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EVALUATION OF PALM KERNEL SHELL CONCRETE STRENGTH AT VARIOUS MIXES AND WATER/CEMENT RATIOS WITH NONDESTRUCTIVE METHOD

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Abstract: Ultrasonic Pulse Velocity (UPV) measurement is one of the most popular nondestructive techniques used in the indirect assessment of mechanical properties of concrete. This paper investigates the compressive strength-UPV relationship of palm kernel shell concrete (PKSC) to develop strength based quality assurance model for construction of vegetative lightweight concrete pavement. A total of 420 cubes (150mm) and 28 PKSC slabs 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. The PKSC elements were cured in water at laboratory temperature for 3, 7, 14, 21, 28, 56 and 91 days, and then subjected to nondestructive testing using the Pundit apparatus for determination of the respective ultrasonic wave velocity and elastic modulus at the various ages. The unconfined compressive strength of the PKSC was determined after the pulse velocity to establish a velocity-strength data set, which was employed for the development of statistical model. Results show that the UPV and the compressive strength of PKSC 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 over 90%. The application of the developed model as rigid pavement maintenance/deterioration planning and design was demonstrated in the paper.

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

1.0 Introduction

Traditionally, quality assurance of concrete construction and condition assessment for structural adequacy have been performed largely by visual inspection of the construction process and sampling by coring the concrete for performing standard tests on fresh and hardened specimens. This approach does not provide data on the in-place properties of concrete. Nondestructive 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. Coring to examine internal concrete conditions and obtain specimens for testing is a sort of introduction of weak spots to the whole structure. This approach limits what can be detected, while the cores only provide information at the core location and core holes needed to be repaired. The assessment of in-situ compression strength of a rigid pavement structure plays a key role in the evaluation of its safety, feasibility in terms of strength at the time of production and the knowledge of the main physical properties of the concrete and its state. Maintenance of rigid pavements is more effective if the deterioration rate of the strength could be monitored as the pavement is being affected by traffic and weather conditions.

NDT methods are 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 direct loading, access or testing that causes no structurally significant damage to the concrete element. Nondestructive test methods are significant in concrete construction for mechanical (strength) and other attributes to address (i) quality control of new construction; (ii) troubleshooting of problems with new construction; (iii) condition evaluation of older concrete for rehabilitation purposes; (iv) quality assurance of concrete repairs and (v) detection of flaws or discontinuities (Tomsett, 1980). Thus, the various NDT methods can be divided into two groups: (1) those whose main purpose is to estimate strength; and (2) those whose main purpose is to evaluate conditions other than strength, integrity evaluation. It is clear that the most reliable tests for strength are those that result in superficial local damage, and the term in-place tests are preferred for this group. The integrity tests, on the other hand, are nondestructive, 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).

Ultrasonic Pulse Velocity (UPV) is a nondestructive technique that involves measuring the speed of sound 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 damage. The technique is applicable where intrusive (destructive) testing is not desirable and can be applied to concrete, ceramics, stone and timber. The main strength of the method is in finding general changes in condition such as areas of weak concrete in a generally sound structure. Absolute measurements should be treated with caution. At the same time, the UPV technique is not always practicable in testing sound concrete. Especially, in investigation of crack depth, it is ineffective if the crack is water filled. The performance is also often poor in very rough surfaces. Sometimes good contact requires the use of a coupling gel between the transducers and the structure. This may be aesthetically unacceptable on some structures. 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. 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.

Some previous studies have concluded that, for concrete with a particular mix proportion, there is a good correlation between UPV and the compressive strength (Lawson *et al*l., 2011) and (Mahure *et al*., 2011) but no clear rules or explicit quantification on the effect of mix proportions on lightweight concrete or rigid pavement in particular.

Palm kernel shell (PKS) concrete, is an emerging vegetative lightweight concrete derived from recycling the biomass waste for pavement. The palm kernel shells were used as substitutes for natural/traditional coarse aggregates in rigid pavement construction to provide protection for the environment by conserving natural resources and the lands for mining and for landfills, will provide a new source of aggregate, thus extending the life of sand and gravel mines, extending the life of the regional landfill, and eliminating costs for processing the road waste materials at the landfill. Benefits include economic development opportunities and reduced pollution hazards, thus protecting human health (Yusuf and Jimoh, 2013).

