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Structural performance of sawdust ash blended steel slag aggregate concrete

S. O. Ehikhuenmen[1,*], E. E. Ikponmwosa[1] and F. A. Falade[1]

[1] Civil and Environmental Engineering Department, Faculty of Engineering, University of Lagos, Lagos, Nigeria.
* Correspondence: sehikhuenmen@unilag.edu.ng

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Abstract: Out of the top ten current global issues, climate change and pollution top the list. These issues have brought about adverse effects on our climate, health and communities. This study aims to investigate the structural performance of sawdust ash blended steel slag aggregate concrete and modelling their structural properties using a multivariate interpolation method. In order to achieve this, the physical properties, physio-chemical, chemical composition, mechanical properties tests were conducted. The result revealed that sawdust ash is classified as a class C type pozzolan having a total of 61.59% combined percentage masses of silica, alumina and ferric oxides, while steel slag aggregate is classified as poorly graded. The composite concrete recorded higher density, compressive and split tensile strengths when compared with normal concrete cured in potable water. The results revealed that normal concrete with normal aggregate is more durable than sawdust ash blended steel slag aggregate (composite) concrete when cured in an aggressive environment. The developed models were found to agree strongly with the experimental data, with an outstanding correlation level. This research has led to the creation of high strength pozzolan blended steel slag aggregate concrete, thus improving waste management, reduction in environmental pollution and CO_2 gas emission.

Keywords: Curing medium, mathematical modelling, sawdust ash, steel slag aggregate, structural strengths.

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1. Introduction

In December 2018, the world's population was estimated to be 7.7 billion. Nigeria ranked number seven and was estimated to have an equivalent of 2.57% of the world population (Worldometers, 2018). Nigeria, being the most populous African country, has an urban population of 51.0% of its population and this has a direct link to the demands on food, clothing and shelters [1]. Urban cities like Lagos, Ibadan, Warri, Kano, Ibadan, Kaduna, Abuja, Calabar, etc, are housing a large number of people and due to their landmass, there are high demands on taller buildings in order to accommodate the population [2]. In most developing countries like Nigeria, Portland cement as a water-based binder in concrete is the most utilized construction material [3] and is not an environmentally friendly material because its production and usage emit over 5% of the total CO_2 anthropogenic emissions [4]. In 2015, the Fredonia group projected that in 2019 the global demand for cement would reach 5.2 billion metric tonnes. The cost of construction continues to increase globally, especially in Nigeria where construction cost is one of the highest [5].

According to the National Ready Mixed Concrete Association, in mix designs, the binder content is largely a function of the amounts of carbon dioxide CO_2 embodied in concrete. For every ton of cement manufactured, over half a ton of CO_2 emissions is on the loose into the atmosphere which makes cement the third-largest CO_2 producer in the world [6]. The mining process of aggregates (fine and coarse) has an adverse effect on the ecosystem around the operation areas [7]. Quarry activities have a major impacton the environment like engineering impact (chemical spills, noise, vibrations, erosion, dust, loss of habitat, etc), cascading impacts (removal of rock) and geomorphic impact [8].

Nigerian Environmental Society (NES), said that Nigeria as a nation generates over 60 million tonnes of waste annually with less than 10% waste management capacity [9]. One of the goals of sustainable construction is the reduction of cement usage in the production of concrete. Also, the reusability of industrial and agricultural waste materials in concrete production offers environmental gains and the preservation of natural resources [10].

Sawdust, an industrial waste generated from the timber industry, produced as wood chippings or loose particles from sawing of timber into desired or standard usage sizes [11]. Due to the nation's poor waste management techniques, sawdust poses a nuisance to the health of citizens and the environment. Steel–slag, a by–product of the steel, produced when scrap metals and irons are liquefied together with fluxes under oxidizing conditions by injecting an enormous amount of air or oxygen [12]. Cordeiro *et al.*, [13] proposed the usage of pozzolanic and blended cement to reduce the use of Portland cement in concrete production. Abdullah *et al.*, [14] supported the proposition by saying blended cement and concrete incorporated with pozzolanic materials have created an innovative solution for producing concrete with savings in energy, improvement in certain properties of hardened and fresh concrete (like extensibility, workability, heat of hydration, resistance from sulphate attack, and other environmental considerations, by decreasing CO_2 emissions). Raheem *et al.*, [15], investigated saw dust ash as a partial replacement for cement in concrete and they observed that the compressive strength decreased with increasing SDA replacement at early stages but improves significantly with curing age. It was concluded that 5% SDA substitution is adequate to enjoy the maximum benefit of strength gain. The inclusion of SDA into the concrete matrix causes little expansion due to low calcium content [3], saturating the cement mix with oxides such as K_2O and MgO in SDA which form composites that may inhibit the formation of strength-giving calcium silicate hydrates from cement hydration [16] and the optimum replacement level of 10% by volume SDA can be used to partially replace cement [17–19].

