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MODELING RESIDUAL STRENGTH OF PALM KERNEL SHELL CONCRETE USING THE ULTRASONIC PULSE VELOCITY FOR RIGID PAVEMENT MAINTENANCE

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Abstract: This paper reports the Ultrasonic Pulse Velocity (UPV) test method as a strategy for monitoring the flexural strength of palm kernel shell (PKS) concrete and adoption for routine maintenance of rigid pavements. The direct and indirect UPV measurements were made alongside respective mechanical properties of compression (cube) and flexural (slab) elements of concrete at various mixes and water/cement ratios. A total of 420 cubes (150 mm size) and 28 slabs of the PKS concrete were casted for nominal mixes of 1:1:1, 1:1:2, 1:11/2:3 and 1:2:4 and varying water/cement (w/c) ratios of 0.3-0.7(0.1). The two forms of the structural test elements were cured in water at laboratory temperature for 3, 7, 14, 21, 28, 56 and 91 days. The elements were then subjected to nondestructive testing using the Pundit apparatus for determination of direct ultrasonic wave velocity and the elastic modulus at the various ages. The cubes were subsequently subjected to destructive compressive test. The established velocity-strength data set was then employed for the development of statistical Compressive strength-UPV and strength–Age relationship for the palm kernel shell concrete. Also the indirect UPV measurements were made on the PKS concrete slabs and correlated with the direct UPV. The corresponding flexural strength model at w/c ratio of 0.5 was formulated, and its use as both the quality assurance model and routine rigid pavement maintenance for a lightweight concrete was equally developed. Results show that the UPV and the compressive strength of PKS Concrete increased with age but decreased with increase in w/c ratio and mixes. The strength-UPV models developed for all mixes were in the form of logarithm equation, at R2 values of 90% and more. The application of the developed model for a slab as rigid pavement maintenance/deterioration planning and design was substantially demonstrated in the paper.

Keywords: *Compressive strength, palm kernel shell concrete, nondestructive technique, rigid pavement maintenance, direct and indirect ultrasonic pulse velocity.*

1.0 Introduction

Maintenance of rigid pavements is more effective if the prevailing condition, residual strength and or deterioration rate of the strength could be monitored as the pavement is being affected by traffic and weather. Non-Destructive Test (NDT) methods offer the advantage of providing information on the in-place properties of hardened concrete, such as the elastic constants, density, resistivity, moisture content, and hardness characteristics. Unlike coring, a destructive testing (DT) approach that introduces weak spots while obtaining the test specimens, with the attendant threats to the integrity and safety of the entire structure. Besides, the approach limits what can be detected to information at the core location and additionally implies the need for the core holes to be repaired. The assessment of in situ compression strength of a rigid pavement structure plays a key role in the evaluation of its adequacy in strength at the time of production (Quality control and assurance, QA/QC) and or even later at service; which is very desirable in the maintenance practice of infrastructural facilities. The knowledge that the critical properties of the concrete and its state are within the expected values and presumptions would restore the confidence of the user of the facility.

The NDT methods are the most used to determine the properties of hardened concrete as well as to indirectly evaluate the condition of concrete in deep foundations, bridges, buildings, pavements, dams and other concrete construction without the direct loading or the need for direct access to testing position or location. The significance of the methods in virgin concrete construction based on mechanical (strength) property has been much demonstrated for quality control of the new construction or troubleshooting of problems; and or condition evaluation of older concrete for rehabilitation purposes, quality assurance of concrete repairs and detection of flaws or discontinuities (Tomsett, 1980). Thus the NDT can be divided into two groups: (i) those whose main purpose is to estimate strength for design and (ii) those whose main purpose is to evaluate conditions other than strength or integrity evaluation, as usually desirable in pavement maintenance. It is therefore clear that the most reliable tests for residual strength are the real time integrity and nondestructive that does not result in either local damage or superficial, non-objective and non-empirical, which had been mostly based on visual inspections. However, modern day analysis and design of pavement desires that elastic properties of material be accurately determined (evaluated) in place and at appropriate time because routine maintenance should be really linked with the actual and prevailing status of the structure, in this case the residual strength or prevailing status of the concrete pavement.

