Periwinkle Shell Ash as Cementitious Material for Sustainable Concrete Production

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ABSTRACT

The study examined the effect of Periwinkle Shell Ash (PSA), as cement supplement, on the compressive strength and durability properties of hardened concrete. The concrete of design target strength of 25N/mm^2 at 28 - day hydration was adopted as the reference. The cement content was substituted with PSA up to 40%, by volume. A total of 225 specimens (135 cubical specimens of 150mm size and 90 cylindrical specimens of size 150 x 300 mm) were cast and cured in water. Ninety cubical specimens and Ninety cubical specimens were tested for compressive strength and elastic modulus respectively at 7, 14, 28, 90, 120 and 180 days; while fifteen specimens were tested for sorptivity at 28, 90 and 180 days. The results revealed that concrete with 0-10% PSA attained the target strength of 25N/mm^2; whereas, 20% PSA content met the design strength at 90 days. Static modulus of elasticity of concrete containing PSA was higher than that of reference (0% PSA) at 28 days hydration period. The sorptivity value indicated that 10-20% PSA content had lower sorptivity than the reference; and observed that the relationship between cumulative mass (i) and square root of time $(t)^{1/2}$ followed the model for conventional concrete with correlation coefficient (R^2) of 0.99. Therefore, it is concluded that the replacement of cement with PSA up to 20% has the potentiality of improving the durability performance of concrete.

Keywords: Compressive strength, Periwinkle shell ash, Pozolan, Sorptivity, Static modulus of elasticity

INTRODUCTION

The importance of incorporation of Supplementary Cementitious Materials (SCMs) in concrete production cannot be overemphasised. In recent years, many researchers, especially in the construction industry, have investigated into the use of locally sourced waste materials derivable from industries and agricultural activities, to either partially or fully replace the conventional materials used in concrete production. The utilization of these waste materials commonly among them being fly ash, slag, silica fume, meta kaolin, rice husk ash and some other SCMs have been reported to contribute immensely towards sustainable development through enhancing concrete properties. Some of the benefits are enhancement of plasticity and workability of fresh concrete, reduction in heat of hydration and consequentially thermal shrinkage, improvement in the microstructure of the concrete as well as reducing the calcium hydroxide usually released during hydration, which is being consumed through a pozzolanic reaction and thereby making the concrete insusceptible to attack by sulphate, chloride and other chemically aggressive agents. Supplementary cementitious materials are also useful in the production of non-conventional concrete such as self-compacting concrete, high performance concrete, geopolymer concrete, etc.

Nigeria is blessed with abundant agricultural and natural resources. The wastes and by-products from agricultural activities are raw materials that could be processed and used for building construction. The utilization of these cheap and abundantly available materials in construction, apart from saving storage and disposal costs will also protect the environment from pollution, and thereby contributing to resource conservation and environmental sustainability.

One of such agricultural waste materials that has the potential of a cementitious properties which can be used as cement supplement in concrete is Periwinkle Shell Ash (PSA).

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 (Okon,1987; Olorunoje and Olalusi, 2003). 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. Ten (10) out of the eighty (80) species of periwinkle in the world are found in West Africa (Dance, 1980). 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 (Badmus et.al., 2007). It is reported that there is abundance of periwinkle in most riverside communities of Akwa Ibom State (Olusola and Umoh, 2012). Massive periwinkle harvesting is also reported from some communities in Bayelsa, Cross River and Edo states of Nigeria (Jamabo and Chinda, 2010). A study by Mmom and Arokoya (2010) 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. 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 has resulted in great heaps constituting menace especially in villages in Rivers and Akwa Ibom states of Nigeria (Adewuyi and Adegoke 2008). Therefore, this work examined the possibility of processing and utilization of the shell ash with a view to assessing the compressive strength, durability and elasticity performance when used as supplementary cementitious material in concrete production.

Literature Review

Compressive Strength

Concrete exhibits its best strength characteristics when subjected to compressive loading. The compressive strength is one of the most important and useful properties of concrete, and as such in most structural applications concrete is employed primarily to resist compressive stresses (Shetty, 2006). Thus, compressive strength is the most common measure for assessing the quality of hardened concrete due to its ease of determination and influence on other properties of concrete.