The usage of waste aggregates such as steel slag can help reduce the dependence on the natural rock (granite), hence preserving our natural resources, recycling and optimum utilization of by–products for economic, environmental and construction aims [20]. The investigation of the compressive strength of steel slag aggregate concrete by many researchers shows an increase in strength up to 75% replacement and a further increase in steel slag resulted in a decline in strength [20,21]. Thangaselvi [22] stated that the improvement in strength may be due to shape, size and surface texture of steel slag aggregates, which provide better bonding between the particles and cement paste. Awoyera *et al.*, [23] studied the performance of steel slag aggregate concrete with varied water–cement ratio, observing an increase in strength gain due to steel slag aggregate inclusion and concluded that a rapid strength development can be obtained in concrete by reducing the water–cement ratio. Presently, the desire to drastically reduce CO_2 emissions, high demand for cement and its energy consumption and the dependence on other natural resources in the production of high performing concrete have led to the search for innovative binders and aggregates with the view to produce high strength and more durable concrete. These materials range from industrial bye products like silica fume, steel slag, blast furnace slag and fly ash to agriculture wastes like sugarcane bagasse ash, rice husk ash, sawdust ash, and com cub ash. Therefore, it is valuable to study the performance of concrete having a certain percentage of sawdust ash as binder and steel slag aggregate as normal coarse aggregate regarding the strength and durability properties of concrete. Hence, exploring innovative materials incorporated into concrete production is of great significance to the civil engineers for sustainable development, sustainable concrete production, sustainable construction and hence, sustainable development.

2. Materials and methods

2.1. Materials

The binders used were ordinary Portland cement (OPC), which conforms to the relevant standards (ASTM C-150, BS 12 and BS EN 197-1) and sawdust ash. The sawdust ash was sieved using the sieve size $90\mu m$ micron size. Coarse aggregates were crushed granite ranging from $12.5mm$ to $19mm$ sizes and steel slag aggregate collected from an iron producing company (Top Steel Nigeria Limited, Odogunyan, Ikorodu, Lagos State, Nigeria), mechanically crushed using mechanical crusher set from $12.5mm$ to $19mm$ aggregate size. The fine aggregate used was river sand gotten from River Ogun, which was free from organic matter and salt. The water used for this research was clean, portable and impurities-free obtained from University of Lagos Water Distribution System, which was in accordance with BS 3148.

2.2. Methodology

2.2.1. Mix design and sample preparation

A design mix proportions of 343.17Kg/m^3 cement, 622.85Kg/m^3 sand, 1264.58Kg/m^3 granite and 188.74Kg/m^3 water with W/C ratio of 0.55 for a target strength of 30N/mm^2. A total of 48Nos. 150$mm \times$ 150$mm \times$ 150mm concrete cubes and 32Nos. 150$mm \times$ 300mm concrete cylinders specimens were produced. A concrete mixer was used in mixing the concrete constituents to produce freshly mixed concrete. The mixtures were poured into various moulds for different concrete elements and compacted using tapping rod and vibrating machine. The moulds used for the cubes and cylinders were smeared with oil and the specimens were produced. The specimens were demoulded after 242 hours and cured in potable and lagoon water until the age of the test of 7, 14, 21 and 28 days for the cubes and cylinders. The Control sample consists of cement, sand and granite while the composite sample consists of 90% cement, 10% sawdust ash, sand, 75% steel slag aggregate and 25% granite.

2.2.2. Testing procedure

Chemical analysis was carried out on the Portland cement and sawdust ash at the Department of Chemistry, University of Lagos. The physical properties of the research materials were investigated. The workability was determined in the fresh state of the composite concrete. A compressive strength test was conducted using Avery Universal Testing Machine having a loading rate of 120kN/min which was in accordance with BS EN 12390 − 3. Splitting tensile strength test was done in accordance with BS EN 12390 − 6 and ASTM $C496 - 96$ using a loading rate of 120kN/min.

2.2.3. Mathematical model

Formulation of mathematical models

The results of the experimental data for the mechanical properties of the sawdust ash blended steel slag aggregate concrete were analyzed using a multivariate interpolation method to develop mathematical models for predicting parameters with respect to its variables.

