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THE TRANSFER MODELS OF COMPRESSIVE TO TENSILE, FLEXURAL AND ELASTIC PROPERTIES OF PALM KERNEL SHELL CONCRETE

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ABSTRACT: Vegetative concrete has application as lightweight concrete for pavements, embankments, dams and foundation of structures in the major loading forms of axial, shear and bending. The respective performance characterization parameters with various standard procedures are the compressive (cube), flexural and indirect tensile test (ITT) strength. In this paper, the mechanical strengths of palm kernel shell (PKS) concrete were studied with the aim of developing transfer models from the compressive strength to the various other mechanical properties in order to take advantage of the current advances, relative cost and convenience of the compression test, which is the most popular mechanical strength evaluation of concrete works. The mechanical strength parameters at various nominal mixes of 1:1:2, 1:1$^1/_2$:3, 1:2:4 and 1:3:6 for the PKS concrete were determined under the laboratory curing conditions for 91 days. For each of the parameters, PKS concrete strengths were determined for 3, 7, 14, 28, 56 and 91 days. The developed strength data base was subjected to statistical and correlation analysis with the Microsoft Excel software (2007). The results show that a vegetative light weight concrete behaves in very similar pattern to that of the normal concrete with each of the mechanical properties. The mechanical properties of the palm kernel shell concrete (PKSC) increase with curing age and quality of the mix rapidly from 7 to 56 days but very slowly (almost constant) between 56 and 91 days. For the four specimens tested for each parameter, the coefficient of variation fall within 0.001 and 0.06 %, which is an indication of the consistency of either measurement taken, the properties tested and/or both. An Index model (mathematical relationship) for the mechanical property of flexural, splitting tensile and modulus of elasticity with respect to the compressive strength was developed at high coefficient of correlation (R^2 values of 0.996, 0.773 and 0.980 respectively) and in the form af^n. The corresponding values of the a – characteristics are 0.399, 0.043 and 0.001 while the n – values are 0.591, 0.056 and 0.549.
KEYWORDS: Compressive strength, Lightweight concrete pavement, Mechanical strength, Palm kernel shell concrete, Transfer models

INTRODUCTION

Rational design of concrete structures requires an accurate knowledge of concrete properties under anticipated loading types and form; compressive, bending, tensile, repeated or creep. A large volume of information is available on behavior of concrete under static loading conditions. However, when concrete is subjected to other forms of loading such as dynamic and repeated loadings from traffic, the fatigue response behavior needs be properly modeled, which is a process of progressive permanent internal changes that occur in the materials under the actions of cyclic loadings [1]. Many concrete structures, such as highway pavement sand bridges, railroad bridges, airport pavements and marine structures, etc. are subjected to dynamic loads. However, the AASHTO rigid pavement design model reflects the flexural and elastic properties of concrete only, equation (1) [2]. Thus correct material characterization for concrete pavement desires that the routine testing procedures for the two mechanical properties (bending and elastic) be performed.

A great deal and a grossly disproportionate amount of attention has been given to compressive strength in concrete works, which makes concrete grade (the 28 - day compressive strength) to be the traditional way of specification, purchase quality and the most important performance attribute of concrete [3]. Apart from the complexity in the conduct of the other mechanical strength properties of concrete, the relative ease with which compressive testing equipment by even low rated construction outfits and the relative lower cost implication are added advantage to the popularity of compressive strength over the bending and splitting tensile properties. Also, the description of the fatigue phenomena for repetitive load-induced cracking due to a repeated stress or strain level below the ultimate strength of the concrete material was done by Portland Concrete Association (PCA) design procedure for rigid pavements with the compressive stress ratio and traffic load repetitions relationship for the rigid highway pavement constructed with the conventional dense concrete produced from the natural aggregates [4].

