concrete with less creep strain. Light weight aggregate shows significantly higher creep than normal weight aggregate. Therefore, it is of paramount interest to investigate the creep of palm kernel shell concrete [5].

The quality and amount of concrete paste are important factors that determines creep. Concrete with a poorer paste structure recorded higher creep. In other words, creep is given as being inversely proportional to the strength of concrete [7]. Concrete with PKS has been known to be less workable in some instances than normal concrete, because PKS absorbs more water than natural coarse aggregate. It is expected that this particular factor will have a significant influence on the creep of concrete made with PKS, since it has been reported by various researchers that palm kernel shell concrete usually has less strength compared to normal concrete at the same mix and water-cement ratio [1, 7, 8].

The extent of concrete creep will be influenced greatly by the age at which the concrete member is loaded. This is explained in that the concrete matrix gains strength with time. Aged gel creeps less, whereas a younger gel under load being not as strong creeps more. Although moisture content of the concrete being different at different ages will also have a significant influence on the magnitude of creep. Over the years, there have been so many researches work on the use of palm kernel shell in concrete, but little or nothing is known on the shrinkage and creep of palm kernel shell concrete, hence the significance of this work.

2. EXPERIMENTAL SETUP

The raw materials used in this investigation were locally available and these included ordinary Portland cement (OPC) as binder, river sand as fine aggregate, crushed granite and PKS as coarse aggregate. Potable water was used for mixing and curing throughout the entire investigation. PKS has comparatively high water absorption characteristics. As a result, to avoid water absorption during the mixing process, it was essential to mix PKS aggregate at saturated condition based on 24 h immersion in potable water.

Concrete was mixed at 0.55 water-cement ratio, mix proportion of 1:1:2 and percentage replacement of natural aggregate with PKS at 0%, 25% and 50%. For each concrete mix, nine 100 mm x 100 mm x 400 mm short columns were made, six to evaluate its shrinkage behavior and three for creep characteristics; this makes a total of twenty-seven (27). The concrete specimens were demolded 24 hrs. after casting. The specimens for shrinkage test were set up for observation while the specimens for creep test were cured for 13 days.

For Shrinkage test, three concrete columns from each of the concrete mix were sealed (by covering the entire surface with paraffin wax, 3 mm thick to prevent loss of moisture) while another set of three from each concrete mix were unsealed to measure the total, basic and drying shrinkage of the concrete. The concrete columns were set on measuring rigs for the shrinkage measurement after 24 hrs. of casting. The shrinkage deformations were measured by using loading and measuring rigs as recommended by Salau et al [9]. The details and construction of the rigs were done such that it consists of a base plate that holds the concrete prism and a simple steel frame with an adjustable height beam on which the measuring gauge hangs. The measuring gauge is then placed centrally on the concrete prism. The calibration of the measuring gauge is 0.01 mm. Once the specimen is set up, the deflection of the measuring gauge is recorded every day in the first two weeks, and then three times a week up to 180 days. Figure 1 shows the set up for the shrinkage test.

The compressive strength of all specimens for creep test were predetermined (Figure 2). The specimens were loaded at 14 days age for six months. The load applied was 40 % of the compressive strength of the specimen at

the time of loading. A helical spring which allows a constant load application was used. The pressure was applied at the center of the specimen.



Fig. 1. Specimens under Shrinkage Test.



Fig. 2. Specimens under Creep Test.

3. RESULTS AND DISCUSSION

3.1. Physical properties of aggregates

Average bulk density of palm kernel shell was found to be 694 kg/m^3 , this falls within the specified limits for lightweight aggregate of $250\text{-}1000 \text{ kg/m}^3$ [10]. The specific gravity of PKS is 1.27 (Table 1). This is 2.2 times less than that of normal aggregate, given as 2.81. The specific gravity of a material reflects its porosity; lower specific gravity is an indication of higher porosity.