The use of supplementary cementitious materials (or 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 (Snelson, *et al*., 2009). Water curing promotes gradual hydration of cement, eliminates shrinkage and absorbs the heat of hydration produced, thus creating a favourable environment for strength development. The longer the curing period, the higher the strength developed. Therefore, long curing age will be of advantage to concrete incorporating pozzolanic materials since pozzolanic reaction is time dependent. Therefore, this study investigated the effect of periwinkle shell ash on concrete up to a curing age of 180 days, so as to allow more time for pozzolanic reaction to take place.

Static Modulus of Elasticity

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 determination of elastic properties of concrete has become very important from a design point of view when the deformations of the different structural elements of a structure have to be calculated. When an elastic body is subjected to stress, a proportional strain is produced. This is a statement commonly referred to as Hooke’s law. This implies a linear relationship termed Young’s Modulus.

Concrete is defined as a three-phased anisotropic brittle material that behaves differently under various loads (Topcu and Ugurlu, 2007). Total deformation of a structural element that has an elastic property under any load is directly proportional with applied load and size of the concrete component, but is inversely proportional, with cross sectional area of the element (Mehta, 2006).

Concrete is a brittle, composite, multiphase, and elasto-plastic material. However, it has elastic behaviour under low stresses. Theoretically, this is equal to a value of 30-40% of its compressive strength (Mehta, 2006). It is known that concrete is not an elastic material; neither is the strain on instantaneous loading of a concrete specimen found to be directly proportional to the applied stress, nor is it fully recovered upon unloading. The cause for nonlinearity of the stress-strain relationship has been due to progressive development of micro cracks (Mehta and Monteiro, 2006).

The stress-strain diagrams are used for explaining elastic behaviour of concrete determined by experimental methods. In the linear portion of the curve, the ratio of the stress to strain is constant and is termed Young's modulus. There are other different elastic moduli existing as a result of the non-linearity of the stress-strain relationship. These have been identified as tangent modulus, secant modulus and chord modulus (Mehta and Monteiro, 2006). The tangent modulus is given by the slope of a line drawn tangent to the stress-strain curve at any point on the curve; the secant modulus is given by the slope of a line drawn from the origin to a point on the curve corresponding to a 40% stress of the failure load; while the chord modulus is given by the slope of a line drawn between two points on the stress-strain curve. However, the most useful of all is the secant modulus, hereafter referred to as modulus of elasticity. It is a measure of the stiffness of a material of concrete.

According to Myers (1999), 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. Knowledge of the modulus of elasticity is essential in the determination of deformation, deflection or stresses under short-term and long-term loading (Jackson and Dhir, 1996). The modulus can be estimated using static methods (then it is called static modulus of elasticity) or dynamic methods (then it is called dynamic modulus of elasticity).

The static modulus of elasticity is usually determined by subjecting a cube or cylinder specimen to uniaxial compression and measuring the deformation by means of dial gauges fixed between certain gauge lengths. Dial gauge reading divided by gauge length gives the strain and load applied divided by area of cross section gives the stress. A series of reading are taken and the stress-strain relationship is established. The static modulus of elasticity can also be determined by subjecting a concrete beam to bending and then using the formulae for deflection and substituting other parameters. The modulus of elasticity so found out from actual loading is called static modulus of elasticity.

The uses of SCMs as replacement of cement have also been reported to affect the static modulus of elasticity of concrete. For instance, the use of rice husk ash in concrete as reported by Ramezanipour *et. al.*, (2009) contributed to higher value in static modulus of elasticity when compared to the reference concrete. Modulus of elasticity is reported to be low at early ages and high at later ages for fly ash-blended cement concrete (Bhanumathidas *et al.*, 2005).

