COMPRESSIVE STRENGTH AND STATIC MODULUS OF ELASTICITY OF PERIWINKLE SHELL ASH BLENDED CEMENT CONCRETE

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ABSTRACT

The study examined the effect of periwinkle shell ash as supplementary cementitious material on the compressive strength and static modulus of elasticity of concrete with a view to comparing it's established relation with an existing model. The shells were calcined at a temperature of 800^{o}C. Specimens were prepared from a mix of designed strength 25N/mm^2. The replacement of cement with periwinkle shell ash (PSA) was from 0 to 40% by volume. A total of 90 cubical and cylindrical specimens each were cast and tested for 7 to 180 hydration periods. The results revealed that the PSA met the minimum chemical and physical requirements for class C Pozzolans. The compressive strength and static modulus of elasticity were observed to increase with increased in curing age but decreased with increasing PSA content. The design strength was attained with 10%PSA at standard age of 28 days. In all the curing ages, 0% PSA content recorded higher value than the blended cement concrete. the statistical analysis indicated that the percentage PSA replacement and the curing age have significant effect on the properties of the concrete at 95% confidence level. The relation between compressive strength and static modulus of elasticity fitted into existing model for normal-weight concrete.

Keywords: *Blended cement; Compressive strength; Periwinkle shell ash; Static modulus of elasticity*

1.0 INTRODUCTION

Modern pozzolanic cements are mix of natural or artificial Pozzolans and Portland cement. in addition to under water use, the pozzolan's high alkalinity makes it especially resistant to common forms of corrosion from sulphates [1]. Once fully hardened, the Portland cement blended with Pozzolans may be stronger than Portland cement due to its lower porosity, which also makes it more resistance to water absorption and spalling [2]. The uses of Pozzolans in concrete have been reported to mitigate the effect of sulphates and alkali – silica reaction, especially deleterious in concrete structures, by the development of a faster pozzolanic reaction [2].

The commonly used Pozzolans have been fly ash, silica fume, metakaolin, and blast furnace slag. Recently, efforts have also been made in the use of agricultural wastes as Pozzolans. Some of the Pozzolans of agricultural origin include sawdust ash [3], rice husk ash [4], corn cob ash [5-6], millet husk ash [7], palm oil fuel ash [8] and periwinkle shell ash [9-10].

The processing and utilization of periwinkle shell, which is cheap and abundantly available in most riverine communities of Niger delta region of Nigeria, in construction; apart from improving certain properties of concrete will as well protect the environment from pollution, and thereby contributing to resource conservation and environmental sustainability. Periwinkle Shell Ash is obtained by burning periwinkle shell which is the by-product of Periwinkle.

Periwinkle is described as any small greenish marine snail from the class of gastropod, the largest of the seven classes in the phylum mollusc [11]. They are herbivorous and found on rocks, stones or pilings between high and low tide marks; on mud-flats as well as on prop roots of mangrove trees and in fresh and salt water.

The common periwinkle (*Littorina littorea*) is one of the most abundant marine gastropods in the North Atlantic, but *Tympanotonus fuscatus* is commonly found in the estuaries and mangrove swamp forest of the Niger Delta of the South – South region of Nigeria [12]. A study [13] indicated that there are about 40.3 tonnes of periwinkle per year being harvested from 35 mangrove communities of Delta and Rivers states of Nigeria. A survey, by the researchers, of some riverside communities of Itu, Oron, Issiet, Okobo, Ikot Offiong, and Uta-ewea in Akwa Ibom state showed abundance of periwinkle in these communities. Massive periwinkle harvesting is also reported from some communities in Bayelsa, Cross River and Edo states of Nigeria [14-15]. When the periwinkle is big enough, the edible part is removed after boiling in water, and the shell dumped as waste. The continuous dumping of the shells [16] has resulted in great heaps constituting menace especially in villages in Rivers and Akwa Ibom states of Nigeria. Therefore this work examined the possibility of processing and utilization of the shell ash with a view to establishing its performance on the compressive strength and static modulus of elasticity when used as supplementary cementitious material in concrete production.