Multivariate interpolation method

The algorithm for multivariate interpolation method (bilinear interpolation) for the value of the unknown function f at points x and y. For a known value of f at four points;

$$Q_{11} = (x_1, y_1), \quad Q_{12} = (x_1, y_2), \quad Q_{21} = (x_2, y_1) \quad \text{and} \quad Q_{22} = (x_2, y_2).$$

Linear interpolation in the x-direction gives

$$f(x, y_1) = \frac{x_2 - x}{x_2 - x_1} f(Q_{11}) + \frac{x - x_1}{x_2 - x_1} f(Q_{21}),$$
$$f(x, y_2) = \frac{x_2 - x}{x_2 - x_1} f(Q_{12}) + \frac{x - x_1}{x_2 - x_1} f(Q_{22}).$$

Interpolating in the y-direction gives the estimate:

$$f(x, y) = \frac{y_2 - y}{y_2 - y_1} f(x, y_1) + \frac{y - y_1}{y_2 - y_1} f(x, y_2).$$

Validation of mathematical models

The validation of the model was done by determining the percentage difference and comparing the predicted values on the basis of the model and those data obtained from the experiment using simple percentage difference formula;

$$\text{Percentage Difference} = \frac{\text{Actual Result} - \text{Model Result}}{\text{Actual Result}} \times 100\%.$$

Table 1. Chemical composition of studied materials

Sample	Sample Description	Chemical Constituents (%)												
		SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	$CaCO_3$	SO_3	P_2O_5	$L.O.I$	Total SiO_2 $+Al_2O_3$	Total SiO_3+ Al_2O_3 $+Fe_2O_3$
Cement	Grey Powdery Solid	2.85	5.26	1.35	64.12	2.72	0.76	0.48	11.45	1.2	0.3	0.1	8.11	9.46
SDA	Grey Powdery Solid	31.29	27.38	2.29	10.72	9.2	6.63	10.45	19.14	0	0.5	2.9	59.3	61.59

3. Results and discussion

3.1. Atomic absorption spectrometry (AAS) analysis

The chemical composition of the samples was determined by conduction AAS analysis and the results are presented in Table 1. The results from Table 1 show that the samples are similar physical observation (colour). The similarity in colour does not translate to the ability to perform alike but its performance is based on the degree of its constituents' chemical elements present in it. The combining percentage masses of silica SiO_2, alumina Al_2O_3 and ferric oxides Fe_2O_3 give a total of 61.59% which is similar to those of class C type pozzolans according to ASTM C618-12a. CaO known for providing strength in cement was observed to be low in sawdust ash leading to a low strength performance and increase in setting time. The absence of SO_3 in sawdust ash makes it unsound. The MgO was found to be within the limit range of less than 5% but the sawdust ash recorded 9.2% which can be attributed to the reduction of the strength of concrete (BS 12, 1996; [17]). The loss on ignition value for sawdust ash is within the limits of 3.0% set by BS 12, 1996. The percentages of Na2O and K2O known as the alkali oxides were observed to be large when compared to the standard range (BS 12, 1996), which resulted in some difficulties in regulating the setting time of cement paste.

3.2. Physio-chemical properties of water used in concrete curing

The Physio-chemical properties of the water used for curing were conducted at Central Research Laboratory, University of Lagos. The potable water (UNILAG Tap Water) and lagoon water used as a curing medium in this study were examined in terms of physio-chemical compositions, and all the results are reported in Table 2. According to BS 3148 (1980), any drinkable water, either treated or untreated for distribution through the public supply, is suitable for making concrete. The percentage of chloride content present in both water specimens was within tolerable range and the TDS value is not above 2000ppm which render the water specimens fit for making and curing concrete (BS 3148,1980). A pH range between 6.0 and 8.0 have no significant effect on the compressive strength of concrete but a high percentage of chloride and some other contents contribute significantly. The values of the sulphates and alkalinity of the two water specimens were within the acceptable limit (WHO; BS 3148, 1980). However, it was observed that lagoon water had high chloride, salinity, TDS, total hardness, alkaline and sulphate contents when compared to tap water.