Sorptivity of Concrete

Sorptivity is a measure of the capillary forces exerted by the pore structure causing fluids to be drawn into the body of the material (Ganesan et al., 2008). The Sorptivity assessment of concrete has been stressed as an important index of concrete durability because the test method used for its determination reflects the way that most concretes will be penetrated by water and other injurious agents and it is an especially good measure of the quality of near surface concrete, which governs durability related to reinforcement corrosion (Dias, 2000). McCarter *et al*. (1992) stated that minimizing sorptivity is important in order to reduce the ingress of chloride or sulphate into concrete. Recently, the use of SCMs in concrete and its effect on the sorptivity have been investigated. For instance, Tasdemir (2003) investigated the effect of mineral admixture and curing condition on the sorptivity of concrete and observed that the sorptivity coefficient of concrete decreases as the compressive strength increases. Similar trend was recorded by Gonen and Yazicioglu (2007) which the value of sorptivity increased with increasing content of fly ash. Kahn and Lynsdale (2002) equally stated that the sorptivity of concrete is influenced by strength, and that sorptivity reduces with increasing strength. They further stated that the sorptivity of conventional concrete when compared with concrete incorporating SCMs at equivalent strengths was noted to always reduce the sorptivity of the later.

Therefore, the study examined the performance of PSA as partial replacement of cement on the compressive strength, static modulus of elasticity and sorptivity characteristics of concrete

EXPERIMENTAL PROCEDURE

MATERIALS

Portland cement (PC) produced to specification of NIS 444-1 (2003) was used. The periwinkle shells for the production of periwinkle shell ash (PSA) were collected from a dumpsite (Figure 1a), after being washed and dried, were fired in a gas furnace to temperature range of 600 - 800 ^{0}C (Figure 1b); ground and sieved with sieve size of 45µm. The Chemical and physical properties of the PSA are presented in Table 1. The fine aggregate was that of river-bed sand passing 4.75 mm sieve and falls within zone 2; while the coarse aggregate was crushed granite of maximum size 20 mm.

Fig. 1a: Dumped Periwinkle shells

Fig. 1b: Periwinkle shell fired in a gas kiln

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) 7 days	14 days	Water used (% of control)	Soundness (mm)	Moisture content (%)	Specific gravity
21.00	78.17	79.12	104	1.00	1.50	2.13

MIX PROPORTION

A concrete of characteristics strength 25 N/mm^2 for Normal-weight concrete (i.e. reference mix: 0% PSA and 100% PC) using the Department of Environment mix design method was adopted. Partial replacement of PC by PSA at percentages of 0, 10, 20, 30 and 40 by volume was used. Replacement by volume was adopted because of the significance differences in their specific gravities. The mix proportions of the mixes are presented in Table 2.

Table 2: Mix proportions (m^3) of PSA blended cement concrete

PSA content (%)	Cementitious Binder (kg)		Water (kg)	Fine aggregate (kg)	Coarse aggregate (kg)	
	PC	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

SPECIMENS PREPARATION AND TESTING

Two types of Specimens were prepared: 150 mm cubes, 150mm by 300mm cylinders, for the purpose of compressive strength, static modulus, and sorptivity tests. The casting was done as specified by BS EN 12390 Part 2 (2009). The specimens were de-moulded after 24 hours, placed in water curing tank kept at temperature of 29 ± 1 ^{o}C until their testing ages.

The concrete specimens were tested for compressive strength at 7, 14, 28, 90, 120, and 180 - day hydration period.

Static modulus of elasticity test was conducted on the cylindrical specimens. The specimens were placed inside Compressometer fixed with dial gauges (Figure 2), 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.

Figure 2: Set-up of cylindrical specimen with Compresometer and Dial gauges for static elasticity test.