Aggregate porosity is an important factor that determines the durability of concrete. Moisture content, water absorption and porosity of PKS were found to be 6.1%, 19% and 22% respectively. This is relatively high, and it is expected to impart on concrete strength by lowering it. The shrinkage and creep of PKS concrete may be higher than that of normal because the concrete matrix will permit easier loss of moisture. The Aggregate Crushing Value (ACV) and the Aggregate Impact Value (AIV) were 5.2% and 6.92% respectively for palm kernel shell aggregates while that of normal aggregates were 6.4% and 11.4%. The low value of AIV and ACV indicate that palm kernel shell is a good energy absorbing material. When palm kernel shell is used as aggregate in concrete, the good energy absorbing capacity would be advantageous to structures which are likely to be exposed to dynamic or shock loading. Aggregate quality adds greater stiffness to the concrete. Aggregate work to arrest cracks when concrete is subjected to flexural loads, increasing aggregate strength increases the compressive and flexural strength of concrete, consequently reducing shrinkage and creep strain.

Table 1. Physical properties of aggregates.

Properties	Palm Kernel Shell	Crushed granite
Maximum aggregate size (mm)	12.5	12.5
Shell thickness (mm)	3.5	-
Specific gravity	1.27	2.81
Bulk density (kg/m^3)	694	1440
Moisture Content (%)	6.1	-
Water Absorption (24hrs) (%)	19	0.5
Porosity (%)	22	-
Abrasion (%)	3.5	24
Aggregate Impact Value (%)	6.9	11.4
Aggregate Crushing Value (%)	5.2	6.4
Uniformity Coefficient (Cu)	2.0	1.5
Uniformity of gradation	1.39	1.04

3.2. Shrinkage deformation of Palm Kernel Shell concrete

The results of the shrinkage of normal and palm kernel shell concrete are presented in Figures 3 to 8. It was observed that shrinkage (all types of shrinkage: basic, drying and total shrinkage) increased as the percentage of PKS content increased in the concrete. The pattern of shrinkage development for both normal and PKS concrete was observed to be very similar. The pattern shows rapid shrinkage at early ages of the concrete (0-40 days), then a steady rate at latter ages. The normal concrete curve achieved the steady rate of shrinkage at an earlier age than PKS concrete.

It was observed that the unsealed concrete prisms (for measuring total shrinkage), irrespective of PKS content, showed higher deformation than the sealed concrete prisms (measuring basic shrinkage). This could have occurred as a result of internal drying (cement hydration) as well as external drying (change in temperature and humidity) while the sealed specimens undergoes shrinkage only because of internal drying.

3.2.1. Basic Shrinkage deformation of normal and Palm Kernel Shell concrete

Basic shrinkage is the shrinkage deformation of a concrete due to internal drying alone i.e. the moisture loss due to hydration. This is achieved by covering the concrete surface with paraffin wax to totally eradicate the effect of temperature and humidity on the specimen. The basic shrinkage curve of the normal concrete is shown in Figure 6, the curve rose rapidly at the early stage (0-10 days of loading), and then followed almost a linear progression for the remaining days of loading. The basic shrinkage of normal concrete rose to a maximum value of 0.00036 mm/m at 175 days of loading and maintained this value over the five remaining days of loading. The basic shrinkage curve of the concrete with 25 % PKS content as shown in Figure 6 showed a similar trend to that of normal concrete, where shrinkage increased significantly at the early age and slowed down to follow a steadier rate after 50 days of loading. The basic shrinkage of concrete with 25% PKS content rose to a maximum value of 0.00054 mm/m (a 50 % increase from that of normal concrete) at 175 days of loading and maintained this value over the five remaining days of loading. The basic shrinkage curve of the concrete with 50% PKS content, also shown in Figure 6, showed that shrinkage increased significantly throughout the days of loading, where no rapid rate is observed at the early age. The basic shrinkage of concrete with 50% PKS content rose to a maximum value of 0.00116 mm/m (a 222% increase from that of normal concrete) at 170 days of loading and maintained this value over the remaining ten days of loading.

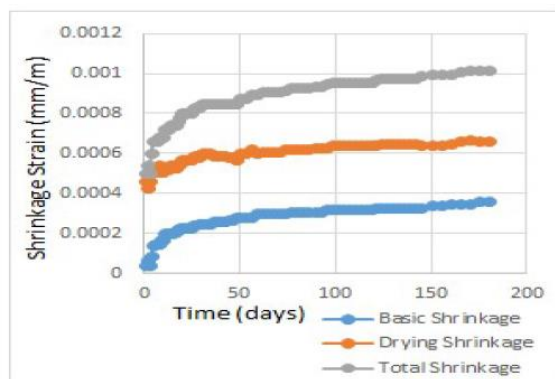


Fig. 3. Shrinkage Strain of normal concrete.