3.3. Physical properties of constituents

Sieve analysis/graduation of aggregates

The results of the sieve analysis for samples are presented in Figures 1 and 2. The results of the investigation on the physical properties of concrete constituents used for this research are presented in Table 3. The fineness of cement or any cementitious materials gives the total surface area of the cement or cementitious materials that is available for hydration. From Table 3, the percentage fineness recorded 53.93% and 37.18% for sawdust ash and cement respectively, indicating that the cement is finer than the sawdust ash. The finer the sample, the more reactive the sample and it offers a greater surface area of particles for hydration. Also, the specific gravities of cement and granite were higher than sawdust ash and steel slag respectively, which signify that cement and granite are denser. This implies that the more the percentage replacement of sawdust ash and

Table 2. Physio-chemical properties of different curing medium

Parameters	UNILAG Tap water	UNILAG Lagoon water	WHO Standard	BS Standard (BS 3148:1980)	Nigeria Standard
ph	6.4	6.3	6.5-8.5	6.0-8.0	6.5-8.5
Temperature(^oC)	27.4	27.5	Ambient	Not mentioned	Not mentioned
Salinity (ppm)	72	460	Not mentioned	Not mentioned	Not mentioned
Conductivity $(uscm^{-1})$	170	340	750	Not mentioned	1000
TDS (mg/l)	125	245	1000	2000	500
Chloride (mg/l)	64	140	250	500	250
Calcium Hardness (mg/l)	48	64	Not mentioned	Not mentioned	150
Total hardness (mg/l)	60	108	100	Not mentioned	Not mentioned
Acidity (mg/l)	12	16	Not mentioned	Not mentioned	Not mentioned
Alkalinity (mg/l)	20	96	100	1000	Not mentioned
Sulphates (mg/l)	60	90	250	1000	100
Colour (pcu)	179	792	15	Not mentioned	Not mentioned
Calcium (mg/l)	7.5	8.86	200	Not mentioned	Not mentioned
Manganese (mg/l)	0.32	0.22	0.5	Not mentioned	0.2
Copper (mg/l)	0.54	0.54	2	Not mentioned	1
Zinc (mg/l)	3.76	5.62	3-5	Not mentioned	3-5
Lead (mg/l)	0.12	ND	0.01	Not mentioned	0.01
Iron (mg/l)	14.98	108.3	0.3	Not mentioned	0.3
Cadmium (mg/l)	0.04	0.21	0.003	Not mentioned	0.003

steel slag in the concrete, the lesser the overall weight of the concrete and structure at large which would be an economic gain for massive structures such as storey buildings and bridges without compromising desired strength.