It has been established that adopting lightweight concrete is quite feasible at certain desirable nominal mixes and water/cement ratios. Thus, this paper tries to adopt different mix proportions and water/cement ratios of PKS concrete as a medium to investigate the relationship between UPV and the compressive strength of hardened PKS concrete, and for eventual adoption of the model for lightweight rigid pavement maintenance planning and design at service.

This paper is aimed at indirectly determining in-situ, the mechanical properties of a PKS concrete through the direct characterization of a physical property at various mixes and water/cement ratios of hardened palm kernel shell concrete elements as a rigid pavement. The specific objectives, therefore, are to:

(a) Determine the Ultrasonic Pulse Velocity (UPV) of hardened PKS concrete cubes and slabs at varying nominal mixes and curing ages using the Pundit Apparatus,
(b) Determine the compressive strengths of the same PKS concrete specimens as used in (a),
(c) Develop the trend of the characteristic compressive strength with respect to the UPV of the PKS concrete at various ages and mixes,

(d) Develop the statistical relationship between the Ultrasonic Pulse Velocity (UPV) and compressive strength of PKS concrete, and hence the strength deterioration model as rigid pavement maintenance parameter.

2.0 Materials and Methods

Palm kernel shells, acquired from wastes of small scale palm oil milling centres were washed, dried and evaluated for suitability as coarse aggregate for production of nominal concrete mixes of 1:1:1, 1: 1: 2, 1:1½:3 and 1: 2: 4 for water/cement ratios of 0.3, 0.4, 0.5, 0.6 and 0.7. Laboratory tests were carried out on palm kernel shells obtained from three different collection points to determine preliminary or index characteristics of sieve analysis, specific gravity, water absorption capacity, moisture content, bulk density and impacts value. The physical properties of PKS to be considered as replacement for conventional aggregates in concrete works are shown in Table 1.

Table 1: Physical Properties of PKS

Property	Batch			Maximum	Minimum
	1	2	3		
Water absorption capacity (%)	13.7	13.9	13.6	13.9	13.6
Specific gravity	1.26	1.23	1.24	1.26	1.23
Bulk Density (g/cm^3)	0.64	0.68	0.65	0.68	0.64
Moisture content (%)	14.49	14.42	14.39	14.49	14.39
Impact value (%)	5.02	5.04	5.05	5.05	5.02

A total number of 420 cubes were produced and batched, cured and tested for compressive strength at 3, 7, 14, 21, 28, 56 and 91 days. Prior to crushing, the PKS concrete cubes were subjected to NDT with the Pundit Apparatus to determine respective transit time, velocity of the pulse and elastic modulus in accordance with the specification of the British standard (BS EN 12504-4, 2004).

Various forms of the UPV-compressive strength relationship of hardened PKS concrete were proposed for the concrete cubes, while the indirect derivation of the flexural strength of the slab was also accomplished using Microsoft Excel Software. The curve relationships between ultrasonic pulse velocity and compressive strength drawn for PKS concrete with the corresponding w/c ratios were plotted with linear, power, logarithm and polynomial trend lines. The logarithm and polynomial trend lines show stronger correlations, but the later was too exaggerative. The logarithm trend line, with R^2 in the range 0.949 – 0.993, was hence chosen for the relationships. 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: 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, 1983

3.0 Results and Discussion

3.1 Physical Properties of Palm Kernel Shell

Particle size distribution shows that the particles of palm kernel shells are poorly graded. The region between D_{10} and D_0 have grain sizes less than 5mm and these are not suitable for use as coarse aggregate, hence the need to sieve out the particles that fall within this region during mixing to avoid altering the properties of the other components in the mix. Figure 1 shows the expected range of particle size distribution for palm kernel shell. The specific gravity and bulk density of PKS were found to be 1.26 and 640kg/m^3 respectively. Average moisture content and water absorption capacity were 14.49% and 13.7% respectively. The PKS aggregate were needed to be presoaked before the mixing due to the relatively high values of these properties (moisture content and water absorption capacity). The impact value of PKS was found to be 5.02%. This value falls outside the range of 9-20% specified for normal aggregates. Therefore, palm kernel shell cannot be classified as a normal weight aggregate. However, the study shows that the environmental management and agricultural waste biomass recycle potentiality of the heaps of PKS was satisfied.