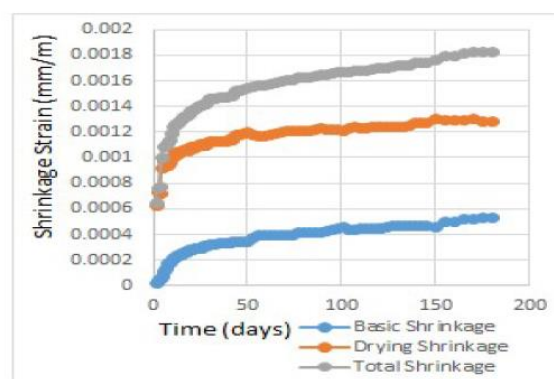


Fig. 4. Shrinkage Strain of 25 % Palm Kernell Shell concrete.

Generally, it was observed that basic shrinkage increased as PKS content increased in concrete. Also, for both normal and PKS concrete (25% and 50 % PKS content), basic shrinkage is less than both the drying and total shrinkage. This means that the shrinkage due to internal drying of concrete (moisture loss due to hydration) is less than shrinkage due to external drying (effect of temperature and humidity). The increase in shrinkage observed in the concrete containing PKS may be due to the reduced hardness property of the coarse aggregate which directly influenced the shrinkage of the concrete. Stiffer (harder) coarse aggregates are better at restraining shrinkage. The PKS with its lower aggregate impact value, aggregate crushing value and specific gravity is not as stiff as natural aggregate and can therefore provide less restraint to shrinkage than the natural aggregate. The potential for strength and resistance to shrinkage of concrete is ultimately determined by the quality of the aggregates.

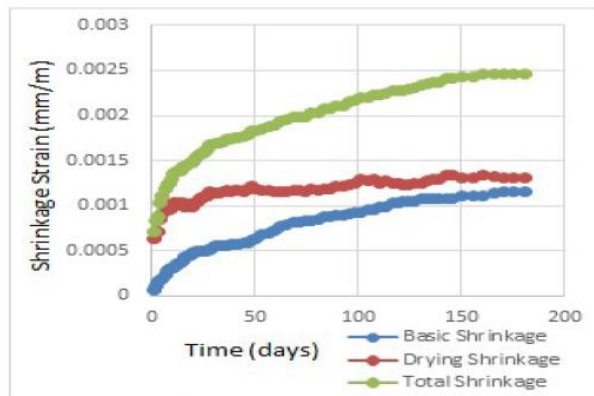


Fig. 5. Shrinkage Strain of 50 % Palm Shell concrete.

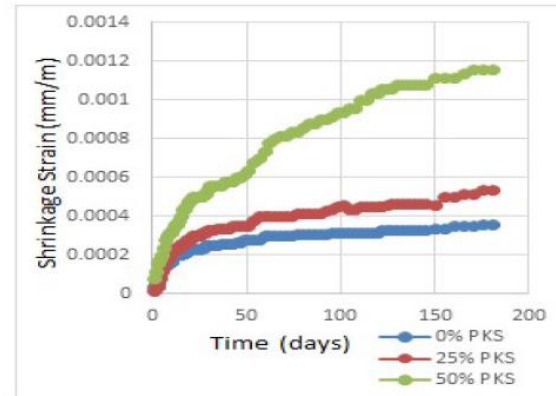


Fig. 6. Basic Shrinkage of Palm Kernell Shell concrete.

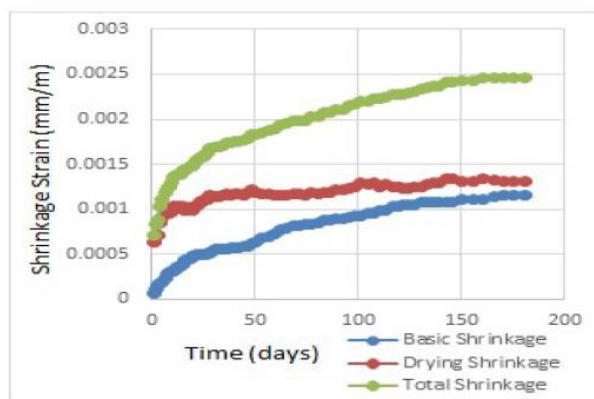


Fig. 7. Drying Shrinkage Strain of Palm Shell concrete.

