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LINEAR REGRESSION METHOD FOR PREDICTING COMPRESSIVE STRENGTH OF PALM KERNEL SHELL CONCRETE

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Abstract: The use of palm kernel shell in concrete is not a new development and a lot of research works have gone into it. There is however the need to investigate the wide range of values that have been reported by various researchers for the physical and mechanical properties of palm kernel shell and concrete produced from it. Nine different palm kernel shells were collected from different regions in Nigeria. They were all tested for their physical properties and in concrete for compressive strength at different mix proportions of 1:1:2, 1:1.5:3, 1:2:4. The results show the natural breeds having better physical properties as aggregates in concrete; thereby producing concretes of higher compressive strengths than the hybrids. Also the range of values reported for the physical properties and the compressive strength of the concrete of the natural breeds are quite close, closer than the range of values of the hybrids. This means that the natural breeds can safely be assumed to produce almost the same mechanical properties when used in concrete. A linear regression model was used to develop a relationship between all the physical properties and the measured compressive strength of concrete in which they are used as aggregate.
Keywords: Palm kernel shell, Concrete, Linear regression, Compressive strength, Dura specie

1. INTRODUCTION

Palm Kernel Shell is a waste product of the palm kernel from the oil palm tree. It is the hard material that encloses the kernels after palm oil extraction from oil palm fruits. Palm Kernel Shell (PKS) may vary in colour, size, shape and other physical properties because of the various species of oil palm tree available. Palm oil fruits are classified majorly into three species: dura, tenera and pisifera. Dura is a homozygous dominant with thick shells while pisifera is a homozygous recessive without shells, this implies that the pisifera specie doesn't bear fruit. Dura is cross-pollinated with pisifera to produce heterozygous tenera with an intermediate shell thickness surrounded by a ring of fibres in the mesocarp. Palm trees require stable climatic conditions, in particular with respect to light and moisture supply. Due to the desire for optimal growth and production, many new varieties of palm kernel have evolved through the process of hybridization, Olanipekun et al. (2006).

Nigeria has been reported as the third largest producer of palm oil in the world after Indonesia and Malaysia, Ndoke (2006). Nigeria's oil palm belt covers at least 26 states of the 36 states in Nigeria with 90% of them falling in the coaster region. The estimate for oil palm plantation in Nigeria ranges from 169,000 to 360,000 hectares. In 2008, Nigeria produced about 850,000 metric tonnes of palm oil, Ndoke (2006). Research has shown that in every one million ton of palm kernel produced, about 0.8 million tons of palm kernel shells are generated. It is expected that Nigeria will be able to produce up to 4.1million tonnes by 2020; this is from a predicted planted area of 2.5million hectares, Olanipekun et al. (2006).

The shape of PKS aggregate varies from angular, circular or irregular flat edge. It depends on the extraction method or breaking of the nut. The thickness of PKS varies between 0.15 and 8 mm depending on the species, Lo et al. (2004). Generally, the surface texture remains fairly smooth in both the concave and convex part of the shell.

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The broken edges show rough and spiky attire, Pappu et al.(2007). Particle size distribution of typical PKS has shown wide range of particles from 3 to 14 mm. Specific gravity of PKS varies but has never been higher than 2.0 as reported by various researchers as given in Table 1. Loose and compacted bulk densities of PKS aggregate varies in the range of 500-600 kg/m³ and 600-740kg/m³, respectively, Jumaat et al. (2009). The water absorption capacity of PKS varies from12.8% to 33%, abrasion is reported between 4.8% and 8.02% while the aggregate impact value ranges from 3.91% to 12.0%, as shown in Table 1. The wide range of values reported by different researchers on the physical property of PKS has sparked the suspicion that PKS may be different in some forms. The climate of the region in which they are grown, the method by which they are grown (they are purely bred for agricultural use, the use of fertilizers and/or hybridization to improve yield) are some of the factors that may contribute to the large variance in the values reported by researchers.

