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Determination of Sulphate Ion Concentration in Some Ground Water in the Cape Coast Metropolitan Area, Central Region, Ghana and Its Effects on Concrete Brick with Admixture of Sawdust Ash

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Authors' contributions

This work was carried out in collaboration among all authors. Author AKA designed the study, performed the statistical analysis and wrote the manuscript. Authors MAA and ES managed the analysis of the study. All authors read through the final manuscript.

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ABSTRACT

The admixture was prepared from Sawdust waste (SDA) and was pyrolysis by placing it in a Nabertherm (SN224350) at a controlled condition. The SDA was characterized using X-ray diffraction technique and applied as an admixture in producing concrete brick with good cementitious properties. Some key factors that contribute to concrete durability such as compacting, curing ages and the essence of quality water were taking into accounts.The sulphate ion concentration in ground water source was determined and its effects on concrete brick with 5 % SDA, 15 % SDA and 25 % SDA replacement were assessed and its compressive strength reported.5% replacements of sawdust ash, concrete brick (no curing) was found to have suffered greater attack at 28 days immersion period as compared to concrete bricks cured for 3 days and 7 days. 3 days curing and no curing of concrete brick showed a greater resistance against Sulphate intrusion with 25% sawdust ash replacements at 28 days immersion period. Premature curing of concrete brick for 7 days, with an increase in sawdust ash replacement were even more vulnerable to sulphate ion attack than concrete brick with 3 days curing and no curing.

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Keywords: Sawdust; sulphate attack; compressive strength; curing; X-ray diffraction; durability.

1. INTRODUCTION

Many structural materials used in the construction industry have some level of porosity. The ingress of moisture and the transport properties of these materials have become the underlying source for many engineering problems such as corrosion of reinforcing embedded steel, and damage due to freeze-thaw cycling or wetting and drying cycles [1]. Concrete is a porous material that interacts with the surrounding environment. Research have showed that good concrete should have water absorption of less than 10% to be durable [2]. Marthong et al. [3] showed that water absorption of concrete with SDA decreased with age. Chemical attack of concrete shows by way of decomposition of the products of hydration and formation of new compounds which, if soluble, may be reached out and, if not soluble may be disruptive in situ.ACI 515.1 [4] gives the lists of substances which attack concrete to varying degrees. Research on the effect of nitric acids and sulphuric acid on mortar specimens containing Saw Dust Ash (SDA), up to 10 % offered better resistance to deterioration than Portland cement mortar [5].

Some research [6] concentration of about 0.2 % sulphate content in the ground water may suffer attack especially with Mg_2SO_4.

Research have shown that, naturally occurring sulfates (Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}), found in soils and groundwater, readily attack concrete by reacting with the tri-calcium aluminate (C_3A) and free lime to form gypsum. In due course, the gypsum is converted to ettringite which, having a higher volume than the original C_3A, causes expansion and disruption of the cement paste. Moreover, the mechanism by which these ettringite swell is a subject under controversy among researchers. While there is agreement that most (but not all) ettringites will expand in this formation, the exact causes are not agreed.

Sawdust is an industrial waste in the timber industry. According to ITTO [7] the Ghanaian industry produced in 2015 was about 2.6 million m^3 of round wood and the majority of this volume is used within the country since only the export of teak logs is permitted.

Also,the use of outmoded milling machines has add up to the ever increasing of sawdust waste and this has impose a serious problem on waste management at the milling sites. This improper management of sawdust waste at milling sites causes nuisance and could be detrimental to health.According to American society of testing materials [8], pozzalan is a siliceous or siliceous aluminous material, which contains little, or cementitious value, but in finely divided form and in the presence of moisture or water, chemically reacts with calcium of moisture at ordinary temperature to form compound possessing cementitious properties. Sawdust by itself has little cementitious value but in the presence of moisture it reacts chemically and form cementitious compounds and attribute to the improvement of strength and compressive properties. The key constituent required for pozzalanic reaction in Portland cement includes the type of pozzalan material, lime, and water.

The use of pozzalan has been found to impart a range of benefits to plastic and/ or hardened properties of concrete, provided they are used properly. The key to successful use of these materials is knowing the technology of both the materials themselves and of the cements with which they are being associated. Mix designs, proportions of binder components, curing needs, relative rates of strength gain are all factors which must be remembered when using pozzalan material to provide the many benefits which can be derived.