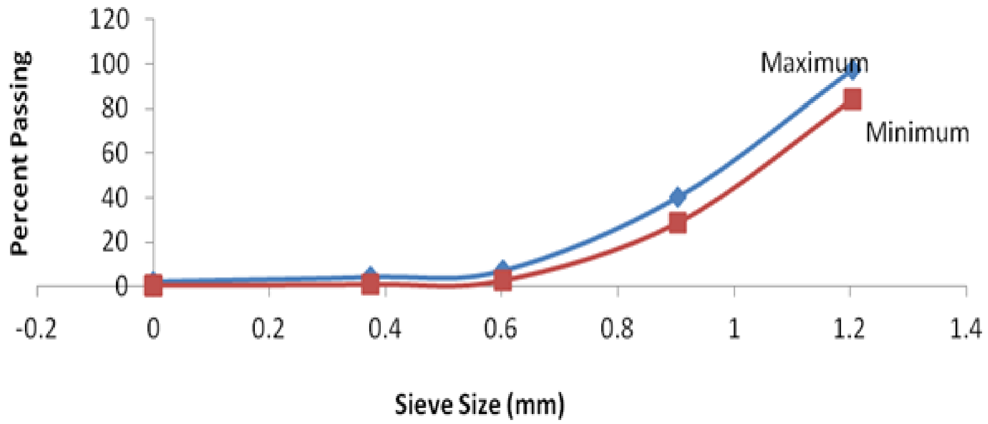

Figure 1: Particle Size Envelope for Palm Kernel Shell

3.2 Ultrasonic Pulse Velocity (UPV) and Compressive Strength of PKS Concrete

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 2, PKS concrete produced for all the mix proportions 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 fairly good only. This implies that PKSC at lower w/c ratios have high workability. The statistical analysis results of the UPV and compressive strength tests are presented in Figures 2- 5.

Results 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 concrete with lower w/c ratio. Also, for all the nominal mixes, 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 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 suggests that it is better to separately consider the effect of age and mix proportion on UPV and compressive strength relationship.

The curves of the relationship between ultrasonic pulse velocity and compressive strength drawn for PKS concrete with the corresponding w/c ratios yielded the equations presented in Table 3. For the five w/c ratios, the relationship between UPV and compressive strength of PKS concrete is good for the mix proportions with a very high coefficient of correlation, R^2 in the range 94.9% – 99.3%. This indicates relevance between data points and the regression curves.

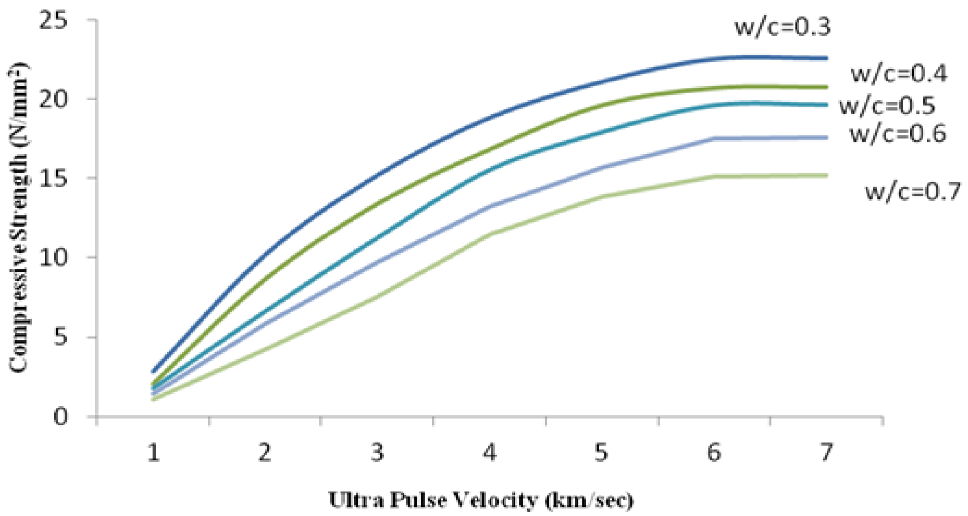

Figure 2: Graph of Compressive Strength Against UPV (1:1:1 Mix)