Table 1: Physical Properties of Palm Kernel Shells

Name of Authour (Year)	Specific gravity	Bulk density (kg/m³)	Water absorption (%)	Abrassion (%)	Aggregate Impact Value (%)
Mannan et al. (2002)	1.17	-	23.00	4.80	7.86
Teo et al. (2006)	1.17	500-600	33.00	4.90	7.51
Ndoke (2006)	1.62	-	14.00	-	4.50
Jumaat et al. (2009)	1.37	566	23.00	8.02	3.91
Mahmud et al. (2009)	1.27	-	24.00	-	3.91
Alengaram et al. (2010)	1.27	-	25.00	-	-
Gunasekaran et al. (2011)	1.17	-	23.00	-	-
Williams et al. (2014)	1.34	569	-	-	-
Oti et al. (2015)	-	-	12.80	-	12.00
Zaruna et al. (2016)	1.21	572	25.64	-	6.65

The compressive strength of Palm Kernel Shell Concrete (PKSC) has been reported to be as low as 3.83N/mm² by Alengaram et al. (2013) and as high as 44.9N/mm² by Shafigh et al. (2010). These values are influenced by the mixed proportions, the water-cement ratio and the addition of admixtures and other reinforcing materials such as steel fibres. The workability of PKSC as shown in Table 2 is mostly good for the various water-cement ratios and mix proportions tested. The supersaturated dry density of PKSC ranged from 1655-1960kg/m³. The splitting tensile strength, similar to the compressive strength was reported to vary widely between 1.9–11.15N/mm². Despite the many factors that may affect concrete strength, it is suspected from the wide range of results reported for the mechanical properties of palm kernel shell concrete that the PKS which is used in this various works may differ in their capability as aggregate in concrete.

Table 2: Fresh and 28days Mechanical Properties of PKS concrete.

Name of Authour (Year)	W/C ratio	Mix proportions	Slump (mm)	Compressive Strength (N/mm²)	Density (SSD) (kg/m³)	Splitting tensile strength (N/mm²)
Mannan et al. (2001)	0.53 0.6	1:2.73:0.85 1:1.28:0.55	0 Collapse	13.65 11.80	1655-1910	-
Mannan et al. (2002)	0.5 0.6	1:1.13:0.92 1:1.41:1.15	- Collapse	14.40 9.65	-	-
Olanipekun et al. (2006)	-	1:1:2	-	17.50	1700-1850	-
Teo et al. (2006)	0.41	1:1.12:0.8	13	22	1792	2.24
Teo et al. (2006)	0.38	1:1.66:0.6	60	28.00		-
Alengaram et al. (2010)	-	-	37.41	3.83	1850-1960	11.15
Mahmud et al. (2009)	0.35	1:1:0.8	160	26.98		1.9
Alengaram et al. (2013)	0.3-0.35	1:0.8:1 (5%FA;10%SF)	-	25.8-30.3	1880	-
Shafigh et al. (2010)	0.38	1:1.736:0.72 (Steel fibres)	-	39.34-44.95	-	2.83-5.55

Previous works on palm kernel shell from different researchers have reported varying values for the physical properties of palm kernel shell. This is a pointer to the fact that not all palm kernel shells are the same, and so their capabilities as coarse aggregate in concrete will not be the same. It is necessary to have a model that predicts the compressive strength of concrete from the physical properties of the aggregate. This will enable a user to determine if the type of palm kernel shell given is suitable for use and/or can produce an expected strength value if used in concrete. This paper employs the linear regression method to model experimental results of compressive strength of concrete made from different types of palm kernel shell.