While consuming what are otherwise industrial wastes in a value added approach, the use of pozzalan material makes another significant contribution to the country.

The high temperature cement clinker manufacturing process and subsequent cement milling processes can produce up to one tonne of greenhouse gas per tonne of clinker.

The use of pozzalan materials to reduce the amount of clinker per tonne of cement used can thus significantly reduce greenhouse gas emissions from the cement industry.

Indeed, the cement industry’s target of reducing greenhouse gas emissions to net zero emissions by 2050 would be extremely difficult, if not, impossible to achieve without the ever increasing use of pozzalan material.

2. MATERIALS AND METHOD

2.1 Materials

The materials used in this research work are

a) Sawdust; Obtained from Cape Coast.
b) Ordinary Portland Cement (OPC), Ghana Cement (Ghacem) of 42.5grade [9].
c) Aggregates (fine and coarse); Construction site in the University of Cape Coast premises [10].
d) Clean water [11] and Water; Sourced from the university premises (Okyeso, Duakrow, Ammamoma and tap water).

2.2 Pre-treatment of Raw SDA

2.2.1 Physical treatment

The physical treatment process is mainly a size reduction process. The raw SDA were washed, soaked in tap water for two days, decanted and filtered to eliminate water-soluble impurities. It was then air dried for two days. It was pyrolysed by placing it in a Nabertherm at a temperature of 450 ^{o} C for 2 hrs. to eliminate incorporated organic matter, impurities and obtain the pure char.

2.2.2 X-ray diffraction analysis of SDA

The SDA were characterized using the EMPYREAN Powder X-ray diffractometer of model 0000000011136412 which was used to collect data with divergence slit type fixed and divergence slit size of 0.2177. It was equipped with a CuKα radiation source (K-Alpha1 [Å]-1.54060, K-Alpha2 [Å]-1.54443, K-Beta [Å]-1.39225, K-A2 / K-A1 Ratio-0.50000) and operated at 25 °C, 40 mA and 45kV). For phase identification, scans were taken from 2θ = 5.0525 to 99.8675 with a step size of 0.1050 at scan step time 47.6850s. The diffraction patterns were identified by comparing them with reference data.

2.3 Hydration Reactions of Ordinary Portland Cement

$$3(CaO.SiO_2) + 5H_2O \rightarrow CaO.3SiO_2.3H_2O + 2Ca(OH)_2$$

(Tricalcium silicate) + (Water) → (Tobermorite gel) + (Calcium hydroxide)

$$2(CaO.SiO_2) + 4H_2O \rightarrow CaO.2SiO_2.3H_2O + Ca(OH)_2$$

(Dicalcium silicate) + (Water) → (Tobermorite gel) + (Calcium hydroxide)

As shown above, the amount of calcium hydroxide varies directly with the calcium silicate content of the cement [12,13]. Reactions involving tricalcium silicate yield twice the amount of calcium hydroxide than reactions with dicalcium silicate yield, and thus indicate a greater potential need for pozzolan materials to counter the presence of calcium hydroxide.

2.4 Proximate Analysis of Char or Carbon

2.4.1 Moisture content

A crucible with lid was taken and weighed 2.0 g of sample was taken in the crucible with lid and weighed. It was kept in a hot air oven at 155 °C for 2 hours. It was taken out and kept in the desiccator. Then the weight was taken out.

$$M = \frac{(B-F)}{(B-G)} \times 100 \quad (1)$$

Where; M = moisture content

B = mass of crucible with lid plus sample

F = mass of crucible with lid plus dried sample.