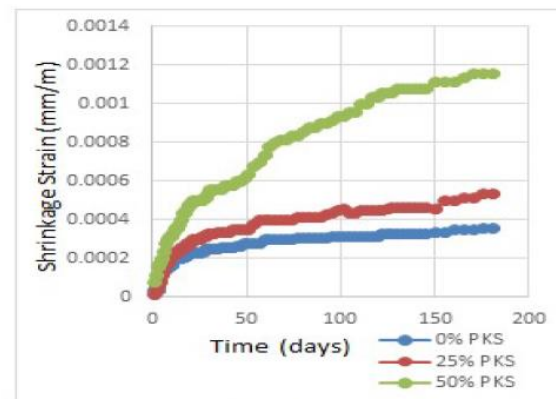


Fig. 8. Total Shrinkage of Palm Kernell Shell concrete.

3.2.2. Drying Shrinkage of normal and PKS concrete

Drying shrinkage is the shrinkage deformation that occurs due to loss of free water from the concrete, because of temperature and humidity. It depends on variables such as water-cement ratio, cement composition, type of aggregate, degree of hydration, curing condition, temperature of curing, relative humidity, moisture content and the duration of drying.

The drying shrinkage curve of normal concrete is shown in Figure 7, the curve is almost a straight line. The maximum value of drying shrinkage of normal concrete is 0.00067 mm/m at 170 days. The drying shrinkage curve of concrete with 25% PKS content rose rapidly in the first 20 days of loading as shown in Figure 7, it then followed a more linear progression afterwards, to appear similar to that of normal concrete. The maximum drying shrinkage of concrete with 25% PKS content was 0.00131 mm/m (95% increase from that of normal concrete) at 150 days.

The drying shrinkage curve of concrete with 50 % PKS content progressed throughout the 180 days of loading (similar to its basic shrinkage), but a more steep trend was observed within the first 10 days of loading. The curve is as shown in Figure 7. The maximum drying shrinkage of concrete with 50% PKS content is 0.00134 mm/m (a 100% increase from that of normal concrete and only a 2% increase from the 25% PKS content) at 160 days of loading.

Generally, drying shrinkage increased as the percentage of PKS increased in concrete, though only a 2% increase between the 25% and 50% PKS content in this investigation. At higher PKS content (50%), it increased throughout the period of loading. The increase in drying shrinkage observed in palm kernel shell concretes can be attributed to the interconnection, content and distribution of pore size of PKS.

3.2.3. Total Shrinkage deformation of normal and PKS concrete

Total shrinkage is the shrinkage deformation of a concrete subjected to all factors that may cause shrinkage. These factors may be categorized into internal factors, such as moisture loss due to hydration and external factors such as temperature and humidity. It is the shrinkage measured from the unsealed concrete specimen, which are affected by climatic conditions. It was observed that total shrinkage increased as the percentage of PKS increased. However, the trends of shrinkage development in both normal and PKS concrete (25% and 50% PKS content) were very similar. The trend shows rapid shrinkage at early ages of the concrete (0-40 days) and a steady rate at latter ages. The total shrinkage curve of the normal concrete rose rapidly within the first 5 days of measuring deformation. It continued to rise slowly and steadily, following almost a linear progression, over the remaining 175 days of observation. The maximum total shrinkage recorded for normal concrete was 0.00102 mm/m at 170 days and this was constant till 180 days.

Considering the palm kernel shell concrete with 25% PKS content, the total shrinkage curve rose rapidly within the first 20 days and like the normal concrete, it followed almost a linear progression for the remaining days of observation. The maximum total shrinkage recorded for concrete with 25% PKS content was 0.00183 mm/m at 170 days and this was constant till 180 days. This is 1.8 times more than that of normal concrete. The total shrinkage curve of concrete with 50% PKS content as shown in Figure 8 rose more rapidly over the first 40 days of observation and continued to rise at a higher rate than was observed in the normal concrete and the 25% PKSC, though it followed a similar trend with them. The maximum total shrinkage measured was 0.00247 mm/m at 160 days and remained constant till 180 days. This is 2.4 times more than that of normal concrete and 1.3 times more than that of 25% PKSC.