2. EXPERIMENTAL PROCEDURES

For the purpose of this research, materials used include Ordinary Portland Cement, river sand as fine aggregate, crushed granite and palm kernel shell as coarse aggregate, and portable water. All particles passing the BS sieve aperture 2mm but retained on BS sieve 150µm were used as fine aggregate in the study. The granite and the palm kernel shells were sieved to conform to a medium to coarse range aggregate by using only particles passing through BS sieve size of 12mm but were retained on 2.36mm BS sieve size. Nine different samples of palm kernel shells were gotten from various regions in Nigeria. Five of them were local breeds while four were hybrids (crossed between two local breeds and /or genetically altered breeds). Since there are only two local breeds that bear fruit, it was decided that they be gotten from different regions to investigate any variations in their properties due to environment and climate. Two of the hybrids were macrocarya and pisifeni, while the other two are only known by their native names "atipa" and "okuso". The palm kernel shell was carefully washed to remove oil coating and other impurities adhering to it. It was then sieved into the required particle sizes. 150mm x 150mm concrete cubes were cast to test the compressive strength of each of the palm kernel shell type at a water-cement ratio of 0.55 and varying mix ratios of 1:2:4, 1:1.5:3, 1:1:2.

Figure 1 : PKS from naturally occurring oil palm trees

3. RESULTS AND DISCUSSION

— Types of Palm Kernel Shell

Table 3 below gives the results of the physical properties of the different types of PKS. Generally, the nine types of PKS have similar shape, which is oval, but some are round with angular edges as shown in Figures 1 and 2. They all have a smooth surface texture. Also, all the nine types of PKS have a dark brown colour with less visible strips but the mesocarya and hybrids-1(atipa) have whitish edges with very visible brown strips. The average maximum aggregate size for the local breeds was 12.4mm, while that for the hybrids was 7.4 mm. The average shell thickness for the local breeds was 3.1mm while that for the hybrids was 1.6 mm.

Figure 2: PKS from hybridized oil palm trees

— Physical Properties of Different Palm Kernel Shells

The specific gravity and the bulk density of the local PKS is higher than the hybrids by an average percentage of 12% and 19% respectively. The implication of this is that when concrete is batched by weight, more PKS will be contained in the batch when the hybrids are used than when the local breeds are used. This will lower the workability, density and most probably the strength of the concrete, because more PKS aggregate mean larger surface area in the fresh concrete matrix, thereby reducing the adequacy of the cement paste. The specific gravity of a material is a reflection of the porosity of the material, lower specific gravity is an indication of higher porosity. Aggregate porosity is an important factor that determines the durability of concrete.

Table 3: Physical Properties of Different Types of PKS (Local and Hybrids)

Properties	Local					Hybrids			
	Dura (Ekiti)	Dura (Ondo)	Dura (Benin)	Dura (Ebonyi)	Tenera (Ekiti)	Macrocarya form	Pisifeni form	Hybrid -1 (Atipa)	Hybrid -2 (Okuso)
Shape	oval	oval/ round	oval	oval/ round	oval/ round	round with angular edges	oval	oval/ round with angular edge	oval/ round with angular edges
Maximum aggregate size (mm)	12.5	12.5	12.0	14.0	11.0	10	6.0	8.0	5.5
Shell thickness (mm)	3.0	3.0	3.5	3.5	2.5	2.0	1.0	1.5	2.0
Specific gravity	1.29	1.25	1.27	1.38	1.22	1.19	1.15	1.17	1.11
Bulk density (kg/m^3)	694	712	659	740	628	607	562	584	555
Moisture Content (%)	6.1	6.0	6.4	6.2	6.2	6.4	7.0	6.8	6.6
Water Absorption (24hrs) (%)	19.0	21.0	22.0	22.0	24.0	24.0	26.0	26.0	24.0
Porosity (%)	20.0	22.0	20.0	20.0	24.0	24.0	26.0	26.0	28.0
Abrasion (%)	3.5	3.6	3.7	3.2	4.0	4.4	4.8	4.7	5.2
Aggregate Impact Value (%)	7.8	6.9	7.2	7.9	6.5	6.4	5.6	6.2	5.4
Aggregate Crushing Value (%)	7.2	6.9	6.8	7.4	6.4	5.4	5.2	5.4	4.8

The average moisture content, water absorption and porosity of the local breeds are 6.2, 21.6 and 21.2 while that of the hybrids are 6.7, 25.0 and 26 respectively. Typically, the higher the values of these properties of the aggregate, the less durable the concrete will be.