$$Log_{10} W_{18} = Z_R S_0 + 7.35\left[Log_{10}(D+1)\right] - 0.06 + \frac{Log_{10}\left[\frac{\Delta PSI}{3.0}\right]}{1+\left[\frac{1.624 \; x \, 10^7}{(D+1)^{8.46}}\right]}$$

$$+ (4.22 - 0.32\,TSI)Log_{10}\left[\frac{S_c C_d\left(D^{0.75} - 1.132\right)}{215.63\,J\left(D^{0.75} - \left(\frac{18.42}{\left(\frac{E_c}{k}\right)^{0.25}}\right)\right)}\right] \quad (1)$$

where, W_{18} is 18-kip-equivalent single axle load (80.1kN), Z_R is the reliability (Z-statistic for the standard normal curve), S_0 is the overall standard deviation of traffic, D is the PCC slab thickness (meters), TSI is the pavement's terminal serviceability index, PSI is the loss in serviceability from when the pavement was new until it reaches its TSI, Sc is the concrete modulus of rupture (N/mm^2), C_d is a drainage coefficient, J is the load transfer coefficient, Ec is the concrete elastic modulus (N/mm^2) and K is the modulus of subgrade reaction.

The justification for this paper is then, therefore, premised on the need to increase the data base of performance characteristics of a new and or emerging material for pavement works and the need to derive the other mechanical strengths of PKS concrete from the compressive strength via the development of transfer models of compressive strength for the other mechanical properties.The primary aim is therefore to provide sufficient information on the procedure forrelating other mechanical properties of PKSC (flexural strength, splitting tensile strength and modulus of elasticity) to the compressive strength. In addition, it will aid the assurance that the requirements for minimum standards of bending and elastic strength as provided for in the Rigid Pavement Design Manual [2] are indirectly met for rigid pavement design, construction and rehabilitation.

The specific objectives of the study, therefore include (a) determination of the trend of the mechanical properties (compressive strength, flexural strength, splitting tensile strength and modulus of elasticity) of PKS concrete, as a vegetative lightweight concrete with respect to age of curing and grade (mix) (b) investigating whether the two main factors of concrete mix and age of curing have effects on the mechanical properties of a palm kernel shell concrete (c) establishment of the similarity, if any, of the compressive strength of the light weight concrete with that of the normal conventional concrete (d) development of models of the other mechanical strengths of PKS concrete from the compressive strength with corresponding level of reliability; and (e) determination of the prevailing range of the values of the characteristic of the developed models for the different PKS concrete mixes.

MATERIALS AND METHODS

The main materials used for the study include the palm kernel shells as coarse aggregate and the other standard concrete production components, that is, fine aggregate (sand), hydraulic binder (ordinary Portland cement) and water, which were all employed to produce palm kernel shell concrete (PKS concrete).Palm kernel shells are the agricultural biomass waste bye product on extraction of palm oil from the juicy fleshy fruits of the palm tree (Elaeisguineensis) plants, which is commonly found on the west coast of Africa and the tropical regions of South America. Indeed, palm kernel form part of the major crops being exported from Nigeria, Ghana, Liberia and the Guinea.

The shells are the waste products in millions of tonnes annually [5] resulting into disposal challenges. When the palm kernel fruit is pressed, it gives up some other bye products, including palm fibre used in building construction, and the palm kernel shells (PKS), which is being considered as the coarse aggregates for rigid pavement in this paper. The PKS is up to about 35%, which makes its recycling much desirable for environmental pollution control and typically for road/pavement works [6]. The characteristic properties of the palm kernel shells are presented in Table 1 and Table 2.

Table 1: Properties of Palm Kernel shells

Property	Average value
Water absorption capacity - 24 hours (%)	13.7
Specific gravity	1.26
Bulk density (kg/m^3)	640
Moisture content (%)	14.49
Aggregate impact value	5.02
Aggregate crushing value (%)	6.5
Fineness modulus	6.24
Thickness (mm)	1.85

Table 2: Particle size characteristics

Sieve size (mm)	16	8	4	2.36	1.0	0.5	0.25
% passing - PKS	96.22	28.84	2.96	1.08	0.70	0.51	0.40
Specifications	94.75	71.75	35.75	16.75	5.25	1.25	0.95