2.0 LITERATURE REVIEW

The compressive strength of concrete is considered one of the most important properties in the hardened state. Neville [17] opined that for the purpose of structural design, the compressive strength is the criterion of quality. However, when the deformations of the different structural elements of a structure have to be calculated, the determination of elastic properties of concrete is also very important [18]. It is also stated [19] that the modulus of elasticity of concrete is one of the most important mechanical properties of concrete since it impacts the serviceability and the structural performance of reinforced concrete structures. The elastic characteristics of a material are a measure of its stiffness. Knowledge of the modulus of elasticity is essential in the determination of deformation, deflection or stresses under short-term and long-term loading [20].
Pozzolanic materials which are either by-products from industry or wastes from agricultural activities had gained wider acceptability in improving properties of concrete and other cement products. Pozzolans have been used to improve the compressive strength performance of concrete as it can continue to react for many years and thereby making the concrete harder and more durable during its service life. Pozzolans as partial replacement of cement in concrete have been reported to have slow strength gain especially during the early ages, a situation that makes it usage not feasible where early strength is of paramount importance. The slow contribution of pozzolanic materials to strength development of concrete have been attributed to the pozzolanic reaction at room temperature which is slow; and therefore a long curing period is needed to observe its positive effects [21]. Available studies on the use of periwinkle shell ash as pozzolanic material and its effects on concrete compressive strength only considered curing age up to 28 days, and noted that the compressive strength of the concrete increases with curing age but decreases as the PSA content increases, and that PSA replacement of OPC up to 40% was found adequate for the production of medium strengths concrete [9-10].

Also the uses of Pozzolans as replacement of cement have also been reported to affect the static modulus of elasticity of concrete [22-24]. For instance the use of rice husk ash in concrete as reported [22] contributed to higher value in static modulus of elasticity when compared to the reference concrete. on the other hand, Wainwright and Tolloczko [23] reported that the replacement of Portland cement by slag in concrete seems to decrease the modulus of elasticity for a compressive strength below $55N/mm^2$ and slightly increase it, by about 10%, for compressive strength greater than $60N/mm^2$. Modulus of elasticity is reported to be low at early ages and high at later ages for fly ash-blended cement concrete [24]. Therefore, the study examined the performance of PSA on the compressive strength and static modulus of elasticity when used as supplementary cementitious material in concrete.

3.0 METHODOLOGY

3.1 MATERIALS

Ordinary Portland cement (OPC) produced by Calcemco (Nig.) Ltd. to the specification of NIS 444 - 1 [25] and branded as 'UNICEM' was used. The periwinkle shells for the production of periwinkle shell ash (PSA) were collected from one of the dumpsites in Otto market in Ikot Ekpene of Nigeria. The shells were washed off unwanted dirt and dried in an open space before calcined in a gas furnace and stopped as soon as the temperature reaches 800^0C. The ash was ground and sieved with 45μm size. The specific gravities for cement and PSA were 3.13 and 2.13 respectively. Chemical and physical properties of the cementitious materials are shown in Table 1. The Strength activity index with Portland cement, which expresses the compressive strength of mortar cube when Portland cement is blended with 20% pozzolanic material by weight, was calculated as the percentage ratio (A/B) ×100 where A = average compressive strength of test mixture cubes, N/mm^2, and B = average compressive strength of control mix cubes, N/mm^2.

Fine aggregate used were river-bed sand passing 4.75mm sieve and falls within zone 2 with a fineness modulus of 3.28; while the coarse aggregate were crushed granite of maximum size 20mm with specific gravity of 2.65. The sieve analyses conducted on the aggregates are presented in Tables 2 and 3.

Table 1: chemical and physical properties of PSA

Chemical composition												
Elemental Oxide (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	P_2O	Mn_2O_3	TiO_2	LOI
	33.84	10.20	6.02	40.84	0.48	0.26	0.14	0.24	0.01	0.00	0.03	7.60

Physical properties						
% retained on 45μm sieve	Strength activity index with Portland cement (% of control)		Water used (% of control)	Soundness (mm)	Moisture content (%)	Specific gravity
	7 days	14 days				
21.00	78.17	79.12	104	1.00	1.50	2.13

Table 2: Sieve analysis of the sand

Sieve size (mm)	Weight of material retained (g)		Cumulative percentage of material retained	Percentage passing
	(g)	(%)		
4.75	0.0	0.0	0.0	100.0
2.36	19.0	3.82	3.82	96.18
1.18	80.5	16.16	19.98	80.02
0.600	185.0	37.15	57.13	42.87
0.300	173.0	34.74	91.87	8.13
0.150	35.0	7.03	98.90	1.10
Pan	5.5	1.10	100	0.00
Total	498.0	100	-	-