G = mass of crucible with lid

2.4.2 Ash content

A crucible was taken and weighed. 2.0 g of sample of char was taken in the crucible and weighed. The sample was kept in a muffle furnace for 3 hrs at a temperature of 650 °C. Then it was taken out and kept in a desiccator for half an hour to cool down. Then the weight is taken.

$$A = \frac{(F-G)}{(B-G)} \times 100 \quad (2)$$

Where; A = ash content

G = mass of empty crucible
B = mass of crucible plus sample
F = mass of crucible plus ashed sample

2.4.3 Volatile matter

A crucible with lid was taken and weighed, 2.0g of char sample was taken in the crucible with lid and weighed. It was kept in the muffle furnace for 7 minutes. Then it was taken out and kept in the desiccator for half an hour to cool down. The weight of the sample in a crucible with a lid was taken.

$$V = 100 \times \frac{100 \times (B - F) - M \ \times (B - G)}{(B - G) \times (100 - M)} \quad (3)$$

Where,

V = volatile matter

B = mass of crucible with lid plus sample
G = mass of empty crucible

F = mass of crucible with lid plus ash sample

M = moisture content

2.4.4 Carbon content

Carbon content is calculated by;

$$\% \ \textbf{Carbon} = \textbf{100} - (\textbf{volatile matter} + \textbf{moisture content+ash content\%} \quad \textbf{(4)}$$

2.5 Proximate Analysis of Water Sample

Analysis of water sample for the work was based on two main parameters; physical and chemical.

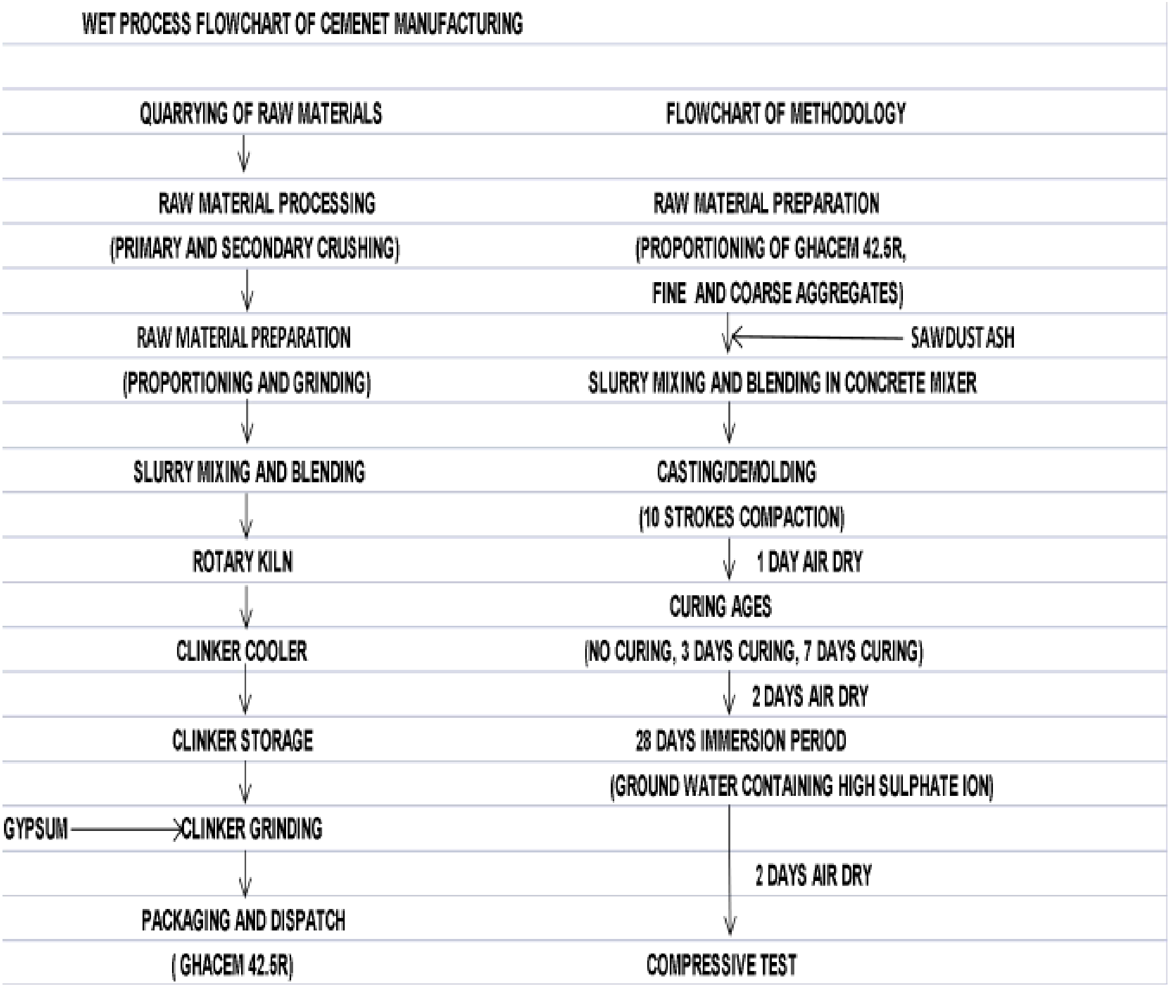

Fig. 1. Shows a flowchart of cement manufacturing (left) and methodology(Right)

