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Developed Prediction Models for Compressive Strength of Periwinkle Shell Concrete using Ultrasonic Pulse Velocity Test

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Abstract

Destructive test (DT) technique being the commonest means of strengths properties determination in concrete, it is characterized with numerous setbacks–time constrain and capital extensiveness of the equipment and energy demand. The study evaluated the relationship between strength and non-destructive parameters of re-vibrated periwinkle shell concrete (PSC). A nominal mix ratio 1: 2: 4 and 0.6 w.c were adopted to produce nine beams and seventy-two cubes of PSC; nine not vibrated, nine vibrated and fifty- four vibrated twice and threefold. The respective specimens were subjected to DT and non- destructive test technique. Effect of density, strength and non-destructive parameters with vibration mode and curing age were studied. The results have shown that optimum density, compressive strength, flexural strength, pulse velocity and stiffness constant are found to be 1873kg/m^3, 18.86N/mm^2, 5.74N/mm^2, 3.96km/s (Good-quality) and 29.54kN/mm^2 respectively at triple vibration mode of 60mins interval 60-60-60 at 28days age. Result obtained were analyzed using descriptive statistical tools and simple regression; where a linear relationship was noted between the strength and non-destructive parameters of the RPSC with stiffness constant showing higher correlation coefficient r=0.684 and was considered the best predictor of the strength property for the RPSC. Further studies should be carried out on the effect of segregation on RPSC, properties such as modulus of elasticity, thermal conductivity and sound insulation should be studied.

Keywords: Density, Non-destructive parameters, RPSC, Strengths relationship, Vibration.

Introduction

The demand for concrete in the construction sector resulted in over dependency on the natural stone deposits, which damaged the environment resulting to ecological imbalance (Alengaram *et al*, 2008). The use of waste products in concrete not only makes it economical, but also helps in reducing disposal problems (Shekhawat & Aggarwal, 2014).

The need to explore suitable and economical replacement materials to substitute the use of natural stone cannot be over emphasized. In developed countries, construction industries have identified many artificial and natural light weight aggregates that have replaced conventional aggregate with strength requirement not compromised. This has brought immense change in the development of high rise structures using light weight concrete (Balogun, 1993).

Possible materials in this regard are the various natural coarse aggregates such as sandstone, river gravel, and local stones that are plentifully available in different hinterland communities. Yet, that would still not solve the problem for coastal communities where these natural aggregates are scarcely found. Thus, some earlier researchers have pioneered investigation of the suitability of using periwinkle shell as coarse aggregate for making concrete in such coastal communities (Falade,1995). Periwinkle shell is waste material commonly found in coastal communities. They are relatively non-degradable, and, as such, constitute a great deal of environmental problems. These environmental problems could be solved by using the periwinkle shells as primary production materials, especially in concrete making. Stow (1969), Balogun (1993), and Ibearugbulem (2009) have classified the shells as lightweight coarse aggregates in accordance with ASTM specifications for concrete. Falade (1995) has also studied the shells as possible coarse aggregates and discovered that concrete made with them falls in the range of lightweight concrete.

Adewuyi and Adegoke (2008) carried out an exploratory study of periwinkle shells as coarse aggregates in concrete works and concluded that up to 42.5% replacement of crushed granite with periwinkle shells by weight still gives concrete with acceptable compressive strengths. Osarenmwinda and Awaro (2009) also investigated the potentials of periwinkle shell as coarse aggregate for concrete and found that concrete produced with different cement:sand:periwinkle mixes had compressive strength values ranging from 14.00 N/mm^2 to 25.67 N/mm^2 at 28 days of age. Agbede and Manasseh (2009) have specifically investigated the suitability of periwinkle shell as partial replacement for river gravel in concrete. They found that the 28-day density and compressive strength of periwinkle shell concrete were 1944 Kg/m^3 and 13.05 N/mm^2 respectively. Falade *et al* (2010) investigated the behaviour of lightweight concrete containing periwinkle shells at elevated temperature and found that the compressive strength decreased with increase in water/cement ratio and temperature. Kamang and Job (1997) tried to relate the strength of periwinkle shell concrete to its non-destructive parameters; Falade and Tella (2002) examined the structural performance of reinforced beams containing periwinkle shells as coarse aggregate. Insufficient vibration of concrete may result in defects, such as honey combing and voids leading to reduction in strength and performance.