Fineness Modulus = (100 + 96.18 + 80.02 + 42.87 + 8.13 + 1.10)/100 = 3.28

Table 3: Sieve analysis of coarse aggregate

Sieve size (mm)	Weight of material retained (g)		Cumulative percentage of material retained	Percentage passing
	(g)	(%)		
20	0.0	0.0	0.0	100.0
14	240.0	16.00	16.00	84.0
9.5	496.0	33.09	49.09	50.91
4.75	670.6	44.74	93.83	6.17
2.36	80	5.34	99.17	0.83
Pan	12.4	0.83	100	0.00
Total	1499.0	100.0	-	-

2.2 PROPORTION AND MIXING OF CONSTITUENTS

The mix proportion involved the British mix-design method (Department of Environment- DOE) approach for 28-day characteristics strength of 25N/mm^2 for Normal-weight concrete (i.e. control: 0% PSA and 100% OPC). A water/cement ratio requirement based on the strength of the Mix design for the requisite workability (slump: 10-30mm) was adhered. Partial replacement of OPC by PSA of various percentages of 0, 10, 20, 30 and 40 by volume as was dictated by their differences in specific gravities was adopted. The ingredients, that is, cement, PSA, aggregates and water, were manually mixed. The cement and PSA blended was spread on already measured sand, and the three ingredients mixed thoroughly before the coarse aggregate and water were added. Slump and compacting factor tests were carried out to determine the workability of each mix. The mix proportions of the mixes are presented in Table 4

Table 4: Mix proportions (m^3) of PSA blended cement concrete

PSA content (%)	Cementitious Binder (kg)		Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	
	OPC	PSA			5-10mm	10-20mm
0	19.18	-	11.05	42.92	27.46	55.74
10	17.26	1.30	10.97	42.92	27.46	55.74
20	15.34	2.60	10.80	42.92	27.46	55.74
30	13.43	3.90	10.70	42.92	27.46	55.74
40	11.51	5.20	10.63	42.92	27.46	55.74

3.3 SPECIMENS PREPARATION

Two types of specimens were prepared: 150mm cubes and 150mm by 300mm cylinders. The casting was done as specified by BS EN 12390 part 3 [26]. As soon as the specimens were cast, they were stored in a place free from vibration and not exposed to direct sunlight or other sources of heat and covered with wet wooden bags. The specimens were de-moulded after 24 hours, placed in water curing tanks kept at temperature of 29±1^{o}C until the testing age

3.4 TESTING

The concrete specimens were tested for cube compressive strength and static modulus of elasticity [27-28]. The cylindrical specimens were placed inside compressometer fixed with dial gauges, and the whole assembly mounted on a compression testing machine. The tests were done for six curing levels of 7, 14, 28, 90, 120 and 180 days for each of the five levels of PSA replacement of cement of 0, 10, 20, 30 and 40% respectively. At least three specimens were tested at each age for compressive strength and static modulus of elasticity to compute the average. A total of 90 cubes and cylinders each were used to determine the effect of PSA on the compressive strength and static modulus of elasticity for the various curing age. The tests were carried out using compression testing machine of 2000KN capacity.

4.0 RESULTS AND DISCUSSIONS

4.1 EFFECT OF PSA ON WORKABILITY

The results of the slump and compacting factor values are shown in Table 5. To attain the same workability level of 10-30mm in the mixes containing PSA with that of conventional concrete (i.e. control), higher water content was required. This is reflected in the gradual increased in the water cementitious material ratio with a corresponding increased in the amount of water over control as the PSA percentage content increases. This higher water requirement in mixes containing PSA could be attributed to the high fineness of PSA which meant a greater specific surface to be wetted and lubricated. This agreed with the earlier finding of the effect of rice husk ash in concrete [4]. The values of the slump range between 25 and 29mm which is within the standard required values of 10 – 30mm based on the mix design for concrete of low workability, while that of compacting factor value is between 0.83 and 0.87 and satisfied the range of 0.85 to 0.90 of compacting factor value for the same concrete [17].