Sorptivity test was conducted as specified by BS EN 1925 (1999). Water was used as the test fluid. After the concrete cubes had attended their respective curing ages, they were removed from the curing water and ambient dried for 21 days at which time there was no more change in mass. The side of the specimens were then covered with paraffin wax, and one of the two remaining sides (which are opposite sides) was covered with a loose plastic sheet attached with masking tape to allow the entrapped air to escape from the concrete pores while at the same time preventing loss of water by evaporation. After obtaining the initial mass of each of the specimens, they were placed on two lines of support (16mm rod), with the uncovered side in contact with the water, maintained at 3-5mm level above the top of the support throughout the duration of the test. The test was conducted over 4 hours and the cumulative change in mass at specified time intervals (in seconds) were determined. The cumulative change in mass at 300 seconds, 600 seconds, 1200 seconds, 1800 seconds, 3000 seconds, 7200 seconds, 10800 seconds, and 14400 seconds were used to obtain the respective cumulative absorption values. The absorption values (I) is found using the equation 1.

$$I = Dm/Ap \qquad (1)$$

Where

I = cumulative absorption value

Dm = cumulative change in mass due to water absorption

A = cross-sectional area of test specimen, mm^2

P = density of water;

The sorptivity was then deduced from the relation given by Hall (1989):

$$I = St^{0.5} \qquad (2)$$

Where

I = increase in mass in g/mm^2 since the beginning of the test per unit of cross-sectional area in contact with water; as the increase on mass is due to the ingress of water, 1 g is equivalent to 1 mm^3, so that I can be expressed in mm.

t = time, measured in seconds, at which the mass is determined, and

S = sorptivity in $mm/second^{0.5}$

In each of the property tested, at least three specimens were tested at each age for each replacement level thereby given a total of 90 cubes, 90 cylindrical specimens and 45 cubes for compressive strength, elasticity and sorptivity test respectively.

RESULTS AND DISCUSSIONS

COMPRESSIVE STRENGTH

The compressive strength development at various ages is given in Table 3. The compressive strength results at 7 days for all the mixes attained over 65% of the design strength thereby satisfying the requirement of normal-weight concrete strength development which is stipulated to be between 50-66% (BS 8110 part 2, 1985).

The control mix (that is, 0% PSA) at 14 days attained a compressive strength of $27.11N/mm^2$, representing 108.44% of the design strength. A percentage attainment of 85.33, 72.18, 68.04 and 65.19 of the design strength were recorded with 10,20, 30 and 40% PSA content respectively. The strength development satisfied the 60-75% of the design strength as stipulated by Illston (1994).

At a standard age of 28 days, the compressive strength of 0% and 10% PSA content was 28 N/mm^2 and 25.56 N/mm^2 respectively which met the desired design strength of $25N/mm^2$, whereas, that of 20, 30 and 40% PSA content were 24.15, 20.71 and $15.91N/mm^2$ respectively. These show that the strength development for mixes containing PSA is slower. However, these are comparable with the values obtained by other researchers (Dahunsi and Bamiseye, 2002), and portray the fact that the pozzolanic reaction depends on the released of calcium hydroxide from cement hydration.

The results at 90 days revealed a positive trend in strength development, confirming that there is both hydration and pozzolanic reactions. At 120 days, 10% PSA recorded compressive strength of $28.53N/mm^2$

representing 14.12% of the design strength, while the control mix recorded strength of 29.92N/mm^2 which represents 19.68% of the design strength. The 20% PSA had strength of 27.89N/mm^2 representing 111.56% of the design strength.

An increment rate of strength development was observed at 180 days as 10% PSA attained strength of 29.04N/mm^2 which is not significantly different from the control which had strength of 30.15N/mm^2. It means that where later age strength is required at later age above 120 - day hydration period, 20% replacement of cement with PSA is adequate The continuous increased in the 10 - 20% 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 3: 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	27.89	27.89	27.89	27.89	111.56
	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	29.92	29.86	29.56	29.78	119.12
	30	21.78	21.33	22.22	21.78	87.12
	40	20.89	20.67	20.44	20.67	82.67

STATIC MODULUS OF ELASTICITY

The results of the Static Modulus of Elasticity are presented in Table 4. The values obtained at 7 - day hydration are 24,359N/mm^2 for 0% PSA; 24,115N/mm^2 for 10% PSA; while 23,872N/mm^2, 23,209N/mm^2 and 20,042N/mm^2 are for 20, 30 and 40% PSA replacement of cement respectively. At 14 - day curing period, the elasticity was observed to increase to 27,032 N/mm^2, 25,312N/mm^2, 23,842N/mm^2, 23,250N/mm^2 and 21,923N/mm^2 for 0, 10, 20, 30 and 40% PSA content respectively. The elasticity of concrete containing different percentages of PSA was noted to increase at a faster rate than the control at 28 – day hydration period. 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 (1985) and that of 14,000N/mm^2 to 42,000N/mm^2 (Oymael and Durmus, 2006).