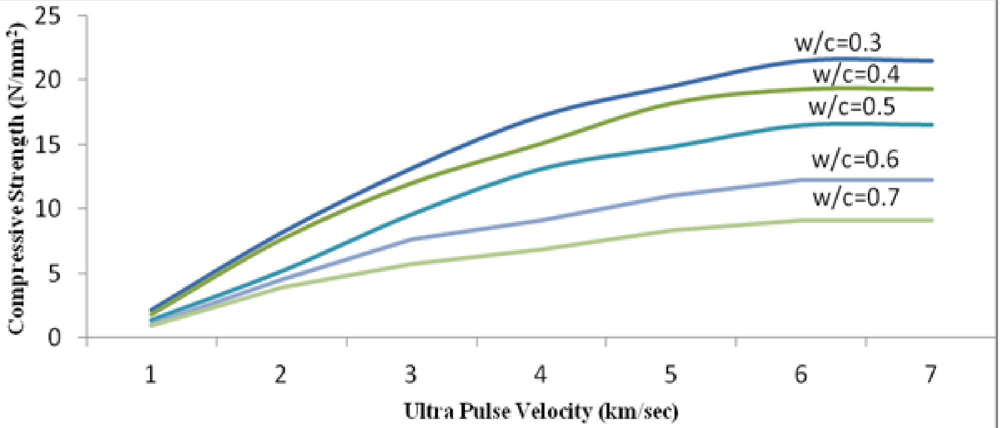

Figure 3: Graph of Compressive Strength Against UPV (1:1:2 Mix)

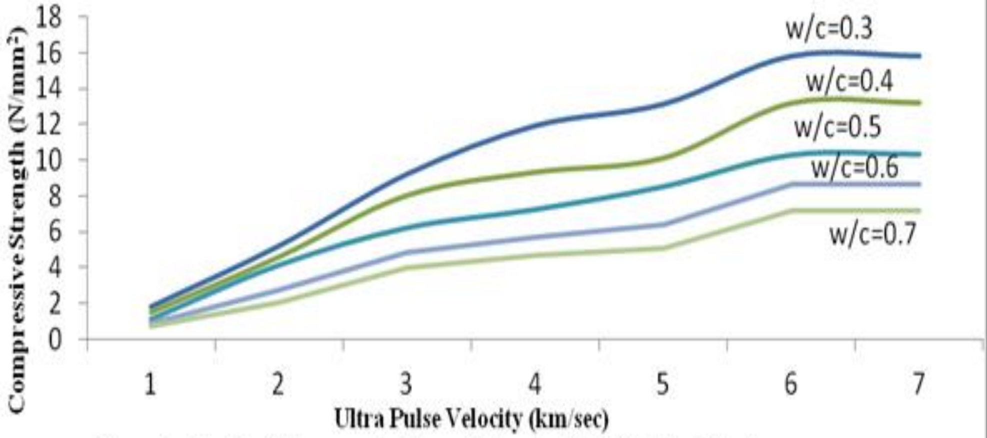

Figure 4: Graph of Compressive Strength Against UPV (1:1$^1/_2$:3 Mix)

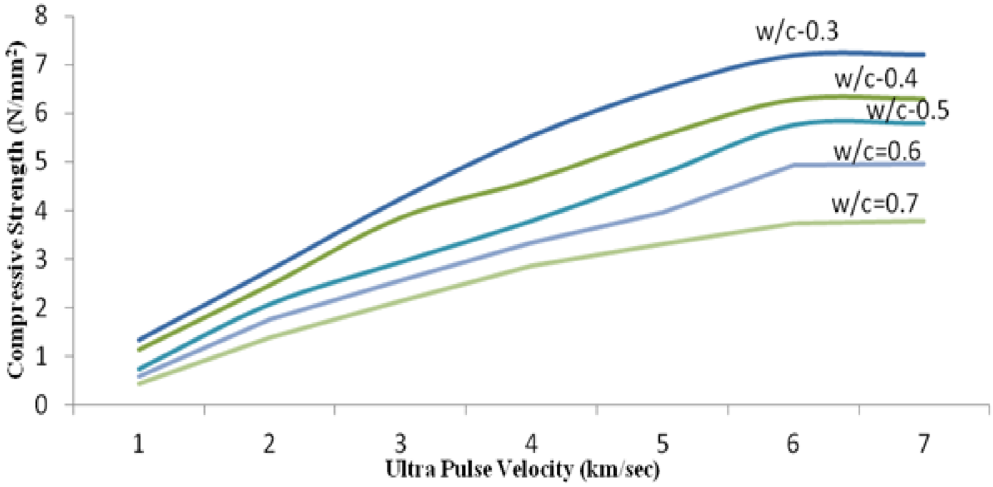

Figure 5: Graph of Compressive Strength Against UPV (1:2:4 Mix)

Table 3: Summary of Formulation and Regression at Different Mix Designs and Water Cement Ratio

