Civil Engineering Dimension, Vol. 15, No. 2, September 2013, 96-101
ISSN 1410-9530 print / ISSN 1979-570X online

CED 2013, 15(2), DOI: 10.9744/CED.15.2.96-101

Performance of Periwinkle Shell Ash Blended Cement Concrete Exposed to Magnesium Sulphate

Umoh, A.A.[1] and Olusola, K.O.[2]

Abstract: The study examined the compressive strength of periwinkle shell ash (PSA) blended cement concrete in magnesium sulphate medium. Specimens were prepared from designed characteristics strength of 25 MPa. The cement replacement with PSA ranged between 0 and 40% by volume. A total of 180 cube specimens were cast and cured in water. At 28 days curing, 45 specimens each were transferred into magnesium sulphate of 1%, 3%, and 5% solution, while others were continuously cured in water and tested at 62, 92, and 152 days. The results revealed a higher loss in compressive strength with the control mix, and that it increases with increased in $MgSO_4$ concentration and exposure period, whereas, the attack on the PSA blended cement concrete was less and the least value recorded by 10% PSA content. Therefore, the study concluded that the optimum percentage replacement of cement with 10% PSA could mitigate magnesium sulphate attack.

Keywords: Blended cement, compressive strength, durability, magnesium sulphate, periwinkle shell ash.

Introduction

The compressive strength of concrete is considered one of the most important properties in the hardened state. The design of concrete structures is based primarily on resistance to compressive stresses. In structural design, the compressive strength is the criterion of quality [1]; however, the compressive strength performance and the service life of concrete may be inhibited by its exposure condition. Therefore, it is expected that concrete produced at any given instance should, among other qualities, have satisfactory performance in compressive strength requirements as well as satisfactory durability in the environment in which the structure is placed. The ability of concrete to resist weathering action, chemical attack, abrasion, or any other process of deterioration is called durability [2]. Inadequate durability manifests itself by deterioration, which can be caused by external or internal factors within the concrete.

Several researchers [3,4] have identified that sulphates, either in natural form or artificially introduced, could be responsible for the reduction in the compressive strength of mortar and concrete.

[1] Building Department, Faculty of Environmental Studies, University of Uyo, NIGERIA
E-mail: umohaa@yahoo.co.uk
[2] Building Department, Faculty of Environmental Design and Management, Obafemi Awolowo University, Ile-Ife, NIGERIA
E-mail: kolaolusola@yahoo.co.uk

Note: Discussion is expected before November, 1st 2013, and will be published in the "Civil Engineering Dimension" volume 16, number 1, March 2014.

Received 11 May 2012; revised 12 April 2013; accepted 08 June 2013

Sulphates may be present in ground water; it can as well come from fertilizers and industrial effluents. Water used in the concrete cooling towers has been stated to be a source of sulphate attack because of the gradual built-up of sulphate from evaporation of the water [5]. Decay of organic matter in the marshes, shallow lakes, mining pit and sewer pipes, often lead to the formation of hydrogen sulphide (H_2S), which can oxidize to sulphate under some conditions, e.g. under compelled air used in excavation. Seawater contains the sodium, magnesium and calcium sulphate in the dissolved form; hence sulphate attack is the common occurrence in concrete environments. Sulphates attack on concrete manifest itself in the form of loss in strength, expansion, surface spalling, mass loss and eventual disintegration [6].

Blending of mineral admixtures like ground granulated blast furnace slag, fly ash, silica fume, rice husk ash, and metakaolin with cement or lime, increases resistance of concrete to sulphate attack. The superior performance of blended cement over plain cement concrete is attributed to the pozzolanic reaction that consumes the calcium hydroxide and to the dilution of calcium aluminates hydrates phase due to a reduction in the quantity of plain cement in the total binder [7]. The use of fly ash and blast furnace slag in making sulphate–resisting concrete has frequently been reported. Slag and other admixtures with low lime contents were reportedly mitigate sulphate attack by reducing alumina levels in the mixture [8]. However, the sulphate resistance of mixtures containing these admixtures is dependent upon the degree to which concrete is cured, as these materials hydrate more slowly and required extended curing to achieve sufficient impermeability; many admixtures result in greater later-age strength and lower permeability and consequently, improve durability and resistance to sulphate attack.

