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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, for a period of 180days. 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 100mm x 100mm x 400mm short columns were made, six to evaluate its shrinkage behavior and three for creep characteristics, this makes a total of twenty-seven (27). Three concrete columns from each of the concrete mix were sealed while another set of three from each concrete mix were unsealed to measure the total, basic and drying shrinkage of the concrete. 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 0.00018mm/m, 0.00057mm/m and 0.00094mm/m respectively. The shrinkage results show that Palm Kernel Shell Concrete (PKSC) has a higher percentage of shrinkage (all types of shrinkage: basic, drying and total shrinkage) than normal concrete. The pattern of shrinkage development for both normal and PKS concrete was seen to be very similar. The maximum total shrinkage strain recorded for 0%, 25% and 50% PKS content was 0.00102mm/m, 0.00183mm/m and 0.00247mm/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 0.00018mm/m, 0.00057mm/m and 0.00094mm/m respectively.
Keywords: Concrete, Palm Kernel Shell, Aggregates, Creep and Shrinkage

INTRODUCTION

The palm oil industry produces wastes such as palm kernel shells and palm oil fibres which are usually dumped in the open thereby impacting the environment negatively without any economic benefits. 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 of time. 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. (2002) indicated that the total length and the depth of micro cracking caused by shrinkage of concrete will increase with larger aggregate size. It has been reported that the elastic property of aggregate determines the degree of restraint to the cement matrix (Topcu et al. 2010). A normal natural aggregate is usually not subject to shrinkage. However, there exist rocks that can shrink up to the same magnitude as the shrinkage of concrete made with non-shrinking aggregate (Bairagi et al. 1993). For example, the shrinkage of a concrete made with steel aggregate will be lower than the one made with normal aggregate. Similarly, the shrinkage of a concrete made with expanded shale aggregate will be higher than the one made with a normal aggregate. In other words, If the skeleton of coarse aggregate in the concrete is stiffer, the shrinkage strain of concrete will be less. The elastic modulus of the aggregate determines the extent of restraining action to the shrinkage of concrete.

Studies by Kim et al. (2016) show that for a fixed mix proportion, there is a considerable variation in the shrinkage strain of the resulting concrete batched with coarse aggregate of different types. This phenomenon is very likely due to the difference in modulus of elasticity among aggregate of different types. Teo et al. (2007) 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 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 of structure under sustained load. Basically, long term pressure or stress on concrete can make it change shape. This deformation usually occurs in the direction the force is being applied. Like a concrete column getting more compressed, or a beam bending. Creep does not necessarily cause concrete to fail or break apart. Aggregate undergoes very little creep. It is really the paste which is responsible for the 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 stronger the aggregate, the more the restraining effect and hence the less is the magnitude of creep. The modulus of elasticity of aggregate is one of the important factors influencing creep. It can easily be imagined that the higher the modulus of elasticity, the less the creep. Light weight aggregate shows substantially higher creep than normal weight aggregate. This is why it is of paramount interest to investigate the creep of palm kernel shell concrete.

The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. In other words, it can also be said that creep is inversely proportional to the strength of concrete. 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. (Ikponmwosa et al. 2018, Olanipekun et al. 2006, Shafigh et al. 2010).

Age at which a concrete member is loaded will have a predominant effect on the magnitude of creep. This can be easily understood from the fact that the quality of gel improves 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 research works 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.

MATERIALS AND METHOD

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 100mm x 100mm x 400mm 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 demoulded 24hrs after casting. The specimens for shrinkage test were set up for observation while the specimens for creep test were cured for 13days.

For Shrinkage test, three concrete columns from each of the concrete mix were sealed (by covering the entire surface with paraffin wax, 3mm 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 24hrs of casting. The shrinkage deformations were measured by using loading and measuring rigs as recommended by Salau et al (2014). The rigs were designed and constructed to consist of a simple steel frame with an adjustable height beam, to hold the measuring gauge and a base plate on which the concrete specimen is placed. The arrangement of the adjustable height beam with the measuring gauge is then placed centrally on the concrete specimen. The measuring gauge is calibrated to read to the nearest 0.01mm. Measurements were taken every day in the first two weeks, and then three times a week up to 180 days. Figure 3 shows the set up for the shrinkage test.

The compressive strength of all specimens for creep test was predetermined. The specimens were loaded at 14days 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.

Figure 1: Specimens under shrinkage test

Figure 2: Specimens under creep test

RESULTS AND DISCUSSION

— Physical Properties of Aggregates

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

Average bulk density of palm kernel shell was found to be 694kg/m^3, this falls within the specified limits for lightweight aggregate of 250-1000kg/m^3, (BS 3797). The specific gravity of PKS is 1.27. This is 2.2 times less than that of normal aggregate, given as 2.81. The specific gravity of a material is a reflection of 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.