Ultrasonic Pulse Velocity (UPV) is a non-destructive technique that involves measuring the speed of sound waves through materials in order to predict material strength, calculate low-strain elastic modulus and/or to detect the presence of internal flaws such as cracking, voids, honeycomb, decay and other damages. The technique is applicable where intrusive (destructive) testing is not desirable and has been much applied to concrete, mainly in finding general changes to condition of such as areas of weak concrete in a sound structure, but less commonly in ceramics, stone and timber. Also, absolute measurements should be treated with caution because the UPV technique is not always practicable in testing sound concrete, in the investigation of water filled crack depth and very rough surfaces (Prassianakis and Giokas, 2003) thereby requiring the use of a coupling gel between the transducers and the structure to provide the smoothness in contact. The leading portable UPV test instrument is the Pundit Ultrasonic Testing Machine, which is used to transmit an irrational pulse to travel through a known distance in concrete. The generated ultrasonic pulse velocity (UPV) is correlated with prevailing compressive strength or other properties for in-situ and timely decision making in material quality/integrity evaluation. Indeed the UPV has been adopted to describe the quality of concrete in accordance with the BS 1881 (BSI, 1983 & 1986) as presented in Table 1.

Pulse velocity is influenced by many variables such as mix proportions, aggregate type, age of concrete, moisture content, and other factors (Lin *et al*., 2003), which might make strength estimation with the pulse velocity suspect and inaccurate. Therefore, for the UPV-strength relations derived for structures to be reliable, at any time during its service period, the risk level involved must be defined quantitatively, especially with the statistical coefficient of correlation, R^2 values.

Table 1: Suggested Quality Criteria for Concrete

Pulse Velocity (km/sec)	*Concrete Quality (Grading)*
Above 4.0	Very Good
3.5 to 4.0	Good
3.0 to 3.5	Medium
Below 3.0	Poor

Source: IS Code, BS 1881 (BSI, 1983 & 1986)

Some previous studies have concluded that, for normal concrete with a particular mix proportion, there is a good correlation between UPV and the compressive strength (Lawson *et al*., 2011 and Mahure *et al*., 2011) but no clear rules or much explicit quantification on the effect as the mix varies nor for lightweight concrete specifically, such as a vegetative lightweight. Palm kernel shell (PKS) concrete, is an emerging vegetative lightweight concrete derived from recycling the biomass waste of palm kernel shells as substitutes completely for the conventional natural/traditional coarse aggregates. The PKS concrete at certain nominal mix and water cement/ratio has been characterized to possess tangible benefits when used in rigid pavement construction (Yusuf and Jimoh, 2013), such as protection of the environment by conserving the natural resources for coarse aggregates, the lands for mining and landfills; serving as a new and alternate source of concreting aggregates, thus extending the life of sand and gravel mines, economic development opportunities and reduced pollution hazards as either waste dump from palm oil extracting processes and improved human health from the burning of the kernels.

This paper is therefore aimed at indirectly determining in-situ, the mechanical properties of a PKS concrete slab through the direct characterization of shear wave velocity at various mixes and water/cement ratios that are non-destructive and thereby present the condition and prevailing condition and strength of a rigid pavement on being subjected to traffic and weather effects. The specific objectives, therefore, are to: (a) determine the Ultrasonic Pulse Velocity (UPV) and corresponding compressive strength of PKS concrete cubes with both direct and indirect methods at varying nominal mixes, curing ages and selected water/cement ratio, (b) develop the statistical relationship between the direct and indirect UPV for the PKS concrete slab specimens, (c) determine the UPV–Compressive strength model for the concrete mixes at selected w/c and transform to flexural strength deterioration model for PKS Concrete, and hence; (d) demonstrate the adoption of the UPV as a routine maintenance parameter for the palm kernel shell pavement.

2.0 Materials and Methods

Palm kernel shell (PKS) wastes were obtained from small scale palm oil milling processes and evaluated for nominal lightweight concrete works. The relevant physical and strength properties are presented in Table 2 while the particle size gradation envelope is displayed in Figure 1. The PKS were washed, dried and employed as coarse aggregate for production of nominal lightweight concrete. Nominal concrete mixes of 1:1:1, 1: 1: 2, 1:1½:3 and 1: 2: 4 concrete and water/cement ratios of 0.3-0.7 at 0.1 intervals were produced with the PKS as the light weight coarse aggregates and the other conventional components of fine aggregates (sand), ordinary Portland cement (ops) and portable water (WHO Standard). The workability of the various mixes for rigid pavement was also evaluated with the standard slump test apparatus at the time of fresh concrete production. A total number of 420 cubes (150x150x150 mm) were batched, cured and tested for compressive strength at 3, 7, 14, 21, 28, 56 and 91 days according to the standard Destructive Test (DT) (ASTM C78 (2000), ASTM C39-93a (2000), ASTM 1170C (2008)) and Non-destructive Test (NDT) procedure (BS EN 12504-4, 2004). Also twenty-eight (28) PKS concrete slabs of 300x200x75 mm dimensions were produced at w/c ratio of 0.5 from the nominal mixes. But prior to the DT crushing, the PKS concrete cubes were subjected to NDT with the Pundit Apparatus (Model PC 1006) (Pundit, 1993) with the direct approach to determine respective transit time, velocity of the pulse and elastic modulus in accordance with the specification of the British standard BS 1881 (BSI, 1983). The indirect approach of the PUNDIT Apparatus was also performed on the PKS concrete slabs (See Figure 2) for physical demonstration of the direct and indirect NDT.