— **Compressive Strength of Palm Kernel Shell Concrete.**

Table 4 above shows the result of the compressive strength of the nine different palm kernel shells when used in concrete. It was observed that the local breeds have higher strength indices than the hybrids. The range of strength of the local breeds is close, the same with the hybrids but a wider margin is observed between the average of the two categories. This indicates that most local breed palm kernel shell will produce higher concrete strength than the hybrids.

Table 4: Compressive Strength of concrete made with the different types of Palm Kernel Shell

Mix Ratio	Age (Days)	Compressive Strength (N/mm^2)								
		Dura (Ekiti)	Dura (Ondo)	Dura (Benin)	Dura (Ebonyi)	Tenera (Ekiti)	Macrocarya form	Pisifeni form	Hybrid -1 (Atipa)	Hybrid -2 (Okuso)
1:2:4	7	4.88	2.14	3.39	5.20	3.21	4.47	1.92	1.22	2.04
	14	6.56	5.48	5.49	7.24	5.95	6.33	2.34	3.69	3.86
	28	8.97	8.23	8.17	9.17	7.68	7.96	3.47	4.03	5.25
1:1.5:3	7	6.77	5.96	6.97	5.82	4.56	3.25	2.30	3.53	4.74
	14	9.11	7.94	8.64	9.85	7.05	6.56	5.11	5.08	6.75
	28	11.52	10.01	11.56	12.89	10.74	9.86	7.12	8.60	8.91
1:1:2	7	9.84	8.24	9.68	9.80	8.61	5.92	3.79	4.19	5.31
	14	12.62	11.06	11.40	13.26	10.54	9.17	5.97	7.31	8.53
	28	15.40	14.88	15.22	16.48	14.73	13.39	10.15	12.31	12.75

Figures 3 and 4 present the result of compressive strength of the nine PKS types at varying curing age and mix ratio. It is seen that the naturally occurring shells have better performance as coarse aggregate in concrete, producing higher compressive strength than the shells from hybrid palm kernel. Considering the shells from naturally occurring palm kernel shell, it was observed that shells from the same region (south-west, Nigeria) have very close values in physical properties and eventually compressive strength of their concrete. The shell from Ebonyi state (south-east, Nigeria) has the best physical property and the highest compressive strength when used in concrete; this may mean that climatic conditions of the environment may have effect on the shell properties. Shells from hybrid palm kernels have shown themselves very poor as coarse aggregate in concrete. The best of them (macrocarya form) produced concrete of 13.39kN/m² in compressive strength at 28days, a value too low to be accepted for structural concrete. Since, the shells of the hybrid palm kernels are structurally weaker, they may be easier to burn and use as pozzolan.