Table 5: Slump and Compacting factor values for PSA blended cement concrete

PSA content (%)	Slump (mm)	Compacting factor	Actual water/cementitious material ratio	Amount of water over control (%)
0	29	0.86	0.58	-
10	28	0.87	0.59	101.72
20	28	0.85	0.60	103.45
30	26	0.84	0.62	106.29
40	25	0.83	0.64	110.34

4.2 COMPRESSIVE STRENGTH

The compressive strength development at various ages is given in Table 6. The compressive strength generally increased with curing age and decreased with increased content of periwinkle shell ash. The results at 7 days show that in all the replacement levels the percentage attainment of the design strength range between 77.63% and 65.66% with 0%PSA content (i.e. control) having 77.63% and 40%PSA content having the least value of 65.66%. These values satisfied the requirement of normal-weight concrete strength development which is stipulated to be between 50-66% [29-30].

At 14 days, the compressive strength of the control mix is 27.11N/mm^2, representing 108.44% of the design strength, closely followed by 10%PSA which had 85.33% of the design strength; while 10, 20 and 30%PSA replacement had compressive strength of 18.04, 17.01 and 16.30N/mm^2 which is also 72.18, 68.04 and 65.19% of the design strength respectively. The strength development at 14 days satisfied the 60-75% of the design strength as stipulated [29].

The compressive strength of 0% and 10%PSA content at 28 days hydration period were 28N/mm^2 and 25.56N/mm^2 respectively which met the desired design strength of 25N/mm^2, while that of 20, 30 and 40%PSA content were 24.15, 20.71 and 15.91N/mm^2 respectively. These are comparable with the values obtained by other researchers [9-10]. The strength development for control mix (i.e. 0%PSA) is faster up to 28 days hydration period whereas mixes containing PSA is slower. This portray the fact that the pozzolanic reaction depends on the released of calcium hydroxide from cement hydration.

The results at 90 days indicated that in all the mixes there is continuous increase in the strength, showing that there is both hydration and pozzolanic reactions particularly with 10%PSA having a higher rate of development than the control. At 120 days, 10%PSA recorded compressive strength of 28.53N/mm^2 representing an increase of 6.89% of the strength at 90 days, while the control mix recorded strength of 29.92N/mm^2 which represents an increase of 3.26% of the strength of 90 days. Other mixes had little or no increase in the design strength beyond 90 days. The 20%PSA had strength of 24.89N/mm^2 representing 99.56% (approximately 100%) of the design strength. It means that where later age strength is required at 120 days hydration period, 20% replacement of cement with PSA is adequate.

A further increased in the rate of strength development was observed with 10%PSA at 180 days as it attained strength of 29.04N/mm^2 which is not significantly different from the control which had strength of 30.15N/mm^2. The continuous increased in the 10%PSA can be attributed to the fact that the quantity of calcium hydroxide liberated from cement hydration is adequate to be consumed by the pozzolanic reaction.

Table 6: Compressive strength of PSA blended cement concrete specimens at all curing ages

Curing Age (Days)	PSA (%)	Compressive strength (N/mm^2)				Attainment of Design strength (%)
		Sample 1	Sample 2	Sample 3	Mean	
7	0	19.56	19.38	19.38	19.41	77.63
	10	18.22	18.67	18.67	18.52	74.07
	20	17.56	17.78	18.22	17.85	71.41
	30	17.33	17.69	17.51	17.51	70.04
	40	16.44	16.27	16.53	16.41	65.66
14	0	27.11	26.67	27.56	27.11	108.44
	10	21.33	20.80	21.87	21.33	85.33
	20	18.22	17.78	18.13	18.04	72.18
	30	17.33	16.71	16.98	17.01	68.04
	40	16.36	16.44	16.09	16.30	65.19
28	0	28.00	27.78	28.22	28.00	112.00
	10	25.78	25.33	25.56	25.56	102.22
	20	24.00	24.44	24.00	24.15	96.59
	30	20.89	20.44	20.80	20.71	82.84
	40	15.56	16.18	16.00	15.91	63.64
90	0	28.89	29.11	29.33	29.11	116.44
	10	26.67	26.76	27.02	26.81	107.24
	20	24.44	24.89	24.89	24.74	98.96
	30	21.33	20.89	21.56	21.24	84.98
	40	17.33	17.78	17.78	17.63	70.52
120	0	29.78	30.22	29.78	29.92	119.70
	10	28.44	28.44	28.71	28.53	114.13
	20	24.89	24.89	24.89	24.89	99.56
	30	20.00	21.33	19.56	20.30	81.19
	40	16.89	17.78	17.33	17.33	69.33
180	0	30.22	30.00	30.22	30.15	120.59
	10	29.33	28.89	28.89	29.04	116.15
	20	24.00	23.78	23.56	23.78	95.11
	30	21.78	21.33	22.22	21.78	87.12
	40	20.89	20.67	20.44	20.67	82.67