There is a growing interest in recent times to use agricultural wastes as mineral admixtures in improving concrete and soil properties. Some of them include sawdust ash [9-10], rice husk ash [11], corn cob ash [12-14], millet husk ash [15], palm oil fuel ash [16-17] and periwinkle shell ash (PSA) [18-21]. However, the use of PSA in concrete has been carried on the effect of the ash on the concrete compressive strength up to 28 days hydration period. The durability performance of PSA blended with cement in concrete is scarce in literature, hence this study attempt to investigate the use of PSA as partial replacement of cement in concrete and its effect on the durability performance when the concrete is exposed to varying concentrations of magnesium sulphate solutions.

PSA is obtained by burning periwinkle shell which is the by-product of Periwinkle. Periwinkle is any small greenish marine snail from the class of gastropod, the largest of the seven classes in the phylum mollusc [22,23]. They are 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 periwinkle that is most abundant in the estuaries and mangrove swamp forest of the South–South region of Nigeria is *Tympanotonus fuscatus* [19]. A study by Mmom and Arokoya [24] 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 of some riverine communities of Itu, Oron, Issiet, Okobo, Ikot Offiong, and Uta-ewea in Akwa Ibom state showed abundance of periwinkle in these communities. Massive periwinkle production is also reported from some communities in Bayelsa, Cross River, and Edo states of Nigeria [25,26]. 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 [27]. Therefore this work posed to examine the use of periwinkle shell ash as partial replacement of cement in concrete with a view to ascertain its durability performance when the concrete is exposed to magnesium sulphate environment.

Materials and Methods

Materials

Ordinary Portland cement (OPC) produced in conformity to NIS 444 -1 [28] was used. PSA was processed from the calcination of periwinkle shells collected from one of the dump-sites in Ikot Ekpene, Akwa Ibom state of Nigeria, at a temperature of $800^{0}C$ and stopped as soon as this temperature was attained. The ash was ground and sieved with 45 μm size. The fine aggregate was that of river-bed and the sieve analysis revealed that it falls within zone 2 fine aggregate (Figure 1); while the coarse aggregate was crushed granite of maximum size 20mm. The properties of the materials are presented in Tables 1 and 2.

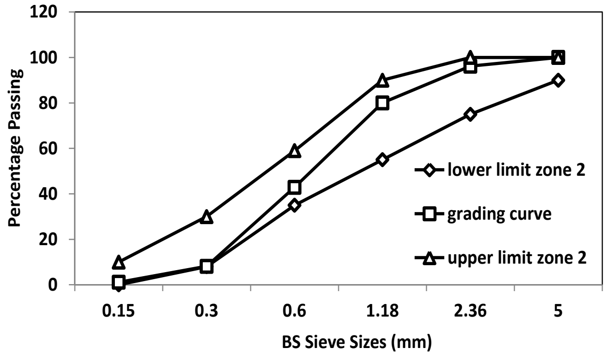

Figure 1. Zone Two Grading Curve of Fine Aggregate

Table 1. Physical Properties of Materials

Properties	Cement	PSA	Fine aggregate	Coarse aggregate
Fineness Modulus	-	-	2.72	6.39
Coefficient of Uniformity	-	-	2.50	2.40
Specific gravity	3.13	2.13	2.65	2.65
Consistency (%)	27.72	-	-	-
Initial setting time (minutes)	98	-	-	-
Final setting time (minutes)	201	-	-	-
Fineness (% retained on 45μm sieve)	32.00	21.00	-	-
Soundness (mm)	0.08	1.00	-	-
Water requirement (% of control)	-	104.00	-	-
Moisture content (%)	-	1.50	-	-
Pozzolanic activity with Portland cement (% of control):				
7 days	-	78.17	-	-
28 days	-	79.12	-	-