— Shrinkage Deformation of Palm Kernel Shell Concrete

The results of the shrinkage of normal and palm kernel shell concrete are presented in Figures 3,4,5,6,7 and 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 (0-40days), 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 (moisture loss due to hydration) as well as external drying (effect of temperature and humidity) while the specimen under the sealed condition shrunk only because of internal drying.

◻ Basic Shrinkage Deformation of Normal and Palm Kernel Shell Concrete

Basic shrinkage is the shrinkage deformation of a concrete that has been shielded from external factors that may affect and aid shrinkage deformation in the concrete. This is achieved by covering the concrete surface with paraffin wax to extinguish 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 (0-10days 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 0.00036mm/m at 175days 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 more steady rate after 50days of loading. The basic shrinkage of concrete with 25% PKS content rose to a maximum value of 0.00054mm/m (a 50% increase from that of normal concrete) at 175days 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 particular rapid rate is observed at the early age. The basic shrinkage of concrete with 50% PKS content rose to a maximum value of 0.00116mm/m (a 222% increase from that of normal concrete) at 170days of loading and maintained this value over the remaining ten days of loading.

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 that shrinkage due to external drying (effect of temperature and humidity). The increased shrinkage obtained in the concrete containing PKS can be attributed to the compressibility or stiffness 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 restrain to shrinkage than the natural aggregate. The quality of the aggregates ultimately determines the concrete specimen's potential for strength and resistance to shrinkage.