The higher shrinkage deformation observed at the early ages of the PKSC can be attributed to the loss of water in the plastic concrete. The PKS was earlier reported in this research to contain higher porosity and water absorption properties than natural aggregate. This increases the loss of water in concrete and consequently lead to increased shrinkage. The irregular surface of the PKS and its concrete increases the porosity of the concrete and the irregular distribution of pore size within the concrete. This also promotes higher shrinkage strain in the concrete.

3.2.4. Linear regression model of Total Shrinkage, concrete age and Palm Kernel Shell content

Linear regression model, equation (1), Table 2:

$$y \sim 1 + x_1 \cdot x_2 + x_1^2 \cdot x_2^2 \quad (1)$$

where y is Total Shrinkage (mm/m), x_1 is Concrete Age (days), x_2 is Palm Kernel Shell Content (%).

Table 2. Regression statistic for Shrinkage model.

Number of observations	237
Error degrees of freedom	231
Root Mean Squared Error	$9.17e^{-05}$
R-squared	0.968
Adjusted R-Squared	0.967
F-statistic vs. constant model	$1.4e^{-03}$
P-value	$1.57e^{-170}$

Table 3. Regression coefficient for Shrinkage model.

	Coefficients	Standard Error	Stat	P-value
Intercept	0.00061509	$1.8255e^{-05}$	33.695	$3.9651e^{-91}$
x_1	$7.4053e^{-06}$	$4.5401e^{-07}$	16.311	$2.6154e^{-40}$
x_2	$2.3859e^{-05}$	$1.1152e^{-06}$	21.395	$1.0215e^{-56}$
$x_1 * x_2$	$1.1603e^{-07}$	$5.6083e^{-09}$	20.69	$1.674e^{-54}$
x_1^2	$-3.4943e^{-08}$	$2.5875e^{-09}$	-13.504	$5.0696e^{-31}$
x_2^2	$-2.3494e^{-07}$	$2.0218e^{-08}$	-11.62	$6.9809e^{-25}$

From Table 3 above, the regression model equation can be written as:

$$y = 0.00061509 + 7.4053 \times 10^{-6} x_1 + 2.3859 \times 10^{-5} x_2 + 1.1603 \times 10^{-7} x_1 \cdot x_2 -$$

$$- 3.4943 \times 10^{-8} x_1^2 - 2.3494 \times 10^{-7} x_2^2 \quad (2)$$

Equation (2) models the progress of total shrinkage with time (age of concrete) and the influence of PKS content on total shrinkage. It was observed that shrinkage increases with concrete age and increase in PKS content as shown in Figure 9. This model can be used to predict the expected shrinkage of palm kernel shell concrete at a certain age and a given PKS content from 0 % to 50 %.

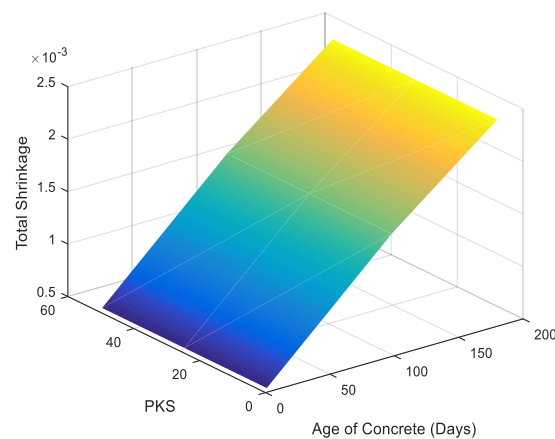


Fig. 9. Three-Dimensional Model of Total Shrinkage-Percentage PKS-Age of Concrete.

3.3. Creep of Palm Kernel Shell concrete

The results obtained from creep of normal and palm kernel shell concrete (25% and 50% content) are as shown in Figure 10. The trend of creep development in the 25% and 50% PKS concrete are more similar than that of the normal concrete. Creep in the normal concrete followed a more linear trend and can be seen to develop steadily throughout the 180 days of observation. For palm kernel shell concrete (25% and 50%), the creep indices rose faster at the early stage (between 0 – 50 days of loading), after which it maintains a steady rise to 180 days. The maximum value of creep measured for normal concrete, 25% and 50% palm kernel shell content are 0.00018 mm/m, 0.00057 mm/m and 0.00094 mm/m respectively. It can be observed from Figure 10 that concrete creep increased as the percentage of palm kernels shell increased. The quality and amount of concrete paste are important factors influencing creep. Concrete with poorer paste structure will record higher creep. The compressive strength results of PKSC has been found (according to Ikponmwosa et al.) to be lower than that of normal concrete, and it decreases as the percentage of PKS increases in the concrete. This explains the increase in creep in PKS concrete than normal concrete and its increase as PKS content increases.

Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. Moisture content of the concrete being different at different ages will also have a significant influence on the magnitude of creep. The concrete specimens in this research were loaded on the 14th day after it was cast. This enabled the measurement of about the highest creep, deformation possible in the concrete.

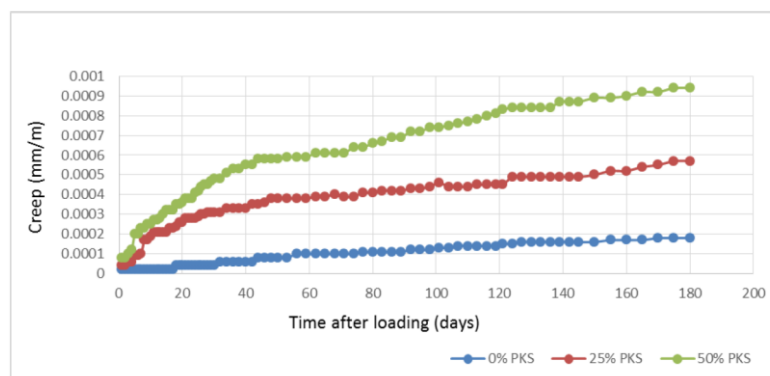


Fig. 10. Creep of Palm Kernel Shell Concrete.

3.3.1. Linear regression model of creep, curing days and Palm Kernel Shell content

Linear regression model, equation (3), Table 4:

$$y \sim 1 + x_1 \cdot x_2 + x_1^2 + x_2^2 \tag{3}$$

where y is creep (mm/m), x₁ is Concrete Age (days), x₂ is Palm Kernel Shell Content (%).

Table 4. Regression statistic for Creep model.

Number of observations	237
Error degrees of freedom	231
Root Mean Squared Error	4.09e ⁻⁰⁵
R-squared	0.974
Adjusted R-Squared	0.974
F-statistic vs. constant model	1.76e ⁷⁰³
P-value	1.45e ⁻¹⁸¹

Table 5. Regression statistic for Shrinkage model.

	Coefficients	Standard Error	Stat	P-value
Intercept	-2.4893e ⁻⁰⁵	8.14e ⁻⁰⁶	-3.0581	0.0024904
x ₁	3.2492e ⁻⁰⁶	2.0245e ⁻⁰⁷	16.049	1.9122e ⁻³⁹
x ₂	6.9351e ⁻⁰⁶	4.9727e ⁻⁰⁷	13.946	1.766e ⁻³²
x ₁ · x ₂	6.6807e ⁻⁰⁸	2.5008e ⁻⁰⁹	26.714	1.3633e ⁻⁷²
x ₁ ²	-1.4593e ⁻⁰⁸	1.1538e ⁻⁰⁹	-12.648	3.2806e ⁻²⁸
x ₂ ²	-3.6253e ⁻⁰⁸	9.0155e ⁻⁰⁹	-4.0212	7.843e ⁻⁰⁵

From Table 5 above, the regression model equation can be written as:

$$y = -2.4893 \times 10^{-5} + 3.2492 \times 10^{-6} x_1 + 6.9351 \times 10^{-6} x_2 + 6.6807 \times 10^{-8} x_1 \cdot x_2 - 1.4593 \times 10^{-8} x_1^2 - 3.6253 \times 10^{-8} x_2^2. \tag{4}$$

Equation (4) shows the dependence of creep of PKSC on age of concrete and percentage PKS content. The positive coefficients of CA and PKS shows that creep will increase as these variables increase while the negative constant of the equation means the rate at which the concrete creeps will reduce as the concrete ages. The inter-dependence of these three variables (creep, concrete age and percentage PKS content) is as shown in Figure 11.