Table 2. Chemical Properties of Cementitious Materials

Elemental oxide	OPC	PSA
SiO_2	20.06	33.84
Al_2O_3	5.85	10.20
Fe_2O_3	3.05	6.02
CaO	62.44	40.84
MgO	1.93	0.48
SO_3	2.71	0.26
K_2O	0.97	0.14
Na_2O	0.14	0.24
Mn_2O_3	0.20	0.00
P_2O_5	0.17	0.01
TiO_2	0.28	0.03
LOI	1.09	7.60

Methods

The concrete was designed to attain a characteristic strength of 25 MPa for normal concrete (i.e. control: 0% PSA and 100% OPC) using the mix design published by the British Department of the Environment (DOE) [29]. A water/cement ratio requirement of the mix design for the requisite workability (slump: 10-30 mm) was adhered. The cement constituent of the control mix was replaced with various amount of PSA in steps of 10 up to 40% by volume. The percentage replacement of the cement was done by volume as there was a remarkable difference in the specific gravities of the cement and the PSA. The mixing of the constituents was done manually. Slump test was carried out to determine the workability of each mix. A total of 180 concrete specimens were cast in steel moulds of 150 mm cube size as specified by BS EN 12390-2 [30]. As soon as the specimens were cast, they were covered with wet wooden bags, de-moulded within 24 hours, and placed in water curing tanks and kept, at temperature of 29 ± 1°C for 28 days. At 28 days of water curing, the specimens were divided into four sets consisting of 45 cubes each. The effect of magnesium sulphate of different concentrations (0, 1, 3, and 5%) on the property of the periwinkle shell ash blended cement concrete was assessed based on loss in compressive strength. The concentrations chosen represent the sulphate concentrations noted in saline soils prevalent in many parts of the South – South region of Nigeria [31]. The first set was continuously cured in water (i.e. 0% concentration), while the second set, third set, and fourth set were transferred to magnesium sulphate of 1%, 3%, and 5% concentration, respectively and tested at 62, 92, and 152 days using compression testing machine of 2000 KN capacity.

Results and Discussions

Slump

The values of the slump are shown in Table 3. To attain the same workability level of 10-30 mm 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 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 [11]. The values of the slump range between 25 and 29 mm which are within the stipulated range for low workability concrete.

Table 3. Slump Values for PSA Blended Cement Concrete

PSA content (%)	Slump (mm)	Actual Water/ Cementitious Ratio	Water (% of control)
0	29	0.58	100.00
10	28	0.59	101.72
20	28	0.60	103.45
30	26	0.62	106.29
40	25	0.64	110.34

Compressive Strength

The compressive strength development of the cube specimens continuously cured in water (i.e. the first set) after the first 28 days is presented in Table 4. It shows that the compressive strength generally increases with curing age but decreases with increase in the PSA content. The decreased in compressive strength as the PSA content increases could be associated with higher water demand by the PSA blended cement concrete that led to higher water to cementitious material ratio and hence lower strength. The compressive strength at 92 days was noted to increase by 2.78%, 6.42%, and 0.61%, for 0, 10, and 20% PSA blended cement concrete, respectively; and reduce to 4.43%, and 1.70% for mixes containing 30 and 40% PSA content, respectively. A further increase in the rate of strength development was observed with PSA blended cement concrete mixes at 152 days, with mix containing 10% PSA having compressive strength comparable with the control. The enhance strength of the blended cement specimens may be attributed to the pozzolanic/cementitious reaction of the PSA with hydration products of the cement; and since the reaction is a function of time, it is envisage that the PSA blended cement concrete, particularly 10% PSA, may outperform that of the control specimens at later ages.