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 - day 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 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 5). 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 exists between the two sets of variable being considered.

Table 4: 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

Table 5: Results of ANOVA for static modulus of elasticity test

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				

SORPTIVITY

In the test, several measurements were taken over a period of up to 4 hours, and a straight line fitted to the plot of the increase in mass versus the square root of time. The results as presented in Figures 3 to 7 revealed that, for both reference and blended cement concrete, the relationship between (i) and $(t)^{0.5}$ followed the model presented in equation (2), where the correlation coefficient (R^2) reaches 0.99 approximately. This means that the capillarity absorption's model (equation 2) of conventional concrete can also be adopted for modelling the relationship between (i) and (t) of PSA blended cement concrete.

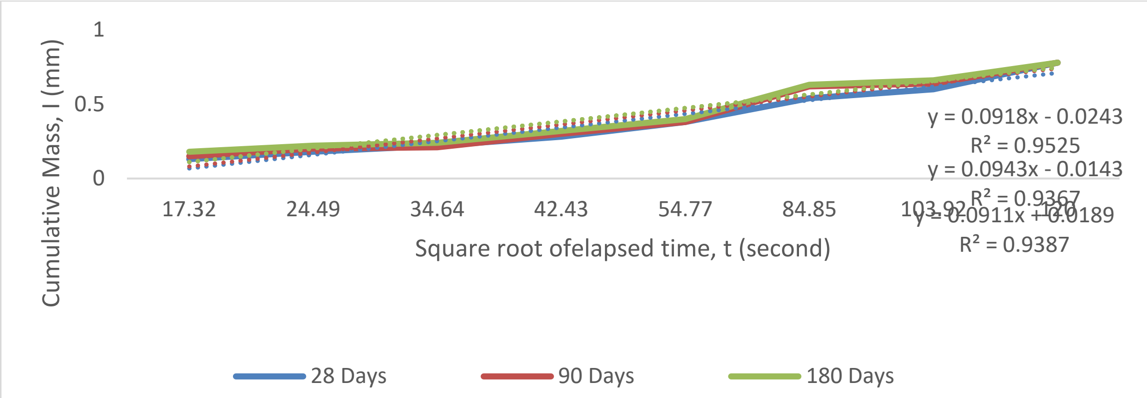

Figure 3: Relationship between Cumulative mass and square root of time for 0% PSA content at 28, 90 and 180 days.