Equation	R^2	Water cement ratio
1:1:1 Mix		
y = 10.740ln(x) + 3.112	98.9%	0.3
y = 10.260ln(x) + 2.097	98.8%	0.4
y = 10.010ln(x) + 1.005	98.2%	0.5
y = 8.974ln(x) + 0.637	98.4%	0.6
y = 8.046ln(x) + 0.009	96.6%	0.7
1:1:2 Mix		
y = 10.691ln(x) + 1.698	98.9%	0.3
y = 9.621ln(x) + 1.591	98.8%	0.4
y = 8.491ln(x) + 0.665	98.0%	0.5
y = 6.115ln(x) + 0.819	99.1%	0.6
y = 4.426ln(x) + 0.895	99.3%	0.7
$1:1^1/_2:3$ Mix		
y = 7.712ln(x) + 1.014	98.1%	0.3
y = 6.211ln(x) + 1.006	97.5%	0.4
y = 4.890ln(x) + 0.869	98.9%	0.5
y = 4.125ln(x) + 0.379	96.2%	0.6
y = 3.437ln(x) + 0.211	94.9%	0.7
1:2:4 Mix		
y = 3.296ln(x) + 0.943	97.8%	0.3
y = 2.847ln(x) + 0.833	97.8%	0.4
y = 2.742ln(x) + 0.345	96.5%.	0.5
y = 2.348ln(x) + 0.288	97.0%.	0.6
y = 1.836ln(x) + 0.273	98.7%	0.7

where, y = compressive strength (N/mm^2) and x = Ultrasonic Pulse Velocity (km/sec)

3.3 *Direct and Indirect UPV of PKS concrete Slab*

The results of the direct UPV (cube reading) and indirect UPV (slab reading) at w/c ratio of 0.5 for the considered nominal mixes are shown in Figure 6. (1) - (4) show the resulting equations relating direct UPV and indirect UPV of PKS concrete slab.

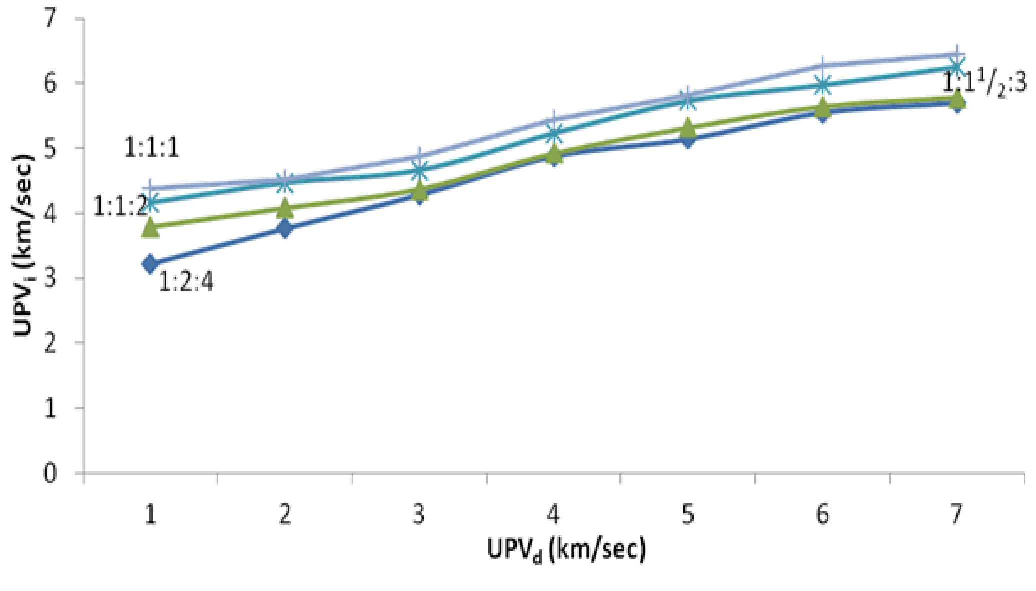

Figure 6: Indirect UPV of PKSC Slab versus Direct UPV at w/c = 0.5

$y = 2.731\ln(x) + 0.507$; $R^2 = 98.3\%$ ……………(1) for 1:2:4 Mix
$y = 2.769\ln(x) + 0.602$; $R^2 = 98.7\%$……………(2) for 1:1$^1/_2$:3 Mix
$y = 2.884\ln(x) + 0.863$; $R^2 = 96.9\%$……….…..(3) for 1:1:2 Mix
$y = 2.609\ln(x) + 1.452$; $R^2 = 98.7\%$..…………..(4) for 1:1:1 Mix

where: y = UPV$_i$ (indirect UPV) and x = UPV$_d$ (direct UPV)

4.0 Conclusions

This paper investigated the relationship between the Ultrasonic Pulse Velocity (UPV) and compressive strength of PKS concrete as well as the influence of the mix proportions, water/cement ratios and the age of concrete on the relationship between UPV and compressive strength. Based on the studies, the following conclusions were drawn:

(a) The PKS concrete produced were either good of fairly good.