4.3 STATIC MODULUS OF ELASTICITY

The results of the Static Modulus of Elasticity are presented in Table 7. At 7 days, the values are 24359 N/mm^2, 24115 N/mm^2, 23872 N/mm^2, 23209 N/mm^2 and 20042N/mm^2 for 0, 10, 20, 30 and 40% PSA replacement of cement respectively. The elasticity was observed to increase to 27032 N/mm^2, 25312 N/mm^2, 23842 N/mm^2, 23250 N/mm^2 and 21923N/mm^2 for 0, 10, 20, 30 and 40%PSA content respectively at 14 days curing period. At 28 days, the elasticity of concrete containing different percentages of PSA was noted to increase at a faster rate than the control. For instance, the values increased at 5.13%, 5.39%, 10.31%, 9.39% and 4.60% for 0, 10, 20, 30 and 40%PSA content respectively. All the mixes at 28 days met the requirement of 18,000N/mm^2 to 30,000N/mm^2 stipulated by BS 8110 part 2 [30] and that of 14,000N/mm^2 to 42,000N/mm^2 [31].

There was an elasticity improvement with 0% and 10%PSA blended cement concrete at 90 days, but a reduction was recorded with 20%, 30% and 40%PSA content. This an indication that there is continuous hydration and pozzolanic reactions with the blended cement concrete of 0% and 10%PSA content as evidence in higher rate of percentage increased.

The elasticity values at 120 days range between 30,210N/mm^2 and 20,479N/mm^2 for 0 - 40%PSA substitution respectively. At 180 days, there was no significant difference between the values recorded for 0% and 10% PSA content. This was closely followed by 20% PSA with a value of 28,208N/mm^2. Generally, the results revealed that the value of the static modulus of elasticity of the control (i.e. 0%PSA) is greater than those of the blended cement concrete in all the curing ages; and that the increased in the value with curing age, particularly with 0 – 20%PSA content, indicated the fact that there is a continuous hydration and pozzolanic reactions. The reduction in elasticity with increase in PSA content could be attributed to higher carbon content (expressed as loss on ignition) in the periwinkle shell ash and low quantity of cement in the mixes as a result of its replacement. This finding agreed with the use of slag in concrete [23] which recorded decreased in modulus of elasticity for compressive strength below about 55N/mm^2 and a slight increase (by about 10%) for compressive strength greater than about 60N/mm^2.

Table 7: Static modulus of elasticity of PSA blended cement concrete at different curing ages

PSA content (%)	Static Modulus of Elasticity (N/mm^2)					
	7 days	14 days	28 days	90 days	120 days	180 days
0	24359	27032	28419	29028	30210	31302
10	24115	25312	26676	27823	29846	30937
20	23872	23842	26299	25655	27215	28208
30	23209	23250	25434	24952	22483	22138
40	20042	21923	22932	21750	20479	18934

The statistical analysis, using analysis of variance (ANOVA), on the effect of PSA content and Curing age on the Static modulus of elasticity indicated that the independent factors (i.e. PSA content and curing age), when considered individually and collectively had significant effects on the Static modulus of elasticity of the concrete (Table 8). The coefficient of determination (adjusted R-Square value) is 0.969 (96.9%). This implies a strong statistical association among the variables. The independent variables were estimated to account for 96.9% of the variance in the Static modulus of elasticity of the concrete. The coefficient of correlation was obtained as R = 0.984. This shows that a very strong linear relationship exist between the two sets of variable being considered.

Table 8: Results of Anova for static modulus of elasticity

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	9.396E8	29	3.240E7	96.250	.000	.979
Intercept	5.746E10	1	5.746E10	170705.050	.000	1.000
PSA	6.420E8	4	1.605E8	476.823	.000	.970
CURAGE	1.216E8	5	2.431E7	72.224	.000	.858
PSA * CURAGE	1.760E8	20	8799457.619	26.141	.000	.897
Error	2.020E7	60	336610.722	-	-	-
Total	5.842E10	90	-	-	-	-
Corrected Total	9.598E8	89	-	-	-	-

4.4 RELATIONSHIP BETWEEN COMPRESSIVE STRENGTH AND STATIC MODULUS OF ELASTICITY

Table 9 shows the Static modulus of elasticity and cube Compressive strength for various PSA replacement levels with cement for all the hydration periods. It indicated that the modulus of elasticity increases with an increase in the compressive strength; and also increased at a higher rate than the compressive strength at later ages (i.e. 120 days and above). This agreed with earlier findings [31-32] which they attributed to the beneficial effect of improvement in the density of the interfacial transition zone, as a result of slow chemical interaction between the alkaline cement paste and aggregate, which is more pronounced for the stress – strain relationship than for the compressive strength of concrete.