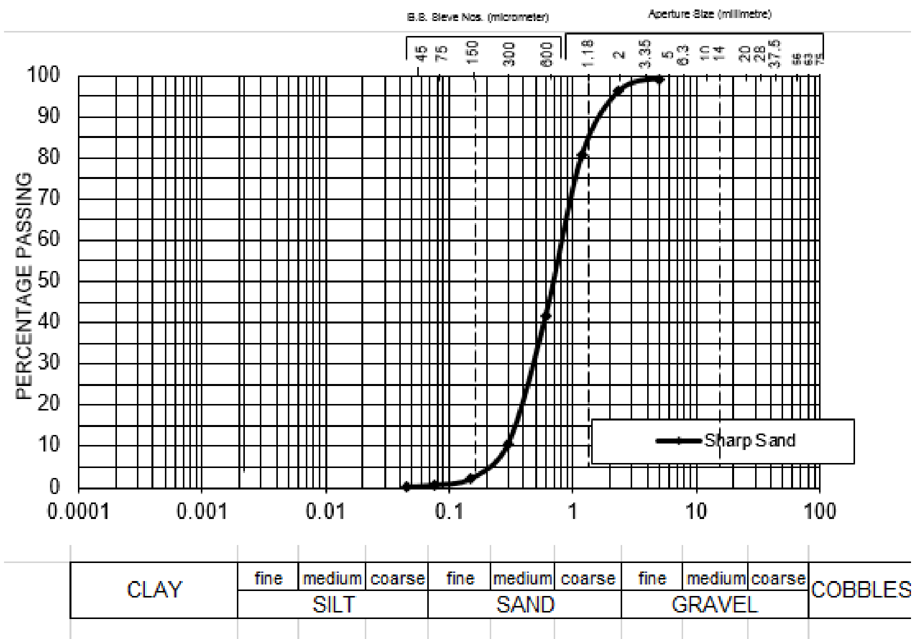

Figure 1. Particle size distribution curve for sand

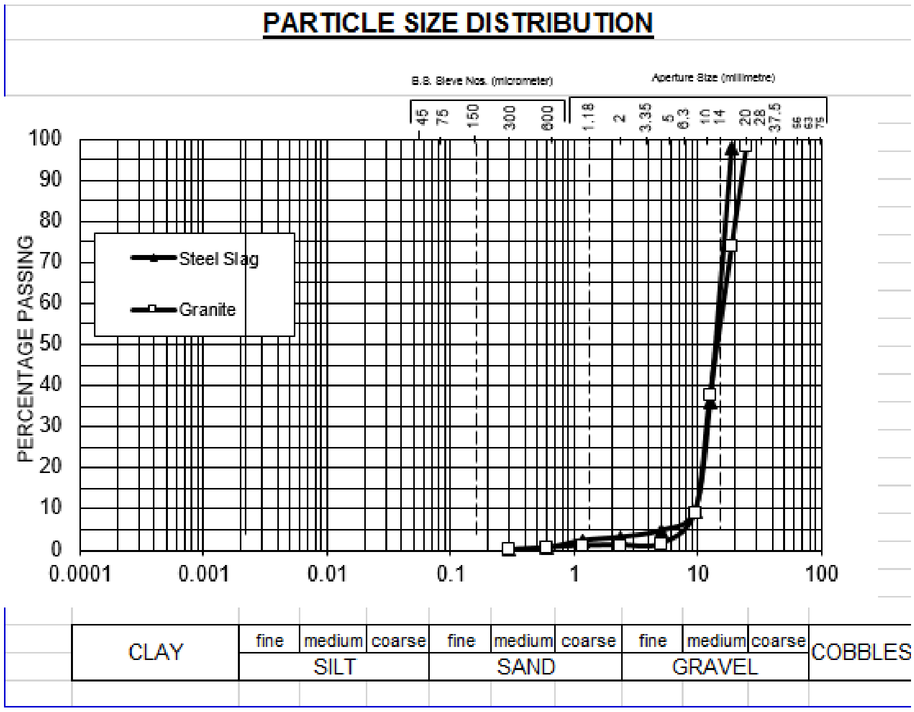

Figure 2. Particle size distribution curve for granite and steel slag

Table 3. Physical properties of studied materials

Physical properties	Cement	Saw Dust Ash (SDA)	Sand	Granite	Steel Slag
Coefficient of Uniformity (C_u)	-	-	2.67	1.7	1.6
Coefficient of Curvature (C_c)	-	-	1.04	0.99	1.06
percentage Fineness (passing 75 microns sieve) (%)	37.18	53.93	-	-	-
Moisture Content (%)	-	-	8.40	0.12	0.87
Dry Density (kg/m^3)	521.01	129.28	126.13	692.66	1098.13
Bulk Density (kg/m^3)	1015.96	511.96	1186.90	1295.27	1229.91
Specific Gravity	2.90	2.11	2.50	2.85	2.64
Water Absorption (%)	-	-	-	1.10	0.61
Aggregate impact value (%)	-	-	-	11.34	22.74
Aggregate crushing value (%)	-	-	-	17.03	25.63
Los Angeless abrasion value (%)	-	-	-	29.50	34.75

The values of dry and bulk density for the concrete constituents are within the standard ranges (BS EN 197-1:2011, BS 12:1996), having steel slag classified as normal weight aggregate according to ASTM C330. The steel slag aggregate recorded a significant increase in moisture content which can be attributed to the presence of voids. The water absorption values for the coarse aggregates are within the standard range of 0.1-2.0%. The results of the aggregate impact value test, aggregate crushing value test and Los Angeles abrasion test revealed that granite has greater resistance, stronger and higher toughness when compared to steel slag.

3.4. Workability of pozzolan blended steel slag aggregate concrete

The results of the slump test and compacting factor test for steel slag aggregate-based concrete are presented in Table 4. From the Table 4, a stiff plastic was observed having no separation of coarse aggregate particles from the mortar matrix during placement. After placement, no notable bleeding was found for fresh concrete.

Table 4. Workability of specimens

	Control	Composite
Slump (mm)	30	20
Compacting factor	0.834	0.825
Degree of Workability	Low	Low
	Stiff plastic	Stiff plastic

The concrete without sawdust ash and steel slag aggregate recorded higher workability compared to the composite mix having sawdust ash and steel slag aggregate. The reduced values of a slump and compacting factor for the composite can be attributed to the presence of water-absorbing properties of sawdust ash and steel slag which left little amounts of water in the mortar available for hydration in the concrete matrix [17,24].

3.5. Density of pozzolan blended steel slag aggregate concrete

The results of the density of sawdust ash blended steel slag aggregate concrete is presented in Figure 3.