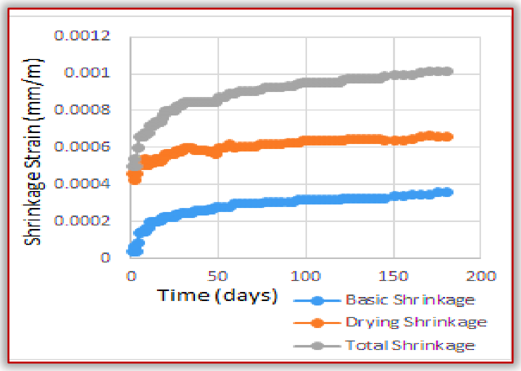

Figure 3: Shrinkage strain of normal concrete

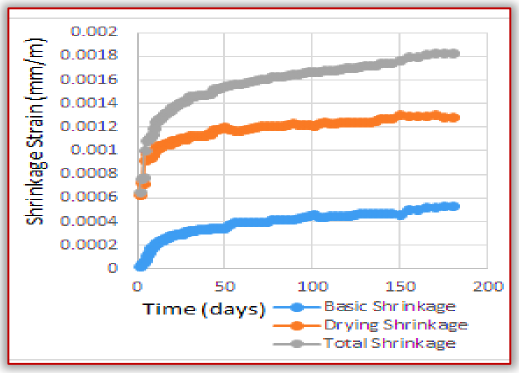

Figure 4: Shrinkage strain of 25% palm kernel shell concrete

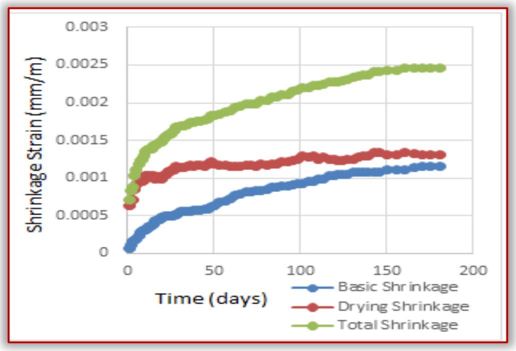

Figure 5: Shrinkage strain of 50% palm kernel shell concrete

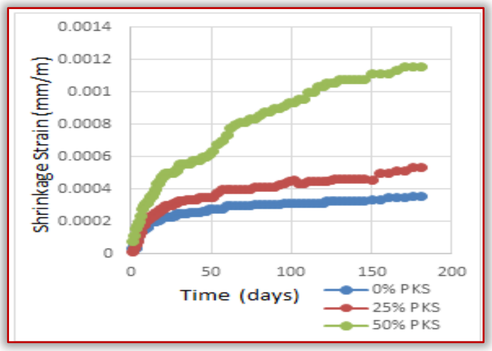

Figure 6: Basic shrinkage of palm kernel shell concrete

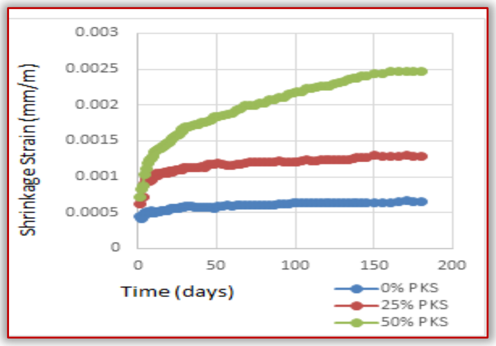

Figure 7: Drying shrinkage of palm kernel shell concrete

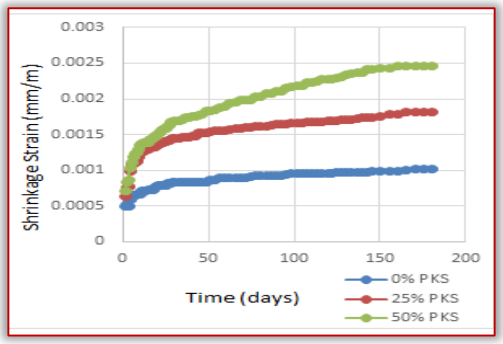

Figure 8: Total shrinkage of palm kernel shell concrete

Drying Shrinkage Of Normal and PKS Concrete

Drying shrinkage is the shrinkage deformation that occurs due to loss of free water from the concrete, due to the effects 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 0.00067mm/m at 170days. The drying shrinkage curve of concrete with 25% PKS content rose rapidly in the first 20days 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 0.00131mm/m (95% increase from that of normal concrete) at 150days. The drying shrinkage curve of concrete with 50% PKS content progressed throughout the 180days of loading (similar to its basic shrinkage), but a more steep trend was observed within the first 10days of loading. The curve is as shown in Figure 7. The maximum drying shrinkage of concrete with 50% PKS content is 0.00134mm/m (a 100% increase from that of normal concrete and only a 2% increase from the 25% PKS content) at 160days 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 content, interconnection and distribution of pore size of PKS.

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 (0-40days) and a steady rate at latter ages. The total shrinkage curve of the normal concrete rose rapidly within the first 5days of measuring deformation. It continued to rise slowly and steadily, following almost a linear progression, over the remaining 175days of observation. The maximum total shrinkage recorded for normal concrete was 0.00102mm/m at 170days and this was constant till 180days.

Considering the palm kernel shell concrete with 25% PKS content, the total shrinkage curve rose rapidly within the first 20days 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 0.00183mm/m at 170days and this was constant till 180days. 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 40days 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 0.00247mm/m at 160days and remained constant till 180days. This is 2.4 times more than that of normal concrete and 1.3times 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.

The purity of the employed palm kernel shell should be taken into account as a factor for the increase in shrinkage reported in the concrete containing PKS. The type and amount of contaminants that might be present in these aggregates is one of the causes for the differences in the shrinkage behavior of the concrete containing

PKS. In order to reduce the effect of contaminants in the palm kernel shell, it was washed thoroughly before being used in concrete.

Linear Regression Model of Total Shrinkage, Concrete Age and Palm Kernel Shell Content.

Linear regression model:

$$Y \sim 1 + X_1X_2 + X_1^2 + X_2^2.$$

where: Y = Total Shrinkage (mm/m); X_1 = Concrete Age (days); X_2 = Palm Kernel Shell Content (%)

Regression Statistics:

- 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: $1.57e^{-170}$

Regression Table

	Coefficients	Standard Error	tStat	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	$6.9809e^{-25}$

The regression model equation can be written as:

$$Y = 0.00061509 + 7.4053 \times 10^{-6} X_1 + 2.3859 \times 10^{-5} X_2 + 1.1603 \times 10^{-7} X_1*X_2 - 3.4943 \times 10^{-8} X_1^2 - 2.3494 \times 10^{-7} X_2^2.$$

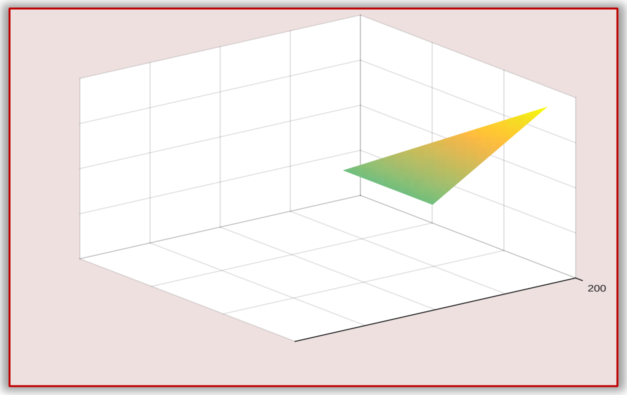

Figure 9 : Three-Dimensional Model of Total Shrinkage-Percentage PKS–Age of Concrete

Equation 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%.