2.5.1 Chemical parameter

2.5.1.1 Determination of sulphate ion concentration in ground water by method of nephelometry

Buffer solution A: 30g magnesium chloride, $\mathrm{Mg}Cl_2.6H_2$, 5.0 g sodium acetate, $CH_3COONa.3H_2O,$ 1.0 g potassium nitrate, $\mathrm{K}NO_3$ and 20 ml acetic acid, $\mathrm{C}H_3COOH(99\%)$ were added to 500 ml distilled water and make up to 1000 ml.

Standard H_2SO_4, approximately 0.1 N was used and 2.8 ml of concentrated sulphuric acid was diluted to 1.0 L.It was standardize against 40 ml 0.05 N Na_2CO_3 with about 60 ml distilled water in beaker and titrated potentionmetrically to pH 5. Electrodes were rinsed into the same beaker and boiled gently for 3 to 5 min under a watch glass cover. Solution were allowed to cool to room temperature and glass cover were rinsed into beaker and titrated to pH of 4.3

2.5.1.1.1 Procedure

Turbidity of sample blank was measured with $BaCl_2$.100 ml of each water source (Duakrow, Okyeso, Ammamoma, Tap-water) was measured into 250 ml flask .20 ml of buffer solution A was added and mixed. A spoonful (0.3g) of $BaCl_2$ was added and stirred for 60 sec. Turbidity of each water sample was measured 5 min after stirring ended. The actual normality of sulphuric acid and the volume of acid required to be diluted to was calculated using the formula as follows;

$$\mathrm{N} = \frac{A \times B}{53 \times C} \quad (2)$$

$$\mathrm{mL\ volume} = \frac{20}{N} \quad (3)$$

Where;

A = $(\mathrm{Na_2CO_3})$g weighed into the 1L flask for $\mathrm{Na_2CO_3}$ standard
B = ($\mathrm{Na_2CO_3}$)ml solution taken for standardisation titration
C = $(\mathrm{H_2SO_4})$ ml acid used in standardization titration
N =normality

2.5.2 Physical Parameters

The key physical parameter determined for this research work was the pH of the ground water sources at specified temperature and this was due to the facts that the strength of the concrete brick is affected by the pH of the ground water to some extent and can lead to decalcification of the C-S-H thereby exposing the concrete brick to sulphate attack if the pH is too low. Also, the conductivity of the ions in the ground water source was determined.

2.5.3 Sulphate Ion Attack

The cubes were demolded after 24 hours and was immersed in the ground water sources (tap-water, Ammamoma, Okyeso and Duakrow). Percentage replacement of (5%, 15% and 25%) of concrete bricks with admixture of sawdust ash with no curing,3 days curing and 7 days curing were fully immersed in the ground water for a period of 28 days. Control bricks were cast and subjected in clean water for 3days,7days and no days and later when dried immersed fully in clean water for 28 days.The concrete cubes were removed from the ground water sources and clean water and allowed to air dry for two days and tested for compressive strength.

2.5.4 Mix Design Preparation

When calculating the amount of different aggregates, the “volume method” in Specification for Mix Proportion Design of Ordinary Concrete (JGJ55-2011) was adopted to design the material mix proportion. The formula is as follows [14]:

$$\frac{m_{ca}}{\rho_{ca}} + \frac{m_w}{\rho_w} + \frac{m_c}{\rho_c} + \frac{m_{sd}}{\rho_{sd}} + \frac{m_f}{\rho_f} + 0.01\alpha = 1 \quad (8)$$

In the formula, m_{ca}, m_w, m_c m_{sd}, and m_f are the amount of coarse aggregates,water, cement,sawdust ash and fine aggregates in one cubic meter concrete brick (unit: kg), respectively. The ρ_{ca},ρ_w ρ_c, ρ_{sd}, ρ_f are the apparent densities of coarse aggregates,water, cement,sawdust ash, and fine aggregates (unit: kg/m^3). The $'\alpha'$ is the percentage of air entrained [15] in the concrete, here the value is equal to one.