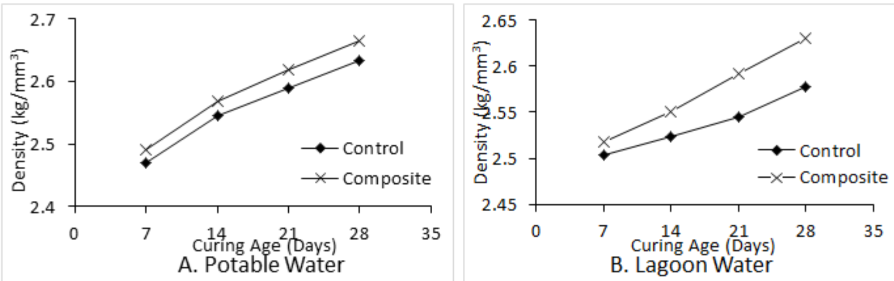

Figure 3. Variation of slump value and compacting factor of pozzolan blended steel slag aggregate concrete

Figure 3 shows the relationship between the control specimen and the composite for two different curing media. The density of concrete increases with an increase in the curing age. A slower rate of strength development was observed for control and composite samples cured in lagoon water due to the presence of some chemicals above the standard level of concentration. Lower densities were recorded for specimens cured in lagoon water. The density at 28 days for the control specimen was about $2640kg/mm^3$ and $2660kg/mm^3$ for the composite. The value of the density of sawdust ash blended steel slag aggregate concrete (composite) was 1.16% higher than the normal concrete with granite (control). The rate of deterioration on the density of the control specimens was 1.16% and 1.26% for composite at 28 days when relating the potable water curing to the lagoon water curing. In both curing media, the composite specimen performed better than the control due to the presence of steel slag aggregate which caused more increase in a unit weight of concrete [25]. The high-density values observed in composite concrete can be attributed to the high dry density of steel slag compared with limestone. Also, the nature of SDA as a good absorbent of moisture contributed to the increase in density [15].

3.6. Compressive Strength of pozzolan blended steel slag aggregate concrete

The results from the compressive strength test performed on the control and composite specimens are presented in Figure 4 for different curing mediums.

From Figure 4, the influence of curing age on the compressive strength of the control and composite specimens was illustrated and it was observed that as the curing age increases, the compressive strength increases for both samples. The compressive strength of the composite was observed to be higher than the control specimens in potable water curing and vice versa in lagoon curing. This was mainly due to cement hydration and the build-up of hydration products which filled up the available pore spaces inside the concrete matrix resulting in strength performance improvement [23]. The rate of internal strength development in the composite depends on the pozzolanic activities of minerals present in the sawdust ash and steel slag as well as their differences in the particle shape, surface texture and zonal composition of aggregates [26,27].

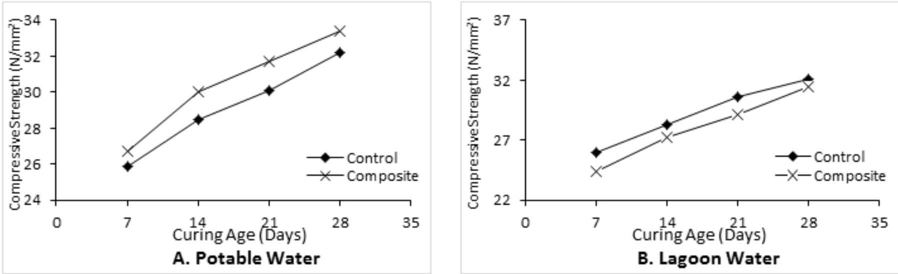

Figure 4. Variation of compressive strength of pozzolan blended steel slag aggregate concrete

The strength gain in the control increased with increase in curing age of 10.03% of 7 days to 14 days curing up to 24.64% gain at 28 days curing in potable water which was observed higher than the specimens cured in lagoon water having 9.13% at 14 days to 23.91% at 28 days. A trend opposite to that of the potable water was observed in the lagoon water curing as the composite having a higher strength gain of 28.96% to that of 24.79% of the control at 28 days. The decrease in the strength of the composite can be attributed to the presence of chloride and sulphate ion which leads to expansion and weakens the bonds between the aggregate and the paste. Therefore, the development of crack formation within the concrete mass together with leaching action of the newly formed compounds would resulting the reduction of the strength. Nevertheless, the swift gain in strength for specimens cured in lagoon water when compared to potable water is due to the quickening effects of some of the chemical compounds present in the curing medium.