Various forms of the UPV-compressive strength relationship of hardened PKS concrete were tried for the concrete cubes, and employed for the indirect derivation of the flexural strength for the slab accomplished using Microsoft Excel Software. The scatter diagram for the development of the relationships between ultrasonic pulse velocity and compressive strength drawn for PKS concrete with the corresponding w/c ratios were plotted with linear, index, logarithm and polynomial trend lines. The logarithm and polynomial trend lines show greater correlations, at R^2 values in the range of 0.949 – 0.993. The quality of PKS concrete in terms of uniformity and integrity was also assessed using the IS Code, BS 1881, 1983 standard (BSI, 1983).

Table 2: Physical Properties of PKS in Comparison with Standards

Property	Batch			*Range	**Specification/ Standard	Remarks
	1	2	3			
Water absorption capacity (%)	13.7	13.9	13.6	13.6-13.9	13.5-14.6	Okay
Specific gravity	1.26	1.23	1.24	1.23-1.26	1.02-1.34	Okay
Bulk Density (g/cm^3)	0.64	0.68	0.65	0.64-0.68	0.5-0.75	Okay
Moisture content (%)	14.49	14.42	14.39	14.39-14.49	13.80-14.55	Okay
Impact value (%)	5.02	5.04	5.05	5.02-5.05	5.0-5.80	Okay

*Source: *Laboratory Results, **Mahmud et al. (2009)*

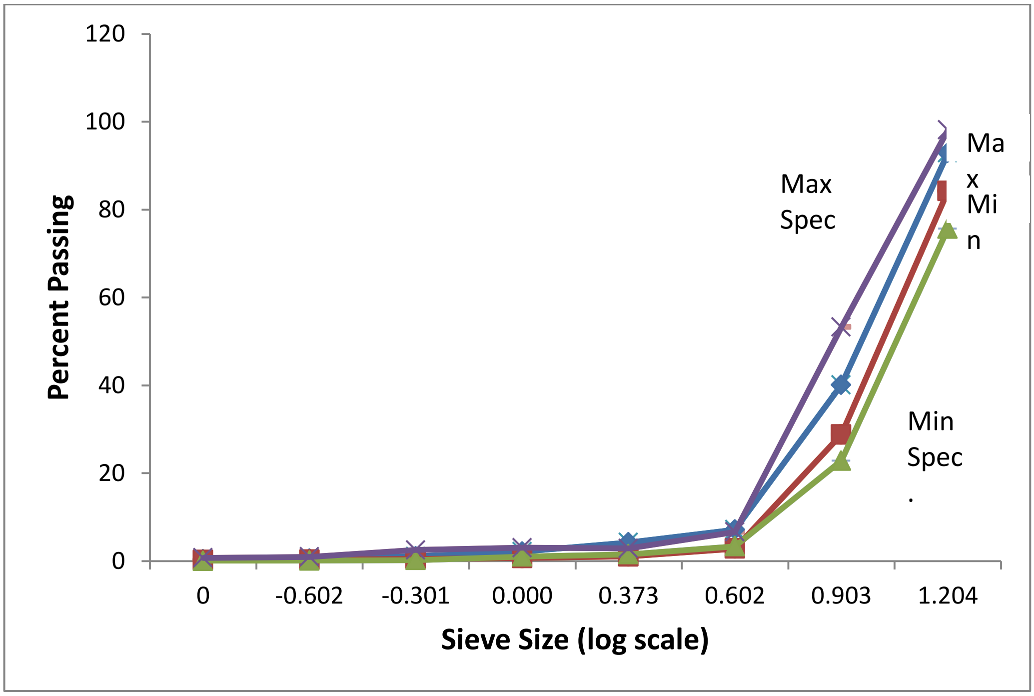
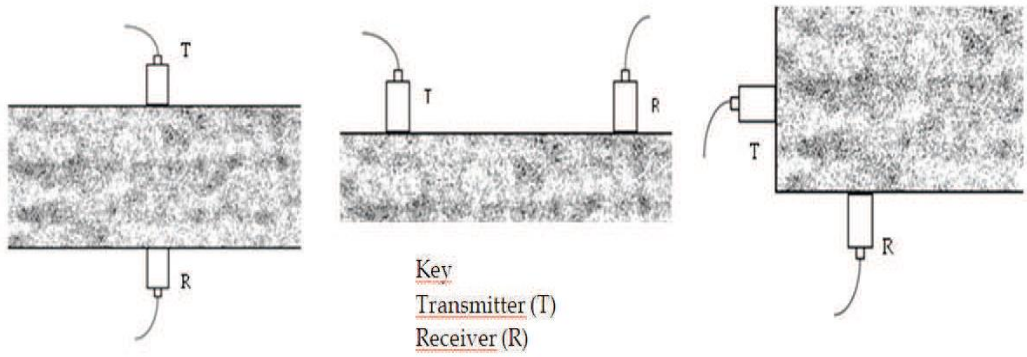