Consolidation by vibration generally accomplishes two actions, first it 'slumps' in the concrete, removing a large portion of air that is entrapped when the concrete is deposited. Secondly, continued vibrations consolidate the concrete, removing most of the remaining entrapped air (Safawi et al., 2004).

Re-vibration is a process where the concrete is vibrated again after a specific time. In concrete construction, re-vibration can be achieved in two ways; first it occurs while placing successive layers of concrete, when vibration in the upper layers of fresh concrete are transmitted to the underlying layer which is partially hardened. Also, re-vibration may be done purposely to achieve certain advantages such as improvement in the bond between concrete and reinforcement (Shetty, 2005).

The importance of proper consolidation of the concrete matrix cannot be overemphasized, as the trapped air, according to MULTIQUIP [MQ] (2003) can be reduced in two ways; the use of more water and the consolidation of the concrete. Insufficient vibration of concrete may result in defects, such as honey combing and voids leading to reduction in strength, density and performance. Re-vibration was noted to yield an excellent strength and performance after the first and second hour of placement of concrete. Even though most of early civil engineers discourage the re-vibration phenomenon as it disturbs the concrete matrix (Ismail, n.d)

Kassem (1992) and falade (2002) noted the physical property of the periwinkle shell as porous and ducted which when not well compacted would jeopardize the performance and density of the shell concrete. Bureau of Reclamation (BOR) (1992) also noted re-vibration is beneficial rather than detrimental provided the concrete matrix is in the plastic form.

Destructive test techniques being the commonest means of determining the strength properties was noted to have numerous setbacks – time constrain and the capital intensive of the machines and energy demand (Luke, 2012; Duna & Omoniyi, 2014). Michael & John (2011) and Mehta & Moneiro (2005) affirmed that no good correlations were found between pulse velocity and strength property as it is affected by a number of variables. In line with the above problems and recommendation by Shekhawat & Aggarwal (2014), periwinkle shell concrete should be considered for possible solution throughout the study.

Materials and Methods

Materials

For this research work, the basic materials for concrete production were used. These materials are cement, fine aggregate, coarse aggregate (periwinkle shell) and water. The properties of all the materials mentioned above that facilitated the determination of the required quantities of concrete constituents in various mixes were tested in the laboratory and recorded. These properties are Bulk densities, Specific Gravities etc.

i. Coarse aggregates (periwinkle shell) from building materials market in Bayelsa, Bayelsa State, tested in accordance with BS 812: Part 103.1:1985 and ASTM C136- 92
ii. Fine aggregates (river sand) from 'Rafin makaranta' Bauchi local government area of Bauchi State, tested in accordance with BS 812: Part 103.1 :1985
iii. Ashaka brand of Ordinary Portland Cement (OPC)
iv. Water (portable drinking water)

Apparatus

i. Slump test (plumb, scoop, rule, tamping bar, cone mould, base plate)
ii. 100×100×100 mm steel cube moulds and 100×100×500mm steel beam mould.
iii. Electric vibrating table (BRIO VSB-15R)
iv. Digital electronic tensile/compression testing machine (TH-8201S)
v. Hydraulic flexural testing machine.
vi. Ultrasonic pulse velocity pundit (PL-200 UPV).

Methods

i. Preliminary test on materials

Sieve analysis, specific gravity and bulk density tests were carried out on fine aggregate and periwinkle shells and recorded in accordance with the relevant British standards

ii. Production, casting/re-vibration and curing of RPSC specimen

Concrete mix ratio of 1:2:4 and 0.6 water/cement (M15) were adopted for this study. Nine beams of size 100 × 100 × 500mm were produced for the flexural strength test at 7, 14 and 28days. Seventy-five periwinkle shell concrete cubes were produced, three cubes for trials and seventy-two cubes were subjected to destructive and non-destructive testing at 7, 14, and 28 days of curing. Nine of the Cubes produced were not vibrated, sixty-three were vibrated/re-vibrated (Once, double and threefold). The vibration was for a period of 60second at an interval of 0, 30, 60 and 90minutes respectively.