3.7. Split Tensile Strength of pozzolan blended steel slag aggregate concrete

The results of the split tensile test have been analysed and presented in Figure 5. These figures clearly demonstrate that the composite performs better in potable water than in lagoon water curing when compared with its control specimens. In the case of potable water curing, composite shows higher strength than control having $2.29 N/mm^2$ to $2.16 N/mm^2$ at 28 days curing age.

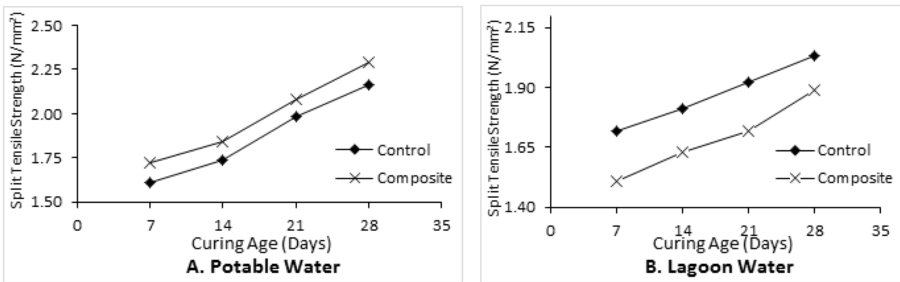

Figure 5. Variation of splitting tensile strength of pozzolan blended steel slag aggregate concrete

In lagoon water curing medium, the split tensile strength for 28 days exposure period is $2.03 N/mm^2$ for control and $1.89 N/mm^2$ for composite. The test reveals that the split tensile strength of both the control and composite is greatly affected by the curing medium and the curing age. From Figure 5, the relationship between relative strength and curing ages or exposure periods for different curing environment was presented. As observed, the strength gain with respect to potable water is 8.07%, 23.04% and 34.16% as the curing age increases for control and 6.98%, 20.93% and 33.14% for composite whereas for lagoon water curing slower strength gains were observed from 5.23% to 18.02% for control while 7.95% to 25.17% for composite at 14 and 28 days respectively. The reason for the lower performance of composite in lagoon water curing is due to expansive materials developed as a result of reactions formed during hydration causing microcracks that weaken the bond between the hydrated products and aggregate particles [28]. Thus, the concrete loses its strength and failure occurs.

3.8. Mathematical models for sawdust ash blended steel slag aggregate concrete using a multivariate interpolation method

Mathematical models were developed from the experimental data to predict some key properties such as density, compression and split tensile strength of sawdust ash steel slag aggregate concrete specimens in different curing medium.

Density prediction model

Potable curing:

$$\begin{aligned}\gamma_d =& -0.17978620 \times 10^{-4} SC^3 + 0.710408163 \times 10^{-2} SC^2 - 0.016976192SC + 0.094000000S \\ &+ 0.3255580 \times 10^{-4} C^3 - 0.0019591837C^2 + 0.042690478C + 0.02255999997.\end{aligned}$$

Lagoon curing:

$$\begin{aligned}\gamma_d =& -0.1 \times 10^{-11} SC^3 + 0.1 \times 10^{-10} SC^2 - 0.001428572SC + 0.010000001S \\ &- 4.859086 \times 10^{-6} C^3 + 0.0003061224C^2 - 0.001904762C + 2.5000000000.\end{aligned}$$

Compressive strength prediction model

Portable water:

$$\begin{aligned}F_{cu} =& -0.3401361 \times 10^{-4} SC^3 - 0.004285714SC^2 + 0.19738095SC - 0.26999998S \\ &+ 0.71914481 \times 10^{-3} C^3 - 0.040000000C^2 + 0.96333334C + 20.81999999.\end{aligned}$$

Lagoon water:

$$\begin{aligned}F_{cu} =& 9.3292260 \times 10^{-4} SC^3 - 0.047653061SC^2 + 0.74928572SC - 4.74999998S \\ &- 0.31098153 \times 10^{-3} C^3 + 0.01214857C^2 + 0.19023809C + 24.010000000.\end{aligned}$$

Split tensile strength prediction model

Potable curing:

$$\begin{aligned}F_y =& 9.718172 \times 10^{-6} SC^3 - 0.3061224 \times 10^{-3} C^2 + 0.001666666SC + 0.0109999999S \\ &- 0.82604470 \times 10^{-4} C^3 + 0.0048979591C^2 - 0.049523809C + 1.760000000.\end{aligned}$$

Lagoon water:

$$\begin{aligned}F_y =& 6.3168124 \times 10^{-5} SC^3 - 0.0031632653SC^2 + 0.049047619SC + 0.4109999996S \\ &- 9.718173 \times 10^{-6} C^3 + 0.0006122449C^2 + 0.003333333C + 1.669999999,\end{aligned}$$

where, C is curing age in days. For control, $S = 0$ and for composite, $S = 1$.