Figure 1: Particle Size Envelopes for Palm Kernel Shell and Standard Lightweight Aggregates



(a) (b) (c)

Figure 2: Methods of propagation and receiving ultrasonic pulses. (a) Direct Transmission (for cube), (b) Indirect or surface Transmission (for slab), (c) Semi-direct Transmission (for wall) (BSI, 2004)

3.0 Results and Discussion

3.1 The Test Data Layout

Table 2 and 3 respectively present the data set of the results for the physical properties of the PKS lightweight aggregates and the workability of fresh PKS concrete, and in evaluation for rigid pavement (rolled concrete). Tables 4-7 show the trend with respect to age of the compressive strength and UPV at the various water cement ratios and nominal mixes. The direct UPV and indirect UPV data set for cube specimens at w/c ratio of 0.5 for the considered nominal mixes are shown in Tables 8-11. The resulting equations relating direct UPV and indirect UPV for PKS concrete slab are also shown in Table 12, while the relating compressive strength to ultrasonic pulse velocity of PKS concrete is also shown in Table 13. Table 14 shows the equations relating the indirect UPV (UPV_i) to the direct UPV (UPV_d).

Table 3: Slump (cm) of palm kernel shell concrete mixes in comparison for rolled compacted concrete

Mix	Slump (cm) at various w/c ratio [+]					Standard slump for Rolled Compacted Concrete (cm) *	Remarks
	0.3	0.4	0.5	0.6	0.7		
1:2:4	2.15	2.25	2.45	8	10	2.00	w/c of 0.3-0.5 meet requirement for rolled compacted concrete
1:11/2:3	2.20	2.30	2.25	6.5	8	2.25	
1:1:2	2.55	2.60	2.75	4.5	6.5	2.65	
1:1:1	2.60	2.65	2.90	4.0	5.5	2.85	

*Source: *ASTM C1170/c1170M (2008); EN 206-1:2000; [+] Yusuf, (2013)*

Table 4: Compressive Strength (N/mm^2) versus Ultrasonic Pulse Velocity (km/sec) of PKS Concrete (1:2:4 Mix Ratio)

Age (Days)	w/c = 0.3		w/c = 0.4		w/c = 0.5		w/c = 0.6		w/c = 0.7	
	Strength	UPV	Strength	UPV	Strength	UPV	Strength	UPV	Strength	UPV
3	1.3	4.2	1.1	3.7	0.7	3.2	0.9	2.9	0.4	2.2
7	2.8	4.6	2.5	4.4	2.1	3.8	1.8	3.2	1.4	2.5
14	4.2	5.0	3.8	4.7	2.9	4.3	2.6	3.9	2.1	3.1
21	5.5	5.5	4.6	5.3	3.8	4.9	3.3	4.3	2.9	3.6
28	6.5	5.7	5.5	5.5	4.8	5.1	3.9	4.6	3.3	3.9
56	7.2	6.2	6.3	5.9	5.8	5.6	4.9	4.9	3.7	4.4
91	7.2	6.3	6.3	6.0	5.8	5.7	4.9	5.1	3.8	4.4

Source: Yusuf (2013)

Table 5: Compressive Strength (N/mm^2) versus Ultrasonic Pulse Velocity (km/sec) of PKS Concrete (1:2:4 Mix Ratio)