The Palm kernel shells, sand, cement and water were batched by weight for four nominal mixes of 1: 1: 2; 1:1½:3; 1: 2: 4 and 1:3:6. A total number of 96 test specimens were produced, cured and tested for the four mechanical properties of compressive strength, indirect tensile (flexural) strength, splitting tensile strength and modulus of elasticity in accordance with the relevant standard British and American testing procedures [7] and [8]. Four each of 150mm x 150mm x 150mm cubes, 100mm x 100mm x 500mm beams for the modulus of rupture, 150mm diameter by 300mm high cylinder for the splitting strength and modulus of elasticity tests, comprising of 24 test samples for each of the respective nominal mixes. The concrete samples were tested in groups after 3, 7, 14, 28, 56 and 91 days. The results were analyzed for the statistical estimation of the respective values and corresponding treatment effects of the mixes, the age of curing and mix by age of curing. The Analysis of Variance ANOVA package was employed for the latter. Also the statistical correlation analysis of the determined flexural strength, splitting tensile strength and modulus of elasticity with respect to the compressive strength (as the independent variable) was done with the Microsoft Excel Software [9].

TEST RESULTS AND ANALYSIS

The statistical analysis results of the tests are presented in Tables 3 – 6, displaying the mean of all values and the corresponding standard deviation in parenthesis. The coefficient of variation (COV), defined as:

$$\frac{standard\ \ deviation}{mean} x\ 100\ \% = \frac{\sigma}{\mu} x\ 100 \qquad (2)$$

and the measure of consistency in the measurements taken, the properties tested or both the measurements taken and the properties in combination, falls within 0.001 and 0.06 %. The indication of the computed COV is that the measurements taken, properties tested and/or both for the properties of the PKS concrete examined are consistent.

Table 3: Mean (SD) Compressive Strength of PKS Concrete (N/mm^2)

Mix	Age (Days)					
	3	7	14	28	56	91
1:3:6	1.32 (0.01)	4.80 (0.02)	5.72 (0.36)	6.50 (0.36)	7.18 (0.36)	7.20 (0.03)
1:2:4	1.80 (0.02)	8.90 (0.06)	10.21 (0.26)	12.40 (0.26)	15.80 (0.26)	15.81 (0.04)
1:1½:3	2.13 (0.16)	12.10 (0.26)	18.10 (0.20)	20.10 (0.20)	21.49 (0.20)	21.50 (0.03)
1:1:2	2.83 (0.02)	14.20 (0.17)	19.22 (0.26)	21.12 (0.26)	22.56 (0.26)	22.60 (0.11)

Table 4: Mean (SD) Flexural Strength of PKS Concrete (N/mm^2)

Mix	Age (Days)					
	3	7	14	28	56	91
1:3:6	0.17 (0.12)	0.98 (0.14)	1.29 (0.05)	1.55 (0.17)	1.63 (0.05)	1.64 (0.04)
1:2:4	0.25 (0.12)	1.12 (0.13)	1.54 (0.05)	1.78 (0.22)	1.87 (0.06)	1.88 (0.07)
1:1½:3	0.29 (0.01)	1.65 (0.02)	1.87 (0.05)	2.00 (0.05)	2.09 (0.07)	2.11 (0.05)
1:1:2	0.34 (0.02)	1.92 (0.04)	2.31 (0.02)	2.40 (0.36)	2.53 (0.04)	2.54 (0.03)

Table 5: Mean (SD) Splitting Tensile Strength of PKS Concrete (N/mm^2)

Mix	Age (Days)					
	3	7	14	28	56	90
1:3:6	0.06 (0.02)	0.21 (0.04)	0.28 (0.05)	0.35 (0.03)	0.42 (0.06)	0.42 (0.06)
1:2:4	0.08 (0.15)	0.26 (0.08)	0.36 (0.05)	0.40 (0.02)	0.46 (0.05)	0.47 (0.04)
1:1½:3	0.11 (0.02)	0.38 (0.05)	0.42 (0.04)	0.50 (0.05)	0.58 (0.04)	0.60 (0.04)
1:1:2	0.23 (0.02)	0.76 (0.03)	0.84 (0.03)	1.00 (0.07)	1.25 (0.04)	1.28 (0.02)

Table 6: Mean (SD) Modulus of Elasticity of PKS Concrete (kN/mm^2)