Table 5. Validation of developed mathematical models for the density of pozzolan blended steel slag aggregate concrete using MVI method

Curing Medium	Curing Age	Control			Composite		
		Exp.	MVI Models	Perc. Diff.	Exp.	MVI Models	Perc. Diff.
Normal Curing	7	2.470123	2.470000008	0.004998	2.4908642	2.489999996	0.0346995
	14	2.545185	2.559000008	-0.54278	2.56888889	2.569999992	-0.04325
	21	2.58963	2.589000003	0.024313	2.61925926	2.619999984	-0.02828
	28	2.634074	2.630000038	0.154667	2.66469136	2.669999997	-0.19922
Lagnoon Curing	7	2.503704	2.499999997	0.147929	2.21851852	2.520000007	-0.05882
	14	2.511882	2.51999999	-0.32319	2.55111111	2.550000016	0.043553
	21	2.545185	2.549999981	-0.18917	2.59259259	2.590000029	0.099999
	28	2.577778	2.57999997	-0.08621	2.63111111	2.630000043	0.042228

Table 6. Validation of developed mathematical models for the compressive strength of pozzolan blended steel slag aggregate concrete using MVI method

Curing Medium	Curing Age	Control			Composite		
		Exp.	MVI Models	Perc. Diff.	Exp.	MVI Models	Perc. Diff.
Normal Curing	7	25.8518519	25.85000004	0.00716317	26.7400000	26.74000006	-2.2438E-07
	14	28.4444444	28.44000011	0.01562461	30.0000000	30.00000014	-4.6667E-07
	21	30.0740741	30.07000021	0.0135461	31.7400000	31.74000026	-8.1916E-07
	28	32.2222222	32.22000038	0.00689537	33.3700000	33.37000046	-1.3785E-06
Lagnoon Curing	7	25.9300000	25.92999996	1.5426E-07	24.4100000	24.41000003	-1.229E-07
	14	28.3000000	28.29999991	3.1802E-07	27.2592593	27.26000004	-0.00271754
	21	30.5800000	30.57999988	3.9241E-07	29.1851852	29.19000006	-0.01649767
	28	32.1300000	32.12999986	4.3573E-07	31.4800000	31.48000008	-2.5413E-07

Table 7. Validation of developed mathematical models for the split tensile strength of pozzolan blended steel slag aggregate concrete using MVI method

Curing Medium	Curing Age	Control			Composite		
		Exp.	MVI Models	Perc. Diff.	Exp.	MVI Models	Perc. Diff.
Normal Curing	7	1.61	1.610000002	-1.2E-07	1.72	1.719999998	1.16E-07
	14	1.74	1.740000002	-1.1E-07	1.84	1.839999999	5.43E-08
	21	1.981	1.979999999	0.05048	2.08	2.079999996	1.92E-07
	28	2.16	59999996	-2.8E+09	2.29	2.289999999	3.06E-08
Lagnoon Curing	7	1.72	1.719999997	1.74E-07	1.51	1.510000001	-6.6E-08
	14	1.81	1.809999995	2.76E-07	1.63	1.629999998	1.23E-07
	21	1.92	1.919999993	3.65E-07	1.72	29.19000006	2.91E-07
	28	2.03	2.029999991	4.43E-07	1.89	1.88999999	5.29E-07

4. Conclusion

From the results of this investigation, the following conclusions are made:

1. The chemical composition of sawdust ash in this investigation revealed a total of 61.59% combined percentage of SiO_2, Al_2O_3 and Fe_2O_3 and thus classified as class C type pozzolan.
2. The application of sawdust ash and steel slag aggregate in the production of concrete for building structures will result in a reduced overall weight of the concrete structure due to their low specify gravities and bulk densities. Steel slag aggregate was found to possess good resistance to impact, crushing and abrasion.
3. Lower workability was observed for composite concrete when compared with normal concrete due to the water-absorbing properties of sawdust ash and steel slag which leaves fever amounts of water in the mortar available for hydration in the concrete matrix.

4. The composite concrete recorded higher compressive and split tensile strengths when compared to normal concrete as the curing age increases from 7 to 28 days when cured in potable water.
5. The density, compressive and split tensile strengths of specimens (composite and control) cured in lagoon water were lower than specimens cured in potable water.
6. The developed mathematical models using multivariate interpolation method were found to be in good agreement with the experimental data.

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