Age (Days)	w/c = 0.3		w/c = 0.4		w/c = 0.5		w/c = 0.6		w/c = 0.7	
	Strength	UPV	Strength	UPV	Strength	UPV	Strength	UPV	Strength	UPV
3	1.8	4.4	1.5	4.1	1.1	3.8	0.9	3.3	0.7	2.7
7	5.2	4.7	4.6	4.5	4.1	4.1	2.8	3.9	2.1	3.3
14	9.2	4.9	8.0	4.8	6.2	4.4	4.8	4.1	3.9	3.6
21	11.9	5.6	9.3	5.4	7.2	4.9	5.7	4.4	4.7	4.1
28	13.1	5.8	10.1	5.7	8.5	5.3	6.4	5.0	5.1	4.3
56	15.8	6.6	13.2	6.2	10.3	5.6	8.6	5.4	7.2	4.8
91	15.8	6.5	13.2	6.3	10.3	5.8	8.6	5.5	7.2	5.1

Source: Yusuf (2013)

Table 6: Compressive Strength (N/mm^2) versus Ultrasonic Pulse Velocity (km/sec) of PKS Concrete (1:2:4 Mix Ratio);

Age (Days)	w/c = 0.3		w/c = 0.4		w/c = 0.5		w/c = 0.6		w/c = 0.7	
	Strength	UPV	Strength	UPV	Strength	UPV	Strength	UPV	Strength	UPV
3	2.8	4.8	2.1	4.6	1.8	4.4	1.4	4.2	1.1	3.5
7	10.2	5.2	8.7	4.9	6.6	4.5	5.8	4.2	4.3	3.8
14	15.2	5.5	13.4	5.1	11.3	4.9	9.7	4.6	7.6	4.1
21	18.9	5.9	16.9	5.7	15.5	5.5	13.2	5.1	11.5	4.7
28	21.1	6.2	19.6	6.0	17.9	5.8	15.7	5.7	13.9	5.3
56	22.6	6.8	20.7	6.7	19.6	6.3	17.5	5.9	15.1	5.6
91	22.6	6.9	20.8	6.7	19.6	6.4	17.6	6.2	15.2	5.6

Source: Yusuf (2013)

Table 7: Compressive Strength (N/mm^2) versus Ultrasonic Pulse Velocity (km/sec) of PKS Concrete (1:2:4 Mix Ratio)

Age (Days)	w/c = 0.3		w/c = 0.4		w/c = 0.5		w/c = 0.6		w/c = 0.7	
	Strength	UPV	Strength	UPV	Strength	UPV	Strength	UPV	Strength	UPV
3	2.8	4.8	2.1	4.6	1.8	4.4	1.4	4.2	1.1	3.5
7	10.2	5.2	8.7	4.9	6.6	4.5	5.8	4.2	4.3	3.8
14	15.2	5.5	13.4	5.1	11.3	4.8	9.7	4.6	7.6	4.1
21	18.9	5.9	16.9	5.7	15.5	5.5	13.2	5.1	11.5	4.7
28	21.1	6.2	19.6	6.0	17.9	5.8	15.7	5.7	13.9	5.3
56	22.6	6.8	20.7	6.7	19.6	6.3	17.5	5.9	15.1	5.6
91	22.6	6.9	20.8	6.7	19.6	6.4	17.6	6.2	15.2	5.6

Source: Yusuf (2013)

On the basis of workability for a rolled concrete as in the case of rigid pavement construction (Table 3), the desirable w/c ratio should be less than 0.5. The fresh concrete at 0.6 and 0.7 w/c ratio for the four nominal mixes would be too fluidal and likely incapable of developing adequate strength. The values of all the mechanical properties evaluated in this study (Table 4-7) are lowest at the 0.5 w/c ratios implying that they are data set at 0.5 w/c ratio (ASTM, 2000) is the most conservative for further consideration. The 28-day compressive strength at the 0.5 w/c ratio for structural concrete standardization of grade 7 was not achievable at nominal mix 1:2:4. This implies that for the PKS concrete to be used for rigid pavement, richer mixes of $1{:}1^1/_2{:}3$ to 1:1:1 and at the 0.5 w/c should be specified.

The Ultrasonic Pulse Velocity (UPV) is the measure of the quality of concrete. The UPV values of the PKS concrete for all w/c ratios, ages and mix proportions fall within 2.0 and 7.0 km/sec. Compared with UPV values in Table 1, the PKS concrete produced for all the mixes and w/c ratios of 0.3, 0.4 and 0.5 are good while the ones for w/c ratio of 0.6 and 0.7 are respectively poorer. This implies that PKS concrete at lower w/c ratios have low workability but high strength, which is adequate for structural works. However, the higher w/c ratios with lower strength are not good enough for rigid pavement, given the same implications when considering the destructive testing procedure of the compressive strength. Thus adopting Tables 4 - 7 showing the compressive strength and/or ultrasonic pulse velocity of PKS concrete for the nominal mixes and water/cement ratios as Quality control /Quality assurance parameter shall give the ultimate result. However, the fact that the Ultrasonic Pulse Velocity is non-destructive gives it higher relevance for pavement maintenance which requires the prevailing condition at any instance or occasion.