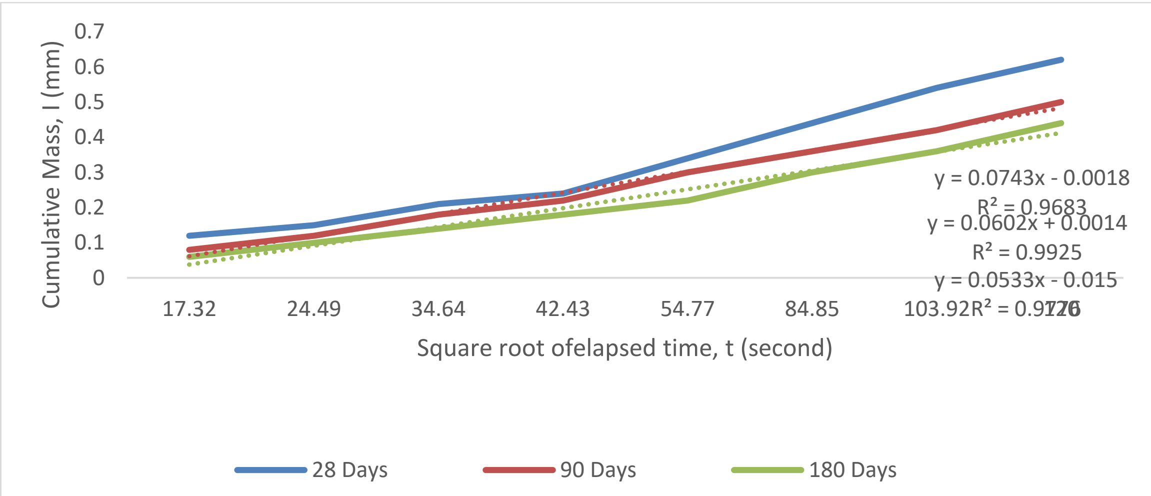

Figure 4: Relationship between Cumulative mass and square root of time for 10% PSA content at 28, 90 and 180 days.

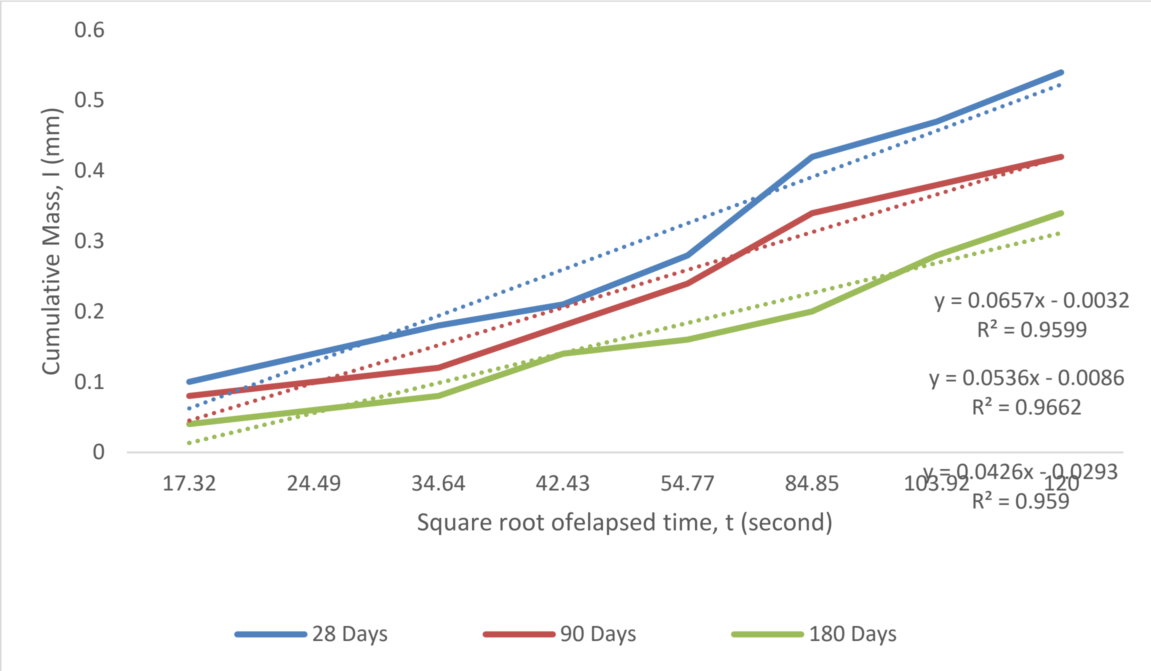

Figure 5: Relationship between Cumulative mass and square root of time for 20% PSA content at 28, 90 and 180 days.