(b) The compressive strength and UPV increased with advancement of age but decreased with increase in water/cement ratio.

(c) Both UPV and compressive strength of PKS concrete with low w/c ratio were higher than those with high w/c ratio at the same age mainly because of the denser structure of concrete with lower w/c ratio.

(d) The equations obtained from the simulation curves can be used to determine the compressive strengths of the concrete mix proportions.

(e) There was a unique relationship between compressive strength and UPV logarithm model of the form $\alpha_1 \ln(x) + c$, that can be used to describe the strength of PKSC at R^2 values of between 94.9% - 99.3%, which indicated relevance between data points and the regression curves.

(f) When the developed equations are used for concrete mixes with same concrete grades and w/c ratios but different materials from different projects, the predicted compressive strength of concrete would show more variation from the actual strength of the specimens.

5.0 Recommendations

(i) The recycle of PKS biomass waste material from palm oil farming helps preserve natural resources as a sustainable material and maintains ecological balances, and must be encouraged in order to effectively address the environmental pollution caused by indiscriminate dumping of PKS.

(ii) It is very difficult to monitor accurately using destructive approaches, especially when functionality is still desired. Thus, NDT characterization and effective pavement maintenance, which deserves the establishment of strength deterioration properties of the pavement layers as being transferred from repeated traffic loads.

(iii) The direct UPV-indirect UPV relationship determined can be used for rigid pavement assessment/maintenance purpose.

(iv) The actual property of concrete being displayed is the flexural strength for bending influence from traffic which necessitates the development of the compressive strength – UPV model combined with the indirect UPV –direct UPV models to be used in obtaining the prevailing flexural strength of a rigid pavement slab.

(v) 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, the UPV-strength relationship should be examined for development of fatigue and other performance-based characteristics of PKS concrete pavement.

(vi) The cost effective analysis of recycling biomass for pavement rehabilitation should be further explored in order to demonstrate the economic viability, energy conservation, efficiency in transportation facility in poor soil conditions and protection of the environment from health hazard.

References

BSI (1983) Method for Determination of Compressive Strength of Concrete Cubes, British Standards Institution, London, BS 1881: Part116.

BSI (2004) Testing Concrete: Determination of Ultrasonic Pulse Velocity, British Standard BS EN 12504-4.

Lawson, I., Danso, K.A., Odoi, H.C., Adjei, C.A., Quashie, F.K., Mumuni, I.I. and Ibrahim, I.S. (2011). *Nondestructive Evaluation of Concrete using Ultrasonic Pulse Velocity*. Research Journal of Applied Sciences, Engineering and Technology 3(6): 499-504. ISSN: 2040-7467.

Lin, Y., Lai, C.P. and Yen, T. (2003). *Prediction of Ultrasonic Pulse Velocity (UPV) in Concrete.* ACI Materials Journa 100 (1): 21-28.

Mahure, N.V., Vijh, G.K., Sharma, P., Sivakumar, N. and Ratnam, M. (2011). *Correlation between Pulse Velocity and Compressive Strength of Concrete.* International Journal of Earth Sciences and Engineering 4 (6): 871-874. ISSN 0974-5904.

Pundit, N. (1993). *Manual of Portable Ultrasonic Non Destructive Digital Indicating Tester.* C. N. S. Instruments, London 98 pp.

Tomsett, H.N. (1980). *The Practical Use of Ultrasonic Pulse Velocity Measurements in the Assessment of Concrete Quality*. Magazine of Concrete Research 32 (110): 7-16.

Yusuf, I.T. (2013). *A Study of Palm Kernel Shell Concrete Characteristics with Destructive and Nondestructive Methods.*Ph.D. Thesis, University of Ilorin, Ilorin, Nigeria, 240 pp.

Yusuf, I.T. and Jimoh, Y.A. (2013). *The Transfer Models of Compressive to Tensile, Flexural and Elastic Properties of Palm Kernel Shell Concrete.* International Journal of Engineering, IJE 11(2): 195-200, http://annals.fih.upt.ro