Regression analyses performed to establish empirical relationship between the cube compressive strength and Static modulus of elasticity of concrete incorporating different percentages of periwinkle shell ash replacing cement was based on the expression $E = 9.1F_{cu}^{0.33}$ proposed by BS 8110 part 2 [30]. The regression equations were as follow:

0%PSA: $E_s = 9.464F_{cu}^{0.33}$; ($R^2 = 0.754$) ----- (1)

10%PSA: $E_s = 9.432F_{cu}^{0.33}$; ($R^2 =0.772$) --- (2)

20%PSA: $E_s = 9.215F_{cu}^{0.33}$; ($R^2 = 0.717$) --- (3)

30%PSA: $E_s = 8.720F_{cu}^{0.33}$; ($R^2 = 0.716$) --- (4)

40%PSA: $E_s = 8.099F_{cu}^{0.33}$; ($R^2 = 0.86$) ---- (5)

The regression equation in each percentage PSA content are $9.464F_{cu}^{0.33}$, $9.432F_{cu}^{0.33}$, $9.215F_{cu}^{0.}33$, $8.720F_{cu}^{0.}33$ and $8.099F_{cu}^{0.}33$ for 0, 10, 20, 30 and 40%PSA content respectively. It indicated that the elasticity decreases with increase in the percentage of periwinkle shell ash. The coefficient of association, r has a value between 0.868 and 0.927, indicating a strong linear relationship between the two variables. The relation between the static modulus of elasticity and cube compressive strength at all curing ages gave a regression equation of $E_s = 9.050F_{cu}^{0.33}$ with $R^2 = 0.651$ (equation 6) and a corresponding r value of 0.807 showing a strong linear relationship. These equations(1 – 6) do not significantly differ from the equation for normal- weight concrete, therefore, for PSA blended cement concrete, a static modulus of elasticity at age up to 180 days can be predicted by the model given by BS 8110 part 2 [30] for normal- weight concrete.

Table 9: Static modulus of elasticity, Compressive strength and Cube root of compressive strength of PSA blended cement concrete for different curing ages

PSA content (%)	Curing age (Days)	Static modulus of elasticity (Gpa)	Compressive Strength (N/mm^2)
0	7	24.359	19.41
10		24.115	18.52
20		23.872	17.85
30		23.209	17.51
40		20.042	16.41
0	14	27.032	27.11
10		25.312	21.33
20		23.842	18.04
30		23.250	17.01
40		21.923	16.30
0	28	28.419	28.00
10		26.676	25.56
20		26.299	24.15
30		24.952	20.71
40		22.923	15.91
0	90	29.028	29.11
10		27.823	26.81
20		25.655	24.74
30		24.952	21.24
40		21.750	17.63
0	120	30.210	29.92
10		29.846	28.53
20		27.215	24.89
30		22.483	20.30
40		20.479	17.33
0	180	31.302	30.15
10		30.937	29.04
20		28.208	23.78
30		22.138	21.78
40		18.934	20.67

5.0 CONCLUSIONS

From the results of the various tests performed, the following conclusions can be drawn:

1. Periwinkle shell ash had the combined acidic oxide of 50.06% and met the physical requirements for high-lime fly ash [33].
2. The slump and compacting factor decreases as the PSA content increases. This means that the concrete becomes less workable (stiff) with increase in PSA content; hence there is high demand for water to maintain the same workability level as the control.
3. The compressive strength of PSA blended cement concrete is lower than the control but there is a continuous strength development comparable with that of the control. The optimum level of PSA replacement is 10% having attained 102.22% of the design strength at 28 days.
4. The values of the Static modulus of elasticity of the control specimens (i.e. 0%PSA) is greater than those of the PSA blended cement concrete however, there was a continuous improvement with ≤20%PSA content in all the curing ages.

5. The relationship between compressive strength and static modulus of elasticity of PSA blended cement concrete up to 180 days fitted into an existing model for normal-weight concrete [29].

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