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 180days 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 up to 180 days. The maximum value of creep measured for normal concrete, 25% and 50% palm kernel shell content are 0.00018mm/m, 0.00057mm/m and 0.00094mm/m respectively. It can be observed from Figure 10 that concrete creep increased as the percentage of palm kernels shell increased. The amount of paste content and its quality is one of the most important factors influencing creep. A poorer paste structure undergoes higher creep. The compressive strength results of PKSC has been found (Ikponmwosa et al. 2018) 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.

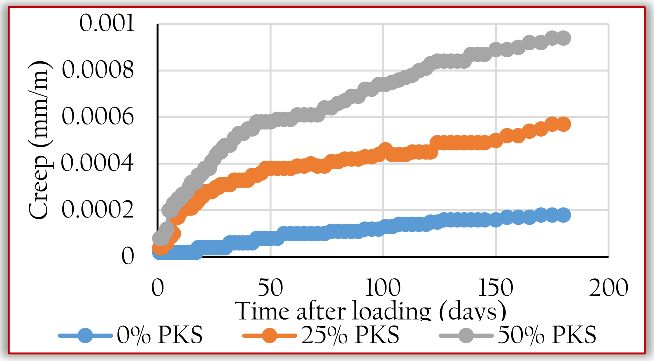

Figure 10: Creep of Palm Kernel Shell Concrete

Linear Regression Model of Creep, Curing Days and Palm Kernel Shell Content

Linear regression model:

$$Y \sim 1 + X_1X_2 + X_1^2 + X_2^2.$$

where: Y = Creep (mm/m); X_1 = Concrete Age (days); X_2 = Palm Kernel Shell Content (%)

Regression Statistics:

- 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: $1.76e^{\mp 03}$
- P-value: $1.45e^{-181}$

Regression Table

	Coefficients	Standard Error	tStat	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	$7.843e^{-05}$

The regression model equation can be written as:

$$Y = -2.4893 \times 10^{-5} + 3.2492 \times 10^{-6} X_1 + 6.9351 \times 10^{-6} X_2 + 6.6807 \times 10^{-8} X_1{*}X_2 - 1.4593 \times 10^{-8} X_1^2 - 3.6253 \times 10^{-8} X_2^2$$

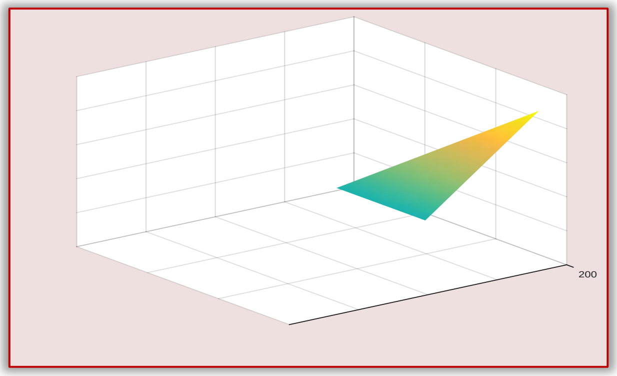

Figure 11: Three-Dimensional Model of Creep – Percentage PKS – Age of concrete

Equation 2 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.

— 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.

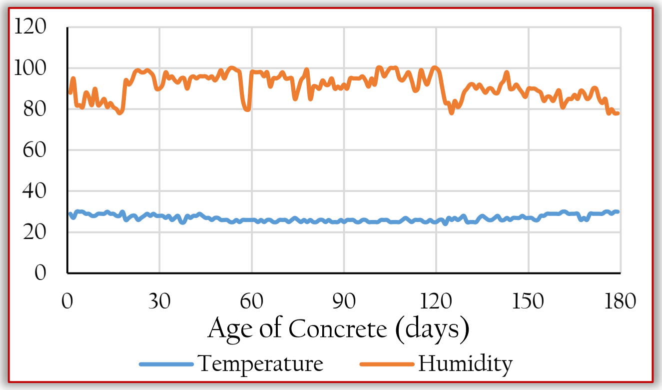

Figure 12: Temperature and Relative Humidity Result

The ultimate creep/shrinkage in air at 50% relative humidity will be about three times as large. (Bisschop 2002). The relative humidity recorded during the experiment varied between 78% and 100% while the temperature varied between 24^{0}C and 30^{0}C, [see Figure 12]. This range is believed to be close enough not to affect the shrinkage and creep results significantly.

CONCLUSIONS AND RECOMMENDATION

Average bulk density of palm kernel shell was found to be 694kg/m^3; this falls within the specified limits for lightweight aggregate of 250-1000kg/m^3, (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 0.00102mm/m, 0.00183mm/m and 0.00247mm/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 0.00018mm/m, 0.00057mm/m and 0.00094mm/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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