Table 8: Direct and Indirect UPV of PKS Concrete Cube at 0.5 w/c Ratio (1:2:4 Mix)

UPV (km/sec)	Age (Days)						
	3	7	14	21	28	56	91
Direct	3.214	3.760	4.278	4.874	5.142	5.551	5.701
Indirect	0.719	2.063	3.286	4.463	5.138	5.468	5.653

Source: Yusuf (2013)

Table 9: Direct and Indirect UPV of PKS Concrete Cube at 0.5 w/c Ratio (1:1$^{1}/_{2}$:3 Mix)

UPV (km/sec)	Age (Days)						
	3	7	14	21	28	56	91
Direct	3.785	4.075	4.369	4.922	5.321	5.649	5.787
Indirect	0.725	2.271	3.472	4.725	5.226	5.631	5.781

Source: Yusuf (2013)

Table 10: Direct and Indirect UPV of PKS Concrete Cube at 0.5 w/c Ratio (1:1:2 Mix)

UPV (km/sec)	Age (Days)						
	3	7	14	21	28	56	91
Direct	4.159	4.466	4.662	5.230	5.732	5.975	6.254
Indirect	0.904	2.325	4.484	5.183	5.634	5.960	6.145

Source: Yusuf (2013)

Table 11: Direct and Indirect UPV of PKS Concrete Cube at 0.5 w/c Ratio (1:1:1 Mix)

UPV (km/sec)	Age (Days)						
	3	7	14	21	28	56	91
Direct	4.378	4.520	4.870	5.450	5.823	6.273	6.445
Indirect	1.225	3.425	4.434	5.352	5.625	6.078	6.277

Source: Yusuf (2013)

Table 12: Equations Relating Mechanical Properties of PKSC to Age at 0.5 w/c Ratio

Equation	R^2	Mix Proportion
(a) Compressive Strength		
$f_{cu} = 14.81x^{0.295}$	0.941	1:1:1
$f_{cu} = 12.9x^{0.362}$	0.917	1:1:2
$f_{cu} = 8.64x^{0.39}$	0.930	$1:1^1/_2 3$
$f_{cu} = 4.802x^{0.268}$	0.984	1:2:4
(b) Flexural Strength		
$\sigma = 1.968x^{0.175}$	0.944	1:1:1
$\sigma = 1.633x^{0.158}$	0.903	1:1:2
$\sigma = 1.169x^{0.333}$	0.944	$1:1^1/_2 3$
$\sigma = 1.007x^{0.337}$	0.959	1:2:4
(c) Splitting Tensile Strength		
$STS = 0.718x^{0.35}$	0.914	1:1:1
$STS = 0.365x^{0.304}$	0.969	1:1:2
$STS = 0.266x^{0.374}$	0.981	$1:1^1/_2 3$
$STS = 0.209x^{0.461}$	0.982	1:2:4
(d) Modulus of Elasticity		
$E_d = 0.113x^{0.472}$	0.982	1:1:1
$E_d = 0.059x^{0.429}$	0.987	1:1:2
$E_d = 0.047x^{0.463}$	0.908	$1:1^1/_2 3$
$E_d = 0.020x^{0.909}$	0.980	1:2:4

where, f_{cu} = Compressive strength of PKS concrete (N/mm^2), σ = Flexural strength of PKS concrete (N/mm^2), STS = Splitting tensile strength of PKS concrete (N/mm^2), E_d = Modulus of Elasticity of PKS concrete (kN/mm^2), x = Age of PKS concrete in days

Table 13: Polynomial Trend line for Effects of w/c Ratio for the Strength of PKS Concrete