Results and Discussions

SPSS Statistic 21(simple regression) was used for analysis in this study. The impact of re-vibration on Periwinkle shell concrete was noted after a controlled laboratory tests on the constituents of the concrete. Preliminary test results on the periwinkle shell and river sand were summarized as shown in Table 1.

Table 1: Preliminary Test Results of Aggregates (Shells and River Sand)

DESCRIPTION	RIVER SAND	PERIWINKLE SHELLS
Specific Gravity	2.65	1.18
Loose Density Kg/m³	1507.00	519.40
Zone	Zone 1	-
Grading size mm	≤ 2.36	Avg. 20
Porosity (%)	-	13.5
Water Absorption	-	3.90
Colour	Brown	Dark gray /Brown
Texture	Granular	Rough

The Sieve analysis of aggregates (periwinkle shell and the river sand) compared with ASTM C-637 fell under 20mm single size and ≤ 2.36 respectively - indicating conformity with BS – Standard. The Specific gravity and Bulk density of shell was found to be 1.18 <<2.6, at the same time gave a better precision compared with the 1.88- 1.89 in 19th centuries and 1.21 (Falade, 2010) and 519.4 **kg/m³**<< 2000 **kg/m³** (BS EN 206-1,2000) which finally classified the shell as a light weight aggregate.

The effect of re-vibration mode in both the destructive and non- destructive tests were noted and recorded as shown in Tables 2,3,4 and 5 shown below.

Table 2: Variations in Density of Re-vibrated Shell Concrete with Curing Age kg/m³

Vibration Mode	Interval (Min)	Curing Age (Days)		
		7	14	28
Not Vibrated	**-**	**1760**	**1790**	**1820**
Vibrated Once	**30**	**1788**	**1830**	**1833**
Re-vibrated twice	**30-30**	**1862**	**1871**	**1871**
Re-vibrated twice	**60-60**	**1866**	**1871**	**1871**
Re-vibrated twice	**90-90**	**1867**	**1870**	**1873**
Re-vibrated thrice	**30-30-30**	**1867**	**1872**	**1872**
Re-vibrated thrice	**60-60-60**	**1868**	**1872**	**1873**
Re-vibrated thrice	**90-90-90**	**1868**	**1872**	**1873**

The result in table 2 indicated significant increase in densities with curing ages from zero vibration. To double re-vibration mode 60-60minutes interval and a steady increase with triple re-vibration mode with 30 and 60 minute with no change in the case of that of 90minute interval which indicated any further re-vibration will not enhance the density but might in turn jeopardize its mechanical properties.

Table 3: Compressive Strength of Re-vibrated Shell Concrete with Age N/mm²

Vibration Mode	Interval (Min)	Curing Age (Days)		
		7	14	28
Not Vibrated	-	9.40	11.60	15.20
Vibrated Once	30	11.96	12.53	15.70
Re-vibrated twice	30-30	12.53	13.80	15.97
Re-vibrated twice	60-60	13.50	17.63	17.88
Re-vibrated twice	90-90	12.13	16.20	16.89
Re-vibrated thrice	30-30-30	12.75	14.40	16.73
Re-vibrated thrice	60-60-60	13.85	18.02	18.86
Re-vibrated thrice	90-90-90	13.60	17.87	18.10

Table 4: Stiffness Constant of Re-vibrated Shell Concrete with Age kN/mm²

Vibration Mode	Interval (Min)	Curing Age (Days)		
		7	14	28
Not Vibrated	-	6.29	10.57	12.30
Vibrated Once	30	11.35	12.37	14.68
Re-vibrated twice	30-30	21.65	22.40	23.47
Re-vibrated twice	60-60	24.45	26.27	26.73
Re-vibrated twice	90-90	25.01	26.16	26.48
Re-vibrated thrice	30-30-30	24.47	26.85	25.91
Re-vibrated thrice	60-60-60	27.47	28.74	29.54
Re-vibrated thrice	90-90-90	26.52	28.17	28.94