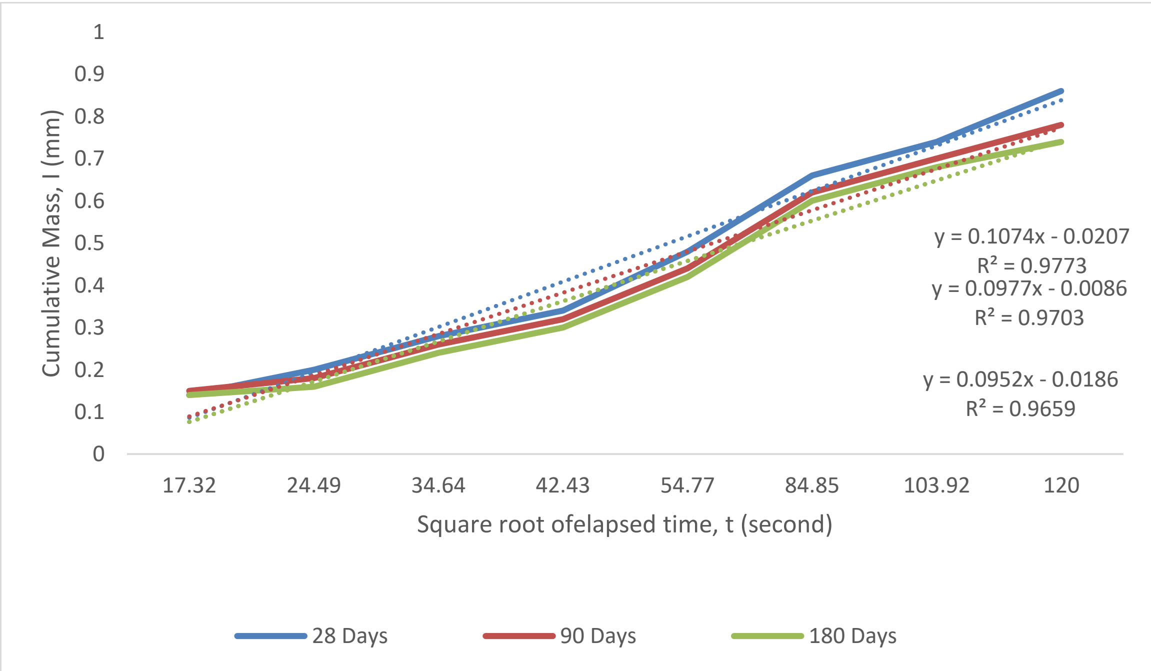

Figure 6: Relationship between Cumulative mass and square root of time for 30% PSA content at 28, 90 and 180 days.

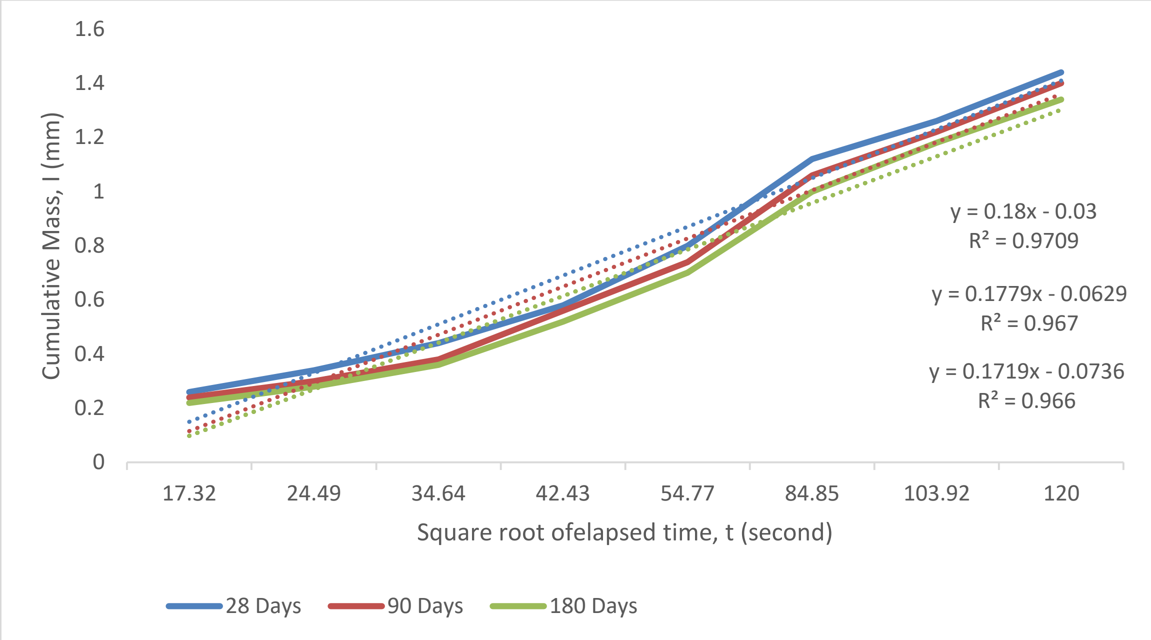

Figure 7: Relationship between Cumulative mass and square root of time for 40% PSA content at 28, 90 and 180 days.