Mix	Age (Days)					
	3	7	14	28	56	90
1:3:6	0.005 (0.01)	0.02 (0.00)	0.04 (0.00)	0.06 (0.01)	0.08 (0.00)	0.08 (0.01)
1:2:4	0.01 (0.01)	0.05 (0.01)	0.06 (0.00)	0.07 (0.00)	0.10 (0.05)	0.10 (0.05)
1:1½:3	0.014 (0.00)	0.06 (0.00)	0.08 (0.00)	0.09 (0.00)	0.11 (0.00)	0.12 (0.00)
1:1:2	0.03 (0.01)	0.11 (0.00)	0.16 (0.00)	0.20 (0.04)	0.22 (0.00	0.23 (0.01)

THE ANOVA

The significance of the influence of the treatments of mixes and the age of curing or the combined treatment effect on the PKS concrete was tested with the ANOVA. Performing ANOVA on the compressive test data gave a summary result presented in Table 6. At 5% level, the effect of mix, age *of curing and combined treatment effects are insignificant, since the computed p values are less than the 0.05. Hence a model to describe the trend of concrete compressive strength with age was developed (Figure 1). The results for all other three properties are the same. The strength - age models developed from Figure 1 for the compressive strength are as follows:*

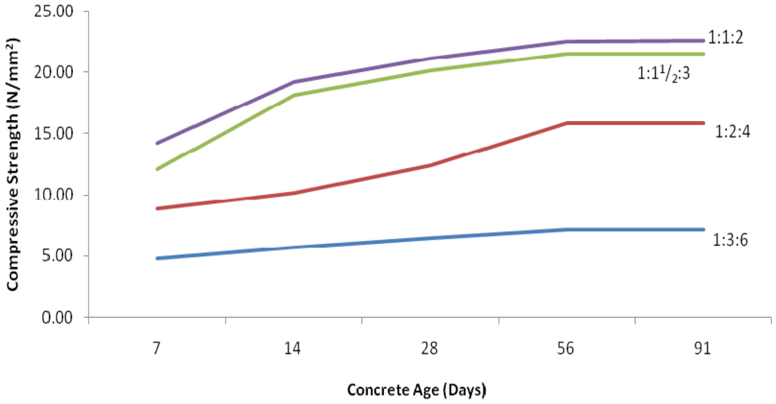

Figure 1. Compressive strenght - age trend of palm kernel shell concrete mixes

Equations relating compressive strength (y) to age of PKS concrete (x)

1:1:2 $y = 14.81x^{0.295}$; $R^2 = 0.941$ 1:1$^1/_2$:3 $y = 12.9x^{0.362}$; $R^2 = 0.917$

1:2:4 $y = 8.64x^{0.39}$; $R^2 = 0.930$ 1:3:6 $y = 4.802x^{0.268}$; $R^2 = 0.984$

STATISTICAL CORRELATION ANALYSIS FOR DEVELOPMENT OF THETRANSFER MODELS

The process of identifying and disregarding unimportant properties is equally as important as recognizing those that are truly important. An inspection of the scatter diagram for the flexural strength and the compressive strength presented in Fig. 2 confirms a nonlinear relationship. However, a mathematical model developed with the statistical spread sheet software gives a probable index relationship, with a correlation coefficient of about 90%. Following similar procedure, the corresponding model for the splitting tensile and the elastic deformation properties for the palm kernel concrete were developed also at about 93.%.The splitting tensile strength and the flexural strength are, thus, related to the compressive strength by the general equation (equation 3) earlier developed by [10] and [11] for normal concrete.

$$f_{ct} or f_r = k\_f'_c \quad (3)$$

where,

f_{ct} = splitting tensile strength, f_r = flexural strength and f'_c = compressive strength k = constant

At low strengths, the splitting tensile strength may be as high as 10% of the compressive strength at 28 days but at higher strengths, it may be reduced to 5% [10].