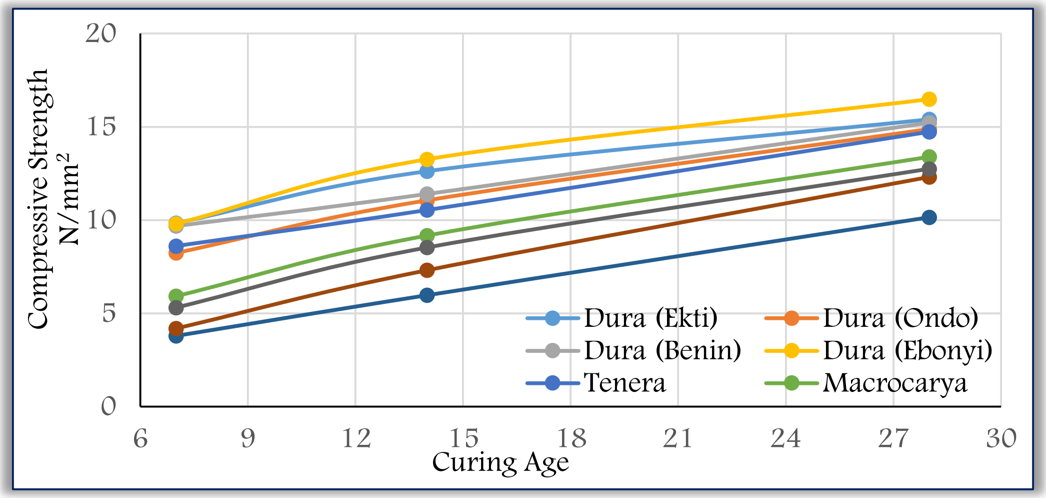

Figure 3: Compressive Strength – Curing Age Curve for Nine PKS Types

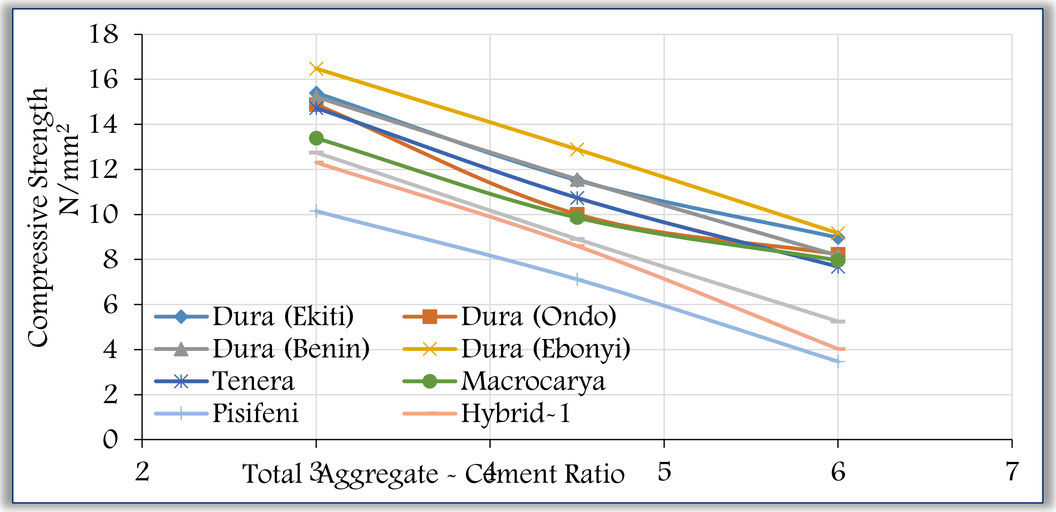

Figure 4: Compressive Strength – Mix Ratio Curve for Nine PKS Types

— Regression Model For Predicting Compressive Strength

This is a model which takes into account the physical properties of different palm kernel shells from different climes, with respect to different mix ratios, curing age of concrete and a constant water-cement ratio of 0.55. Ten different physical properties of palm kernel shell were tested and employed in this model. They include maximum aggregate size(mm), shell thickness (mm), specific gravity, bulk density (kg/m³), moisture content (%), water absorption (%), porosity (%), abrasion (%), aggregate impact value (%) and aggregate crushing value (%) as shown in Table 3.

The model is designed to use the results of the physical properties of the nine different PKS, mix ratio and curing age (as the independent variables) to forecast compressive strength when you have a given PKS tested for these various properties. The model is as expressed in equation (1), the regression statistics and estimates are given in Tables 5 and 6. From the regression statistics table, p-value of this model is $2.53e^{-27}$. This value is indicative of high accuracy of the model. The result of the computed compressive strength from the model is plotted against the measured compressive strength and is shown in Figure 3. The graph is plotted for visual comparison of corresponding points between the measured and computed compressive strength.

The significance of this model arises from the knowledge that different palm kernel shells have varying properties in which some are adequate as coarse aggregate in concrete while some others are too weak to sustain appreciable compressive strength. It is therefore very necessary to test any given palm kernel shell to be used in concrete and with the help of this model, forecast the likely compressive strength that may result when it is used in concrete.