Table 4. Compressive Strength Values for Water Cured Specimens

Continuous Curing (Days)	PSA (%)	Compressive Strength (MPa)
62	0	29.11
	10	26.81
	20	24.74
	30	21.24
	40	17.63
92	0	29.92
	10	28.53
	20	24.89
	30	20.30
	40	17.33
152	0	30.15
	10	29.04
	20	23.78
	30	21.78
	40	20.67

Magnesium Sulphate Effect on Compressive Strength

Results of different concentrations (1%, 3%, and 5%) of magnesium sulphate effect on compressive strength of PSA blended cement concrete at various exposure periods are presented in Figures 2, 3, and 4.

The percentage reduction of the compressive strength of the control mix as shown in Figures 2, 3, and 4 were 1.51%, 2.33%, and 3.26% for 1%, 3%, and 5% $MgSO_4$ concentration, respectively, at 62 days; while most of the PSA blended cement concrete gained strength at the same age. At this age it can be assumed that the pozzolanic/cementitious reaction must have consumed the quantity of deleterious products produced by the cement hydration and thereby reducing the effect of the attack.

At 92 days exposure, loss in strength were recorded by all specimens for all the replacement levels of 0% to 40% PSA, but 0% PSA had the highest reduction of 8.82%, 11.56%, and 14.87% for 1%, 3%, and 5% $MgSO_4$ concentration, respectively. The effect of the sulphate attack at this stage could be as a result of an excess accumulation of the hydrate products which is more than what the pozzolanic/cementitious reaction can consume. A further loss in strength was recorded with 0% PSA concrete specimens at 152 days of exposure in all the concentrations with 10% PSA blended cement concrete specimens having the least strength reduction of 3.10% and 3.65% in 3% and 5% $MgSO_4$ concentration, respectively.

Generally, the strength reduction became much manifested with increase in exposure age and sulphate concentration. The most deleterious effect was on 0% PSA blended cement concrete specimens at 152 days exposure and 5% concentration than other concrete specimens with various percentages of PSA replacement levels with cement.

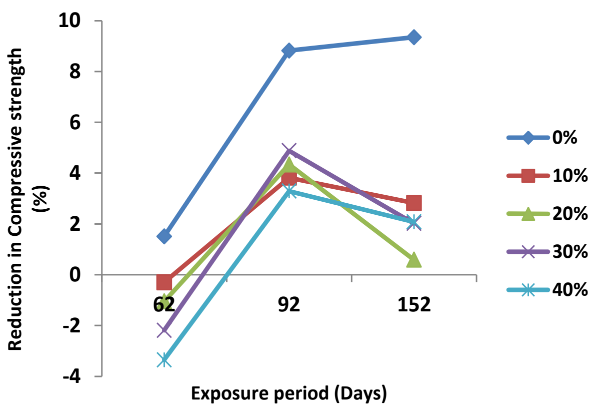

Figure 2. Reduction in Compressive Strength of PSA Blended Cement Concrete Exposed to 1% $MgSO_4$ Solution

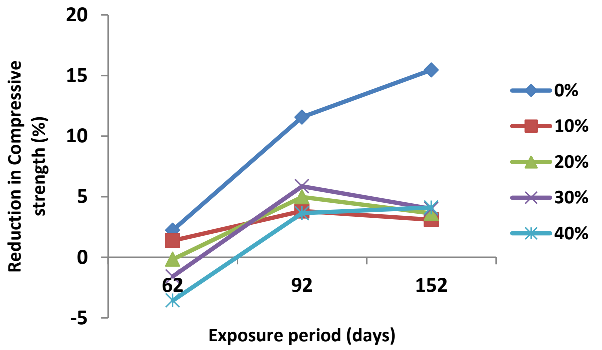

Figure 3. Reduction in Compressive Strength of PSA Blended Cement Concrete Exposed to 3% $MgSO_4$ Solution