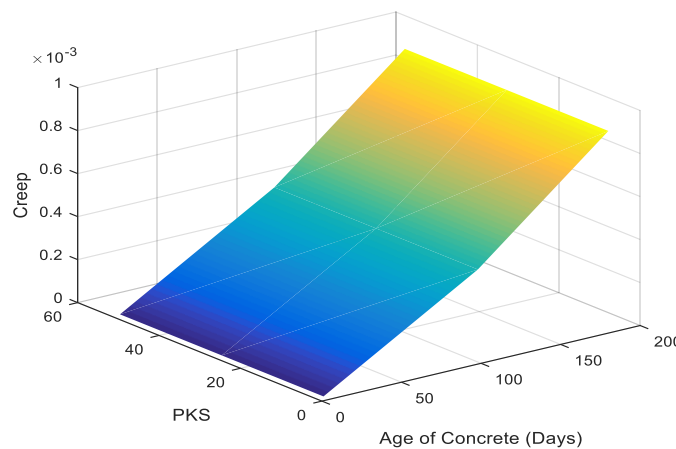


Fig. 11. Three-Dimensional Model of Creep – Percentage PKS – Age of concrete.

3.4. Temperature and relative humidity

It has been reported that the rate and magnitude of creep and shrinkage increases as the humidity of atmosphere decreases. The relation between relative humidity and creep/shrinkage is not linear as concrete under sustained load in air at 70% relative humidity will have a creep/shrinkage deformation about twice as large as concrete in air at 100% relative humidity. The ultimate creep/shrinkage in air at 50% relative humidity will be about three times as large [1]. The relative humidity recorded during the experiment varied between 78% and 100% while the temperature varied between 24 °C and 30 °C (Figure 12). This range is believed to be close enough not to affect the shrinkage and creep results significantly.

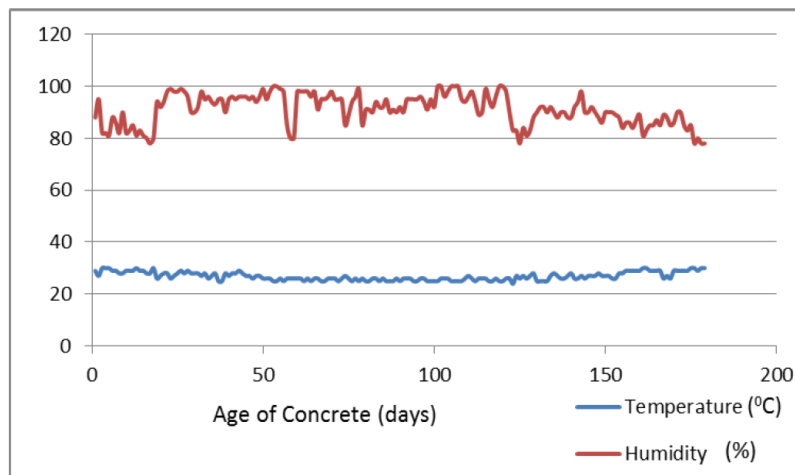


Fig. 12. Temperature and relative humidity result.

4. CONCLUSIONS

Average bulk density of palm kernel shell was found to be 694 kg/m³; this falls within the specified limits for lightweight aggregate of 250-1000 kg/m³, (BS 3739). The specific gravity of PKS is 1.27; this is 2.2 times less than that of normal aggregate, given as 2.81.

It was observed that shrinkage (all types of shrinkage: basic, drying and total shrinkage) increased as the percentage of PKS content increased in the concrete. The pattern of shrinkage development for both normal and PKS concrete was observed to be very similar.

The maximum total shrinkage strain recorded for 0%, 25% and 50% PKS content was 0.00102 mm/m, 0.00183 mm/m and 0.00247 mm/m respectively. Conclusively, the greater the PKS content, the higher the shrinkage strain.

The creep results of Palm Kernel Shell Concrete (PKSC), increased as the percentage content of PKS increased in the concrete. The maximum creep strain observed for normal concrete, 25% and 50% PKS content were 0.00018 mm/m, 0.00057 mm/m and 0.00094 mm/m respectively.

The elastic modulus of aggregate plays an important role in the shrinkage and creep of its concrete as it determines the extent of restraining action to the shrinkage of the concrete. Since PKS has lower modulus of elasticity compared to natural aggregates, this may be one of the reasons for higher shrinkage and creep values.

It is recommended that to avoid large shrinkage and creep strain in palm kernel shell concrete, PKS content should not exceed 25 % in concrete.

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