Linear regression model:

y ~ [Linear formula with 105 terms in 13 predictors]

where: y = Compressive Strength (N/mm²)

x_1 = Total aggregate – Cement Ratio | x_2 = Curing Age (days)
x_3 = Shell thickness (mm) | x_4 = Specific gravity
x_5 = Abrasion (%) | x_6 = Aggregate Impact Value (%)
x_7 = Aggregate Crushing value | x_8 = Maximum Aggregate Size (mm)
x_9 = Bulk Density (kg/m³) | x_{10} = Moisture Content (%)
x_{11} = Water Absorption (%) | x_{12} = Porosity (%)

Table 5: Regression Statistics

Number of observations	81
Error degrees of freedom	46
Root Mean Squared Error	0.745
R-squared	0.975
Adjusted R-Squared	0.957
F-statistic vs. constant model	53.6
P-value	$2.53e^{-27}$

The regression model equation can be written as:

$$\mathbf{y} = 20.922\mathbf{x_1} - 0.045518\mathbf{x_1x_2} - 0.19971\mathbf{x_1x_3} - 28.96\mathbf{x_1x_4} - 4.0045\mathbf{x_1x_5} + 1.5312\mathbf{x_1x_6} - 2.0061\mathbf{x_1x_7} + 0.2431\mathbf{x_1x_8} + 0.011878\mathbf{x_1x_9} + 1.6458\mathbf{x_1x_{10}} + 0.15689\mathbf{x_1x_{11}} + 0.29791\mathbf{x_1x_{12}} - 0.10621\mathbf{x_2x_3} + 0.17875\mathbf{x_2x_5} + 0.099028\mathbf{x_2x_6} - 0.034625\mathbf{x_2x_7} + 0.048856\mathbf{x_2x_7} + 6.5878 \text{ x } 10^{-5}\,\mathbf{x_2x_9} - 0.20456\mathbf{x_2x_{10}} + 0.029581\mathbf{x_2x_{11}} - 0.0048252\mathbf{x_2x_{12}} - 0.02533\mathbf{x_3x_{11}} + 0.014546\mathbf{x_5x_9} + 0.014928\mathbf{x_6x_9} + 0.0673707\mathbf{x_6x_{12}} + 0.010428\mathbf{x_7x_9} + 0.0074344\mathbf{x_8x_9} - 0.022161\mathbf{x_9x_{10}} + 0.0021394\mathbf{x_9x_{11}} - 0.015656\mathbf{x_9x_{12}} + 0.18362\mathbf{x_1^2} - 0.0072695\mathbf{x_2^2} + 5.4289 \text{ x } 10^{-5}\mathbf{x_9^2} + 0.032427\mathbf{x_{11}^2} + 0.18022\mathbf{x_{12}^2} \quad (1)$$

Table 6: Regression Estimates

Variables	Coefficients	Standard Error	tStat
x_1	20.922	15.438	1.3552
x_1x_3	-0.045518	0.0077407	-5.8803
x_1x_4	-0.19971	0.81221	-0.24588
x_1x_5	-28.96	18.037	-1.6055
x_1x_6	-4.0045	2.1904	-1.8282
x_1x_7	1.5312	0.76779	1.9943
x_1x_8	-2.0061	1.1001	-1.8236
x_1x_9	0.2431	0.39787	0.61101
x_1x_{10}	0.011878	0.0066073	1.7977
x_1x_{11}	1.6458	1.3347	1.2331
x_1x_{12}	0.15689	0.13368	1.1736
x_1x_{13}	0.29791	0.19479	1.5293
x_3x_4	-0.10621	0.44108	-0.24079
x_3x_6	0.17875	0.15044	1.1882
x_3x_7	0.099028	0.088568	1.1181
x_3x_8	-0.034625	0.10069	-0.34387
x_3x_9	0.048856	0.13708	0.3564
x_3x_{10}	$6.5878e^{-05}$	0.0010997	0.059907
x_3x_{11}	-0.20456	0.15577	-1.3132
x_3x_{12}	0.029581	0.024407	1.212
x_3x_{13}	-0.0048252	0.015205	-0.31735
x_4x_{10}	-0.02533	0.028374	-0.89272
x_6x_{10}	0.014546	0.0095831	1.5179
x_7x_{10}	0.014928	0.042197	0.35376
x_7x_{13}	0.067307	0.97238	0.069219
x_8x_{10}	0.010428	0.010019	1..0409
x_9x_{10}	0.0074344	0.0083404	0.89137
$x_{10}x_{11}$	-0.022161	0.02385	-0.9292
$x_{10}x_{12}$	0.0021394	0.0056347	0.37969
$x_{10}x_{13}$	-0.015656	0.010838	-1.4446
x_1^2	0.18362	0.078036	2.353
x_3^2	-0.0072695	0.0022346	-3.2532
x_{10}^2	$5.4289e^{-05}$	0.00028537	0.19024
x_{12}^2	0.032427	0.093806	0.34568
x_{13}^2	0.18022	0.11864	1.519