Table 5: Pulse Velocity of Re-vibrated Shell Concrete with Age km/s

Vibration Mode	Interval (Min)	Curing Age (Days)		
		7	14	28
Not Vibrated	-	1.89	2.43	2.60
Vibrated Once	30	2.52	2.60	2.83
Re-vibrated twice	30-30	3.41	3.46	3.54
Re-vibrated twice	60-60	3.62	3.75	3.78
Re-vibrated twice	90-90	3.66	3.74	3.76
Re-vibrated thrice	30-30-30	3.62	3.79	3.72
Re-vibrated thrice	60-60-60	3.83	3.91	3.96
Re-vibrated thrice	90-90-90	3.77	3.88	3.93

The results from the Destructive and non-destructive tests in Tables 3,4 and 5 have shown a significant increase in compressive strength (F_{CU}), stiffness constant (EU) and pulse velocity (v) of the RPSC respectively with optimum result at triple re-vibration 60minutes intervals in all the parameters (F_{CU}, EU & v) indicting that the re-vibration mode indeed had a positive impact on the shell concrete with triple re-vibration mode 60minute interval being the maximum in this study.

SPSS Statistic 21 (Simple regression) analysis was used to analysed the outcomes shown in tables 6 and 7, the mathematical relationship established between the compressive strength, pulse velocity and stiffness constant was found to be linear as shown in figures 1 and 2 respectively which gave rise to model equations.

$F_{CU} = 2.96v + 4.77$ .... (1)

$F_{CU} = 0.25EU + 9.29$ .... (2)

The correlation coefficient **r (≈ 68%)** of the relationships was positive with the later indicating a higher value.

Table 6: Compressive strength visus Pulse velocity of RPSC

S/N	X	Y	XY	X^2	Y^2
1	**1.89**	**9.40**	**17.77**	**3.57**	**88.36**
2	**2.43**	**11.60**	**28.19**	**5.90**	**134.56**
3	**2.60**	**15.20**	**39.52**	**6.76**	**231.04**
4	**2.52**	**11.96**	**30.14**	**6.35**	**143.04**
5	**2.60**	**12.53**	**32.58**	**6.76**	**157.00**
6	**2.83**	**15.70**	**44.43**	**8.01**	**246.49**
7	**3.41**	**12.53**	**42.73**	**11.63**	**157.00**
8	**3.46**	**13.80**	**47.75**	**11.97**	**190.44**
9	**3.54**	**15.97**	**56.53**	**12.53**	**255.04**
10	**3.62**	**13.50**	**48.87**	**13.10**	**182.25**
11	**3.75**	**17.63**	**66.11**	**14.06**	**310.82**
12	**3.78**	**17.88**	**67.59**	**14.29**	**319.69**
13	**3.66**	**12.13**	**44.40**	**13.40**	**147.14**
14	**3.74**	**16.20**	**60.59**	**13.99**	**262.44**
15	**3.76**	**16.89**	**63.51**	**14.14**	**285.27**
16	**3.62**	**12.75**	**46.16**	**13.10**	**162.56**
17	**3.79**	**14.40**	**54.58**	**14.36**	**207.36**
18	**3.72**	**16.73**	**62.24**	**13.84**	**279.89**
19	**3.83**	**13.85**	**53.05**	**14.67**	**191.82**
20	**3.91**	**18.02**	**70.46**	**15.29**	**342.72**
21	**3.96**	**18.86**	**74.69**	**15.68**	**355.70**
22	**3.77**	**13.60**	**51.27**	**14.21**	**184.96**
23	**3.88**	**17.87**	**69.34**	**15.05**	**319.34**
24	**3.93**	**18.10**	**71.13**	**15.44**	**327.61**
∑	**82.00**	**357.10**	**1243.63**	**288.13**	**5464.53**
Note: Pulse velocity (v- Km/s)= X(independent variable)					
Compressive strength (F_{cu} – N/mm²)= Y(dependent variable)					