There is, therefore, the need to determine compliance of other parameters (flexural strength, splitting tensile strength and modulus of elasticity) with the compressive strength of PKS concrete. The statistical correlation analysis of the values of the flexural strength, splitting tensile strength and modulus of elasticity with respect to the compressive strength using Microsoft Excel Software produced the following equations:

$$f_r = 0.399f'_c{}^{0.591} \qquad R^2 = 0.996,$$

$$f_{ct} = 0.043f'_c{}^{1.056} \qquad R^2 = 0.773 \text{ and}$$

$$E_c = 0.001f'_c{}^{1.549} \qquad R^2 = 0.980$$

where, f'_c = Compressive strength, f_r = Flexural strength, f_{ct} = Splitting tensile strength and E_c = Modulus of Elasticity

DISCUSSION OF RESULTS

The results in Table 1 show that specific gravity of 640 kg/m^{3}obtained for palm kernel aggregate confirms its adequacy as both a normal aggregate and lightweight aggregate while the other properties certify it only as lightweight aggregate. The compressive strength properties of PKS concrete for all the mixes at age 28 days (Table 2) indicates it can be used as a lightweight concrete. The values of all the mechanical strength properties for all mix ratios increase with age reflecting the same behaviour as for normal concrete. The density of the normal concrete is in the order of 2200-2600 kg/m^3, while the lightweight concrete has density ranging from 300-1850 kg/m^3. Lightweight structural concrete is considered to be a material of specific weight not more than 18.06 kN/m^3 and developing a compressive strength not less than 17 N/mm^2. Palm kernel shells can be used as aggregate substitution for a grade 20 lightweight structural concrete, which is achievable at higher nominal mixes of 1:1$^1/_2$:3 and 1:1:2.

The slump of concrete decreased with nominal mixes as the proportion of the palm kernels increases. For instance, the nominal mix of 1:1:2 with slump of 10 cm is more workable compared to any other nominal mix. The mechanical strength results (Table 2) show that nominal mixes of 1:1$^1/_2$:3 and 1:1:2 respectively have compressive strengths of 20.10 and 21.24 N/mm^2 and densities of 1777 and

1817 kg/m^3 at 28 days correspondingly. This compressive strength values are greater than 17 N/mm^2, the 28-day minimum specified strength by ASTM-77 for structural lightweight concretes. The results data of Tables 3-5 show that the values of modulus of rupture, splitting tensile strength and modulus of elasticity of PKSC follow a similar trend as that of the compressive strength, all further indicating that the behavior of a vegetative lightweight concrete is essentially similar to that of a structural conventional concrete and hence a rigid pavement.

The standard deviations (ranging between 0.01 – 0.36 N/mm^2) for 3 to 56 days indicate that the strengths are close while that for 91 days are, in addition, very close to zero. Statistical analysis of the values of flexural strength, splitting tensile strength and modulus of elasticity show an index relationship with respect to the compressive strength with coefficient of correlation (R^2) values of 0.996, 0.773 and 0.980 respectively. The corresponding model parameters (in the form af^n) in terms of the compressive strength for the flexural strength, splitting tensile strength and modulus of elasticity PKS concrete are respectively a.= 0.399, 0.043 and 0.001; n = 0.591, 1.056 and 1.549.

Equations developed relating the mechanical properties to curing age of PKSC are non-linear with R^2 values ranging within 0.917-0.984. For instance, the equation relating compressive strength(y) of PKSC to curing age (x) at 1:1:2 mix ratio is $y = 14.81x^{0.295}$; $R^2 = 0.941$. Results show that, for each of the mechanical properties, the plot of the experimental data logarithmic transformed data against the compressive strength can be approximated to a straight line, which is an indication that the index transfer model representing linear correlation of the mechanical properties are appropriate.

The ANOVA data analysis on the compressive strengths revealed that the two treatments of mix and curing age have no effect on the mechanical property of palm kernel shell concrete. Finally, the statistical correlation analysis of the values of three mechanical properties (flexural strength, splitting tensile strength and modulus of elasticity) with respect to compressive strength conducted with the Microsoft Excel Software gave respective index models at R^2 values ranging from 0.773-0.996.