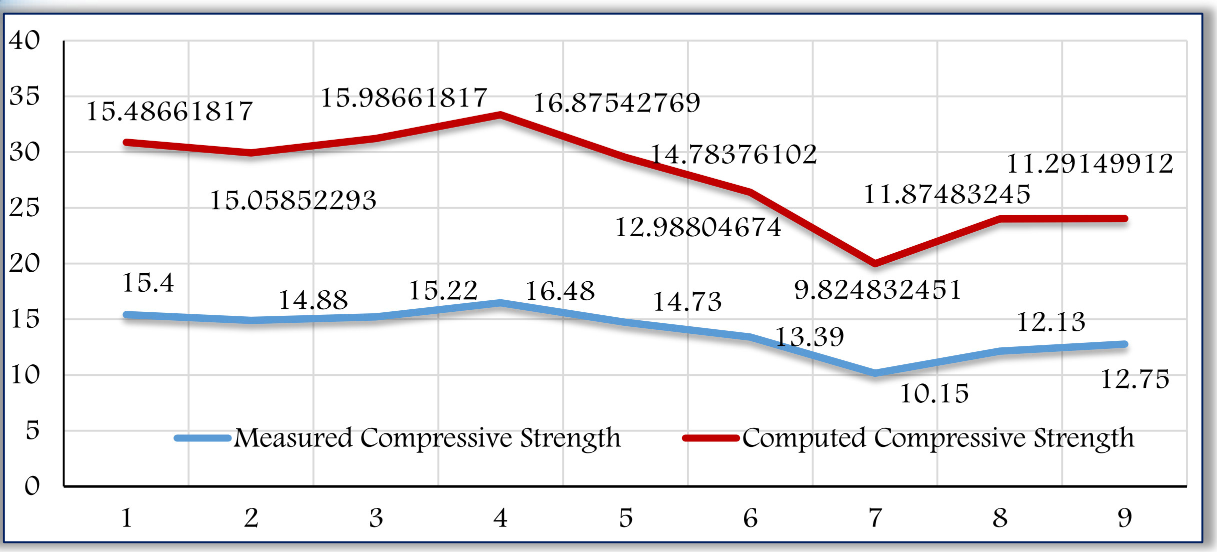

Figure 5: Comparison of the Measured Compressive Strength and Computed Compressive strength at 28-days curing age and Mix ratio of 1:1:2 for the nine shell samples tested.

4. CONCLUSION

Palm kernel shells have many species, most are widely unknown. These varying species differ widely in their physical properties and these depend largely on the breed. Mostly, the naturally occurring species produce harder and stronger shells which can be suitably adapted as aggregate in concrete.

Testing PKS for their physical properties and using the linear regression model to predict their concrete strength is a more accurate way to determine the adequacy of a given PKS as aggregate in concrete.

Further research into the role of climatic conditions on the physical properties of PKS will enhance the knowledge on how and where to source the best PKS for concrete purposes.

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