Equation	R^2	Water Cement Ratio
(a) 1:1:1 Mix		
$y = 10.740\ln(x) + 3.112$	0.989	0.3
$y = 10.260\ln(x) + 2.097$	0.988	0.4
$y = 10.010\ln(x) + 1.005$	0.982	0.5
$y = 8.974\ln(x) + 0.637$	0.984	0.6
$y = 8.046\ln(x) + 0.009$	0.966	0.7
(b) 1:1:2 Mix		
$y = 10.691\ln(x) + 1.698$	0.989	0.3
$y = 9.621\ln(x) + 1.591$	0.988	0.4
$y = 8.491\ln(x) + 0.665$	0.980	0.5
$y = 6.115\ln(x) + 0.819$	0.991	0.6
$y = 4.426\ln(x) + 0.895$	0.993	0.7
(c) $1:1^1/_2:3$ Mix		
$y = 7.712\ln(x) + 1.014$	0.981	0.3
$y = 6.211\ln(x) + 1.006$	0.975	0.4
$y = 4.890\ln(x) + 0.869$	0.989	0.5
$y = 4.125\ln(x) + 0.379$	0.962	0.6
$y = 3.437\ln(x) + 0.211$	0.949	0.7

Table 13 (cont.): Polynomial Trend line for Effects of W/C Ratio for the Strength of PKS Concrete

Equation	R^2	Water Cement Ratio
(d) 1:2:4 Mix		
y = 3.296ln(x) + 0.943	0.978	0.3
y = 2.847ln(x) + 0.833	0.983	0.4
y = 2.742ln(x) + 0.345	0.965	0.5
y = 2.348ln(x) + 0.288	0.970	0.6
y = 1.836ln(x) + 0.273	0.987	0.7

Table 14: Equations Relating Direct UPV and Indirect UPV of PKS concrete slab at 0.5 w/c ratio

Equation	R^2	Mix Proportion
$UPV_i = 2.609\ln(UPV_d) + 1.452$	0.987	1:1:1
$UPV_i = 2.884\ln(UPV_d) + 0.863$	0.969	1:1:2
$UPV_i = 2.769\ln(UPV_d) + 0.602$	0.987	$1:1^1/_2:3$
$UPV_i = 2.731\ln(UPV_d) + 0.507$	0.983	1:2:4

Results further show that compressive strength and UPV increase with advancement of age but decrease with increase in water/cement ratio. At the same age, both UPV and compressive strength of PKS concrete with low w/c ratio are higher than those with high w/c ratio mainly because of the denser structure of the concrete with lower w/c ratio. Also, for a further inspection of the data in the tables and some computations, it can be realized that for all the nominal mixes studied, the PKS concrete with high w/c ratio (w/c = 0.7) at the age of 7 days have UPV values of between 70 and 75% of that of 28 days, but the corresponding compressive strengths are between 50 and 55%. Similarly, at the age of 7 days, PKS concrete with low w/c ratios (w/c = 0.3) have UPV values that fall in the range of 80-85% of that at 28 days while the corresponding compressive strengths are in the range 55-60%. These imply that, the UPV and compressive strength growth rates of high and low w/c ratio concrete are significantly different at an early age. As a result, the relationship between UPV and compressive strength of PKS concrete becomes unclear when age and mix proportion are taken into consideration simultaneously. This observation, therefore, suggests that it is better to separately consider the effect of age and mix proportion on UPV and compressive strength relationship. However, the 7-day to 28-day strength ratio of 60-75% normally reported for conventional concrete for QC/QA (Demirboga *et al.*, 2004) is equally satisfied with the palm kernel vegetative lightweight concrete, as equally related to the UPV. Thus it is reasonable and appropriate to consider the parameter as the criteria to evaluate the quality of the palm kernel shell concrete, at 7 days as an early age confidence for the right quality works. The determination of the UPV without the destructive procedure of the structural set up of the element makes it suitable for assessment of the status or prevailing strength of the rigid slab as the deteriorating traffic and/or weather induced stresses are imposed.

The scatter diagram and the resulting statistical correlation relationship between the age and mechanical properties (Table 12) and the ultrasonic pulse velocity and compressive strength for the PKS concrete with the corresponding w/c ratios (Table 13) yielded corresponding equations at high levels of reliability. For the five w/c ratios and mixes, the relationship developed for the UPV and compressive strength of the PKS concrete is at very high coefficient of correlation, R^2 in the range 0.949 – 0.993.

3.2 The Flexural Strength Inferred From the Direct UPV

The direct UPV of PKS concrete is related to the indirect UPV by,

$$UPV_i = \alpha UPV_d \tag{1}$$

where, UPV_i = indirect UPV (UPV reading on a concrete slab), UPV_d = direct UPV (UPV reading of the concrete cube), α = constant

Also, there exists some transfer models for PKS nominal mixes of compressive to flexural strength (Yusuf and Jimoh, 2013). Thus, the indirect compressive strength of the PKS concrete slab can be determined by generally expressing compressive strength as function of direct UPV (equation (2) in the first instance (stage).

$$f_{cu} = \beta f(UPV_d) \tag{2}$$

$$f_r = 0.399\, f'_c{}^{0.591} \tag{3}$$

where,

f'_c = Compressive strength, and f_r = Flexural strength

The equations are applicable for estimation of the indirect compressive strength of a PKS concrete slab at w/c of 0.5 for all nominal mixes presented in Table 15, ultimately the flexural strength equation (3) whose results generated are in Table 16 as summarized.