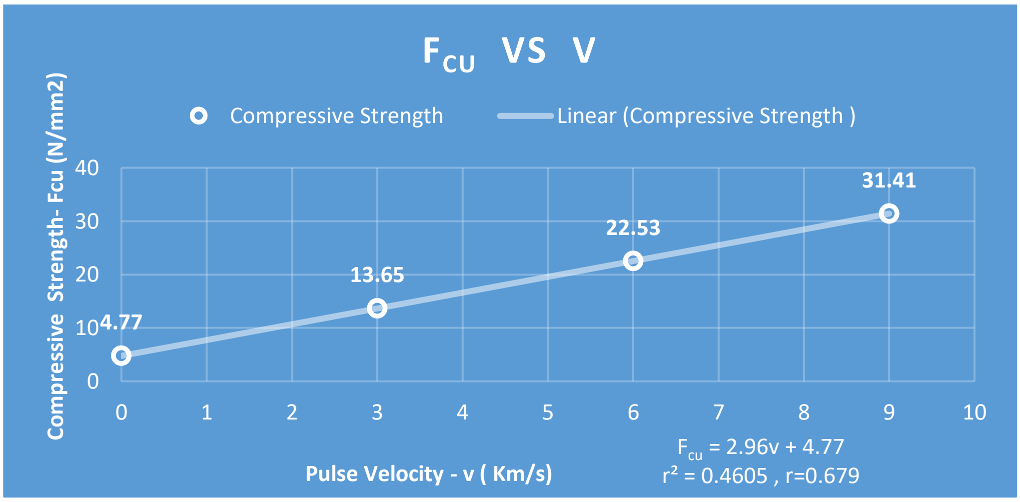

Figure 1. F_{CU} versus v of RPSC

Table 7: Compressive strength visus Stiffness constant of RPSC

S/N	X	Y	XY	X^2	Y^2
1	6.29	9.40	59.13	39.56	88.36
2	10.57	11.60	122.61	111.72	134.56
3	12.30	15.20	186.96	151.29	231.04
4	11.35	11.96	135.75	128.82	143.04
5	12.37	12.53	155.00	153.02	157.00
6	14.68	15.70	230.48	215.50	246.49
7	21.65	12.53	271.28	468.72	157.00
8	22.40	13.80	309.12	501.76	190.44
9	23.47	15.97	374.82	550.84	255.04
10	24.45	13.50	330.08	597.80	182.25
11	26.27	17.63	463.14	690.11	310.82
12	26.73	17.88	477.93	714.49	319.69
13	25.01	12.13	303.37	625.50	147.14
14	26.16	16.20	423.79	684.35	262.44
15	26.48	16.89	447.25	701.19	285.27
16	24.47	12.75	311.99	598.78	162.56
17	26.85	14.40	386.64	720.92	207.36
18	25.91	16.73	433.47	671.33	279.89
19	27.28	13.85	377.83	744.20	191.82
20	28.74	18.02	517.89	825.99	342.72
21	29.54	18.86	557.12	872.61	355.70
22	26.52	13.60	360.67	703.31	184.96
23	28.17	17.87	503.40	793.55	319.34
24	28.94	18.10	523.81	837.52	327.61
∑	536.60	357.10	8263.53	13102.34	5464.53
Stiffness constant (EU- KN/mm²)= X(independent variable)					
Compressive strength (F_{cu} – N/mm²)= Y(dependent variable)					