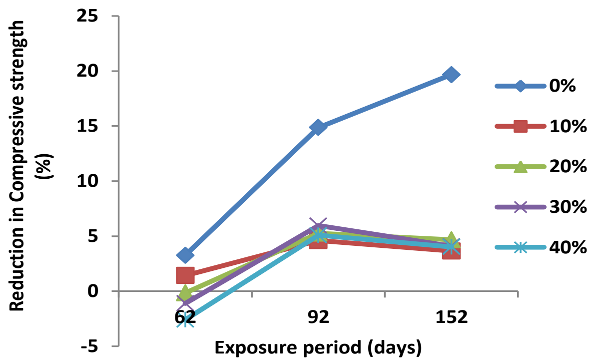

Figure 4. Reduction in Compressive Strength of PSA Blended Cement Concrete Exposed to 5% $MgSO_4$ Solution

Also noticed was a decrease in strength loss as the percentage of PSA content increases from 10% to 40% particularly at 62 and 92 days exposure. Beyond this age, the least lost in compressive strength was experienced with 10% PSA blended cement concrete specimens.

Statistical analysis to determine the influence of percentage of PSA substitution, exposure period, and sulphate concentration on the compressive strength of concrete was carried out using analysis of variance (ANOVA). The analysis was aimed at finding whether the factors considered have significant effect on the compressive strength of PSA blended cement concrete. The results as presented in Table 5 indicated that all the factors: percentage PSA content, exposure period as well as sulphate concentration (called independent variables) had significant effects on the measured compressive strength (called dependent variable). It was also established that the interaction of the factors, pair wise and collectively, have significant effect on the compressive strength at 95% confidence level.

The coefficient of determination (adjusted R^2) was 0.994 (99.4%). This implies that there is a strong statistical association between the three independent variables and the dependent variable. Independent variables were estimated to account for 99.4% of the

Table 5. Result of the Effects of PSA, Exposure Time and Different Magnesium Sulphate Concentration on Concrete Compressive Strength

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	2690.985[a]	59	45.610	333.486	0.000	0.994
Intercept	100592.928	1	100592.928	735504.651	0.000	1.000
PSA	565.060	4	141.265	1032.886	0.000	0.972
Expo. Time	13.873	2	6.936	50.717	0.000	0.458
Concentration	43.701	3	14.567	106.509	0.000	0.727
PSA * Expo. Time	1997.981	8	249.748	1826.078	0.000	0.992
PSA * Conc.	14.290	12	1.191	8.707	0.000	0.465
Expo. Time * Conc.	3.877	6	0.646	4.724	0.000	0.191
PSA * Expo. Time * Conc.	52.203	24	2.175	15.904	0.000	0.761
Error	16.412	120	0.137			
Total	103300.325	180				
Corrected Total	2707.397	179				

a. R Squared = 0.994 (Adjusted R Squared = 0.991)

variance in the compressive strength of blended cement concrete cubical specimens. The coefficient of correlation (square root of adjusted R^2) was obtained as R = 0.997. This shows that a very strong linear relationship exist between the two sets of variables being considered.

Conclusions

From the results of compressive strength test performed, the following conclusions can be drawn: The effect of magnesium sulphate attack on the compressive strength increases with increase in exposure period and concentration. It was noticed that the effect was much severe with 0% PSA mix than the PSA blended cement mixes. The loss in strength for the PSA blended cement mixes increase up to 92 days and starts to decrease, with the 10% PSA mix having the least effect. It is envisage that beyond 152 days there is likelihood of further decreased in strength loss with the PSA blended cement concrete due to pozzolanic/cementitious reaction that must have consumed the deleterious hydration products. Therefore, the replacement of cement with 10% PSA will enhance the service life of structure made from such concrete.

It was statistically observed that sulphate concentration, PSA contents and exposure period, each and collectively had effect on the concrete compressive strength.

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