CONCLUSIONS

The investigation of the trend of the critical and relevant mechanical properties (compressive strength, flexural strength, splitting tensile strength and modulus of elasticity) of palm kernel shell concrete as rigid pavement was conducted for four different mixes (1:1:2, 1:1$^1/_2$:3, 1:2:4 and 1:3:6), and curing age for a period of 91 days. The outcome of the research revealed the following conclusions:

(a) *The compressive strength of PKS concrete increases with age and mix in similar pattern for the normal concrete with standard coarse aggregates*
(b) *The four mechanical properties of a vegetative lightweight concrete considered for all the mixes follow a trend of monotonous increase with age of curing briskly between age 3 and 56 but very gradual at later ages of 56 – 91 days, but at different rates for each of the properties, and remaining approximately constant thereafter. The strength at 91 days for all the mixes remained constant with coefficient of variation values almost tends to zero (0.00 – 0.11%).*
(c) *That is, for the mix ratio of 1:3:6 which is the weakest and lowest grade considered, the compressive strength of PKSC is 1.32 N/mm^2 at 3 days and 7.20N/mm^2 at 91days, while the compressive strength of PKSC at 3 days is 2.13 N/mm^2 and at 91 days, it is 22.60N/mm^2 for 1:1:2 mix proportion. The same trend applies for flexural strength, splitting tensile strength and modulus of elasticity.*
(d) *The ratio of 28-day to 91-day compressive strength for all the mixes of the palm kernel shell concrete are respectively determined as for the 1:1:2; 1:1$^1/_2$:3, 1:2:4 and 1:3:6) as 1:1:1.07.*
(e) *The trend of the various forms of the strength can be described with the age of PKS concrete with an index model (af^n) at R^2 values of 0.903-0.987. The respective characteristics, a of the models are 0.399, 0.043 and 0.001 for flexural strength, splitting tensile strength and modulus of elasticity, while the corresponding index, n are 0.591, 1.056 and 1.549.*
(f) *The results further confirm that palm kernel shell aggregate is adequate for the production of grade 20 lightweight structural concrete at nominal mix of 1:1:2 and therefore as rigid pavement.*
(g) *F values of 1.542, 1.714, 2.941 and 4.547 obtained respectively for 1:1:2, 1:1$^1/_2$:3, 1:2:4 and 1:3:6 mix proportions when $F_{critical}$ (Table) is 5.318 shows strong correlation of the data for compressive strength.*
(h) *There are probable transfer models establishing a reliable relationship between the compressive strength and that of other strength parameters at R^2 values of 0.996, 0.773 and 0.980 for flexural strength, splitting tensile strength and modulus of elasticity respectively for PKS concrete, which indicated a positive adoption of compressive strength as a reliable parameter in characterizing the other mechanical properties of a vegetative lightweight concrete, the PKS concrete.*

RECOMMENDATIONS

(i) *With the paucity of funds in developing countries for construction purposes, the use of wastes should be encouraged in the neighbourhood where the critical and desired materials are scarce, which also has appreciable value for environmental impact aspect of road development.*

(ii) Studies on the response of PKS concrete pavement to dynamic loadings, with other performance indicators with the Non Destructive testing procedure is recommended. The cost effectiveness at mix proportions of $1:1^{1}/_{2}:3$ and 1:1:2 are desirable and must be further conducted.

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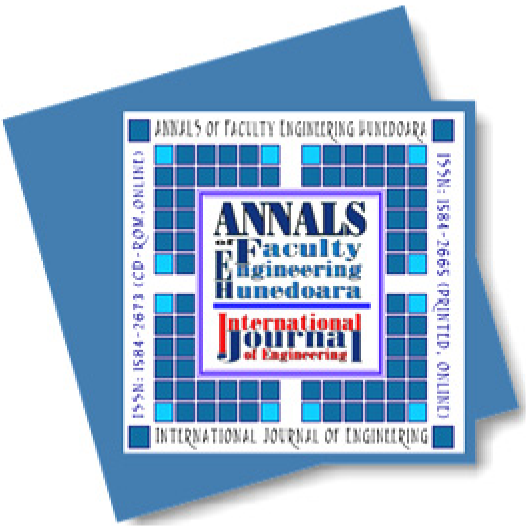

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