The capillary absorption capacities at the end of 4 hours for the mixes are shown in Figure 8. It indicated that mixes containing 10-20% PSA have lower capillary absorption than that of the reference; whereas mixes with PSA › 20% had higher sorptivity.

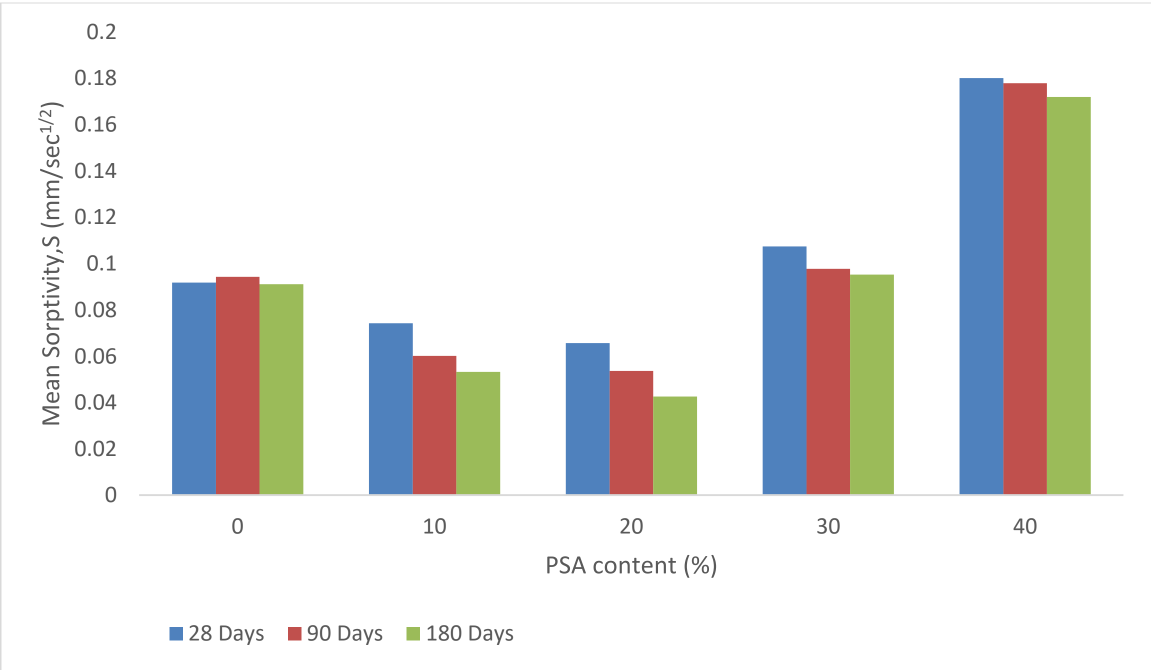

Figure 8: Sorptivity of PSA concrete at Different curing ages.

CONCLUSIONS AND RECOMMENDATIONS

From the results it can be concluded that:

1) The compressive strength of PSA blended cement concrete increases with increased in curing age but decreases with increased in PSA content beyond 20%.
2) Statistical analysis of the effect of PSA on concrete static modulus of elasticity is significant with determination coefficient of 0.969.
3) The capillarity absorption's model for conventional concrete can be used for modelling the relationship between (i) and (t) of PSA blended cement concrete and that water permeability characteristics of concrete can be enhanced by the incorporation of up to 20% PSA as cement addition.

It is recommended that PSA up to 20% replacement of cement in concrete is adequate where other admixtures (like accelerators) are not to be part of the concrete ingredients.

A purpose-made incinerator should be built for the production of Periwinkle shell ash.

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