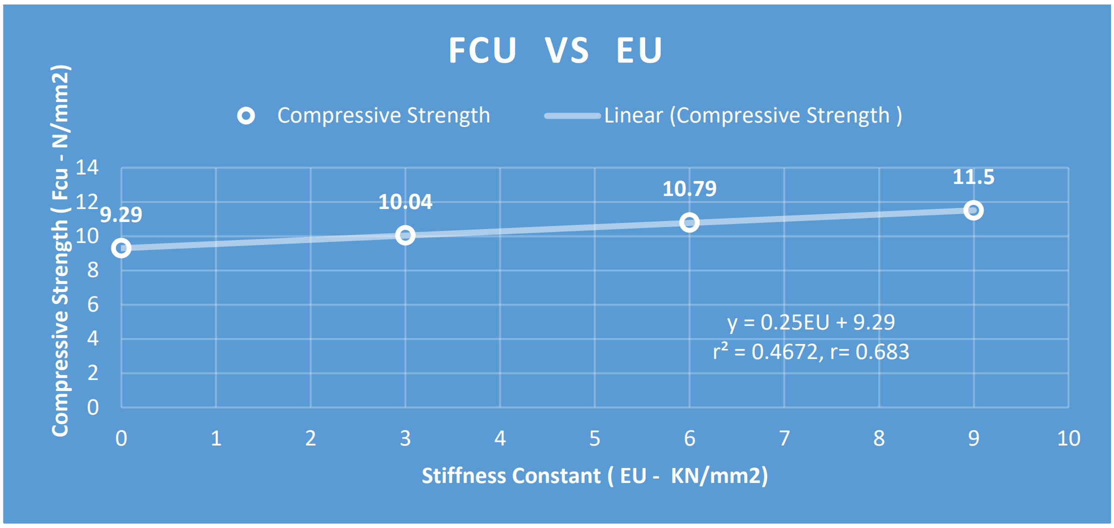

FIGURE 2. F_{CU} VERSUS EU OF RPSC

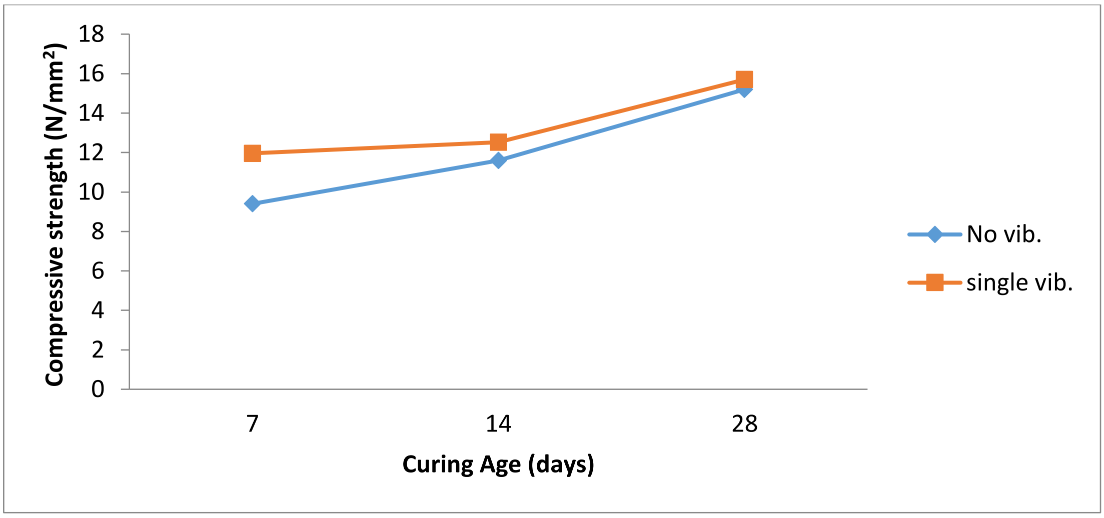

FIGURE 3: F_{CU} VS CURING AGE (NIL & SINGLE)