Table 15: Indirect UPV (km/sec) and Compressive Strength (N/mm^2) of a PKS Slab at w/c of 0.5

Age (Days)	1:2:4		1:1$^1/_2$:3		1:1:2		1:1:1	
	UPV_i	f_{cui}	UPV_i	f_{cui}	UPV_i	f_{cui}	UPV_i	f_{cui}
3	1.46	1.36	2.08	1.85	3.36	2.73	3.72	4.08
7	2.65	3.13	3.62	4.93	3.87	6.02	4.16	6.92
14	3.05	3.93	3.89	7.02	4.34	10.85	4.61	11.01
21	3.48	5.11	4.25	7.56	4.75	14.24	4.98	16.23
28	3.62	5.60	4.67	9.84	5.23	15.37	5.54	18.68
56	4.14	8.04	5.13	11.14	5.62	17.95	5.86	20.04
91	4.32	9.18	5.42	11.27	5.76	18.18	5.97	20.48

Some structures in concrete, such as highway pavements and bridges, railroad bridges, airport pavements and marine structures, etc. are subjected to dynamic loads resulting in fatigue. These changes can cause progressive growth of cracks in the concrete and eventual failure of structures when high levels of cyclic loads (for shorter times) or low levels of loads (for longer times) are applied. Also, the basic principle in the design of rigid pavement structures is that the traffic wheel load is accommodated through the flexural resistance of a slab.

Table 16: Indirect Flexural Strength (N/mm^2) of a PKS Concrete Slab at w/c = 0.5

Age (Days)	Mix Proportion			
	1:2:4	1:1$^1/_2$:3	1:1:2	1:1:1
3	0.478	0.574	0.722	0.916
7	0.783	1.024	1.153	1.252
14	0.896	1.262	1.633	1.647
21	1.046	1.319	1.917	2.071
28	1.104	1.541	2.006	2.251
56	1.368	1.658	2.198	2.346
91	1.479	1.670	2.215	2.377

4.0 Conclusions

This paper investigated the relationship between the Ultrasonic Pulse Velocity (UPV), the Compressive and Flexural Strengths of PKS concrete as well as the influence of the mix proportions, water/cement ratios and the age of concrete. The possibility of adopting the UPV as routing maintenance parameter for rigid pavement was also reviewed. Consequently the following conclusions were drawn:

(a) PKS concrete produced at rich nominal mixes than 1:2:4 and water/cement ratio of 0.3-0.5 are of good quality with compressive strength and UPV increasing at advancement of age but decreased with increase in water/cement ratio.
(b) There is a unique index model in the form of $\alpha_1 \ln(x)$ to describe the relationship between compressive strength and UPV of the PKS concrete at about 95% reliability for transforming the nondestructive test data to destructive, as a conventional strength monitoring quality of lightweight vegetative concrete.
(c) The flexural strength of a palm kernel rigid pavement structure are quite derivable from both the direct and indirect ultrasonic pulse velocity measurement.

The following recommendations were also proposed:

(i) The recycle of PKS biomass waste from palm oil farming as light weight coarse aggregates should be encouraged for rigid pavement works because of its demonstrated potential as a nominal mix concrete of adequate structural strength and for maintenance of ecological balance and effective environmental pollution management of indiscriminate dumping of PKS at palm oil processing areas.
(ii) The NDT characterization with the UPV measurements for effective pavement maintenance, which deserves the establishment of the in-situ status or strength deterioration properties of the pavement layers as being impacted from repeated traffic induced stresses, should be adopted as both the QA/QC and routine procedure for the PKS concrete pavement.
(iii) An index model developed for flexural strength of palm kernel concrete with $0.399(UPV)^{0.591}$ is strongly recommended for routine monitoring performance of PKS concrete slab as a rigid pavement because of the R^2 values greater than 90% for 1:2:4 and richer mixes and at 0.5 w/c ratio.
(iv) For further studies, the effect of changes in the volume fraction of cement paste, the source of PKS coarse aggregate (hinterland and coastal), the weather combined with traffic, and the UPV-strength relationship should be examined for development of fatigue and other performance-based characteristics of PKS concrete pavement as well as cost effective and economic viability analysis of recycling biomass for rigid pavement rehabilitation.

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