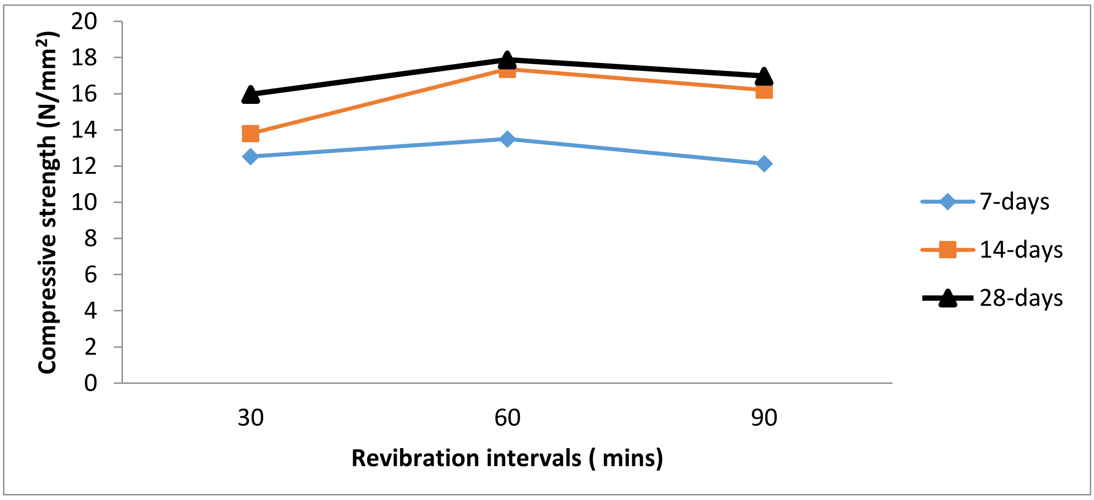

FIGURE 4: F_{CU} VS RE-VIBRATION TIME INTERVAL (DOUBLE)

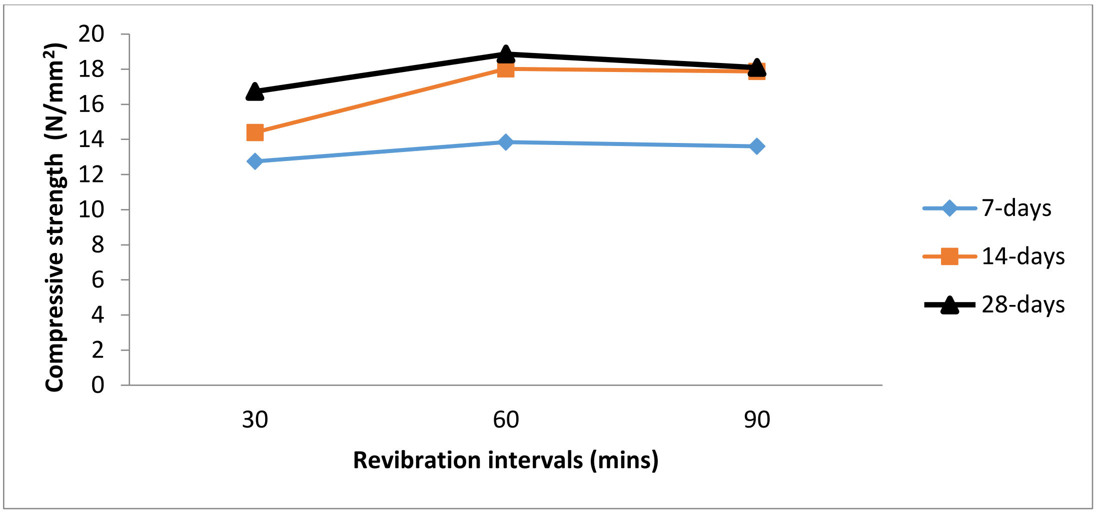

FIGURE 5: F_{CU} VS REVIBRATION TIME INTERVAL (THRIFOLD)

Figures 3,4 and 5 are graphs plotted $\mathbf{F_{CU}}$ against re-vibration time intervals in relation to the curing ages of 7,14 and 28 days. The graphs also confirmed a significant increase in strength with number of re-vibration mode alongside the time interval with optimum strength indicated in figure 5 at 60minutes, 28days curing age.

Conclusions

The physical properties of the Periwinkle shell indeed qualified it to be a good light weight aggregate.

Trifold vibration mode 60min interval yielded optimum strengths, density and other properties of the RPSC M15. The relationship between the compressive strength and non- destructive parameters was found to be linear with stiffness constant **EU** showing slightly higher correlation coefficient (r = 0.684) than the pulse velocity **v** (r = 0.679) and was considered the best predictor of the strength property of the RPSC.

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Appendices

water

River Sand

Periwinkle shell

Ashaka cement

PLATE I: Raw materials used for the production of Periwinkle shell concrete (PSC)

PLATE II: Ultrasonic pulse velocity pundit (PL-200 UPV) and Tensile/compression testing machine (TH-8201S)

PLATE III: Electric vibrating table (BRIO VSB-15R) and Slump test

PLATE IV: 100 x 100 x 100mm cube molds and cubes specimen