2.5.5 CASTING

Mold of dimensions 50.8 mm x 50.8 mm x 50.8 mm were cleaned and oiled and used to cast the concrete cubes. The concrete mix was done by an electric mixer. The concrete mix were filled into the molds in three layers with each layer compacted for 10 strokes and then leveled using the spade and then allowed to set for 24 hours.

2.5.6 COMPRESSIVE STRENGTH

The compressive strength of the concrete cubes was tested using CTM Servo Models Hydraulic Compression Testing Machine, (Y) =0.9943 x load + 3.2747). Samples were placed centrally on the lower plate of the CTM with each concrete brick of sawdust ash percentage replacements (5 %, 15 % and 25 %) repeated for three times without applied shock and continuously increased at a constant rate and their corresponding average load recorded. The compressive strength of the concrete bricks was calculated using the expression below;

$$\text{Compressive Strength} = \frac{\text{LOAD}}{\text{AREA}} \quad \ldots (9)$$

3. RESULTS AND DISCUSSION

The analysis from Table 1 the various contents expressed in percentages where carbon content gave the highest yield. From this analysis, it can be concluded that SDA has a high carbon content.

The work of Elinwa, A.U., and Ejeh when considering the mineralogical properties of SDA through the X-ray diffraction analysis suggested that sawdust ash has a higher amount of silica dioxide (SiO_2) as compared to the other oxidants. He said, the key indicator for the pozzolanic activity occurs in the sawdust ash (SDA). From the Fig. 2, the highest peak was at peak height 2500 and this may be associated with high electron density variation in SDA.

From the graph Fig. 3; it was observed that, ammamoma water source recorded the highest sulphate concentration hence greater possibility of gypsum formation which may lead to enttringite.

From the Fig. 4, Okyeso water source showed high conductivity value as compared to the other water sources and this may be as a result of sea intrusion due to the closeness of Okyeso water source to the sea.

The analysis from the Fig. 5, can be deduced that the load pressure increased in each water source with respect to increase in SDA percentage replacements.

The analysis from Table 2 can be deduced that increase in sawdust ash replacements in concrete brick (no curing) increased with compressive strength in all water sources.Hence,the maximum compressive strength of the concrete brick to resist sulphate ion attack was at 25% SDA replacements.

Table 1. Proximate analysis of char or carbon

Proximate analysis	Value (wt %)
Moisture content	0.324
Ash content	0.512
Volatile matter	34.251
Carbon content	64.913

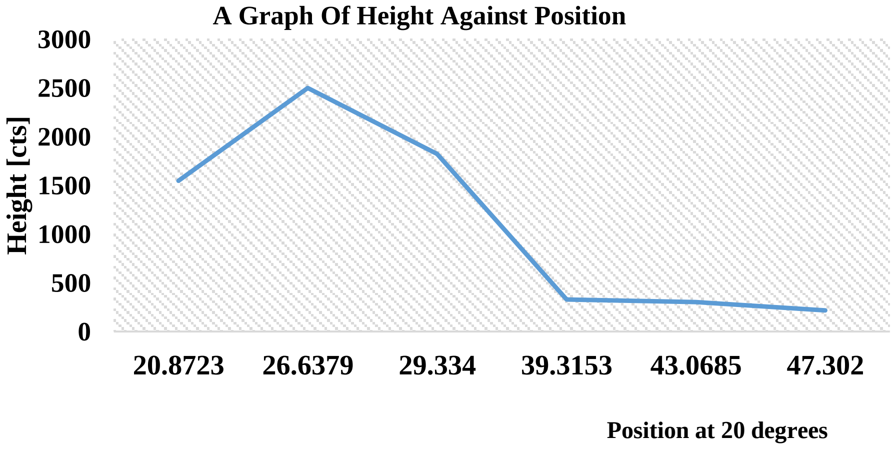

Fig. 2. A graph showing the height against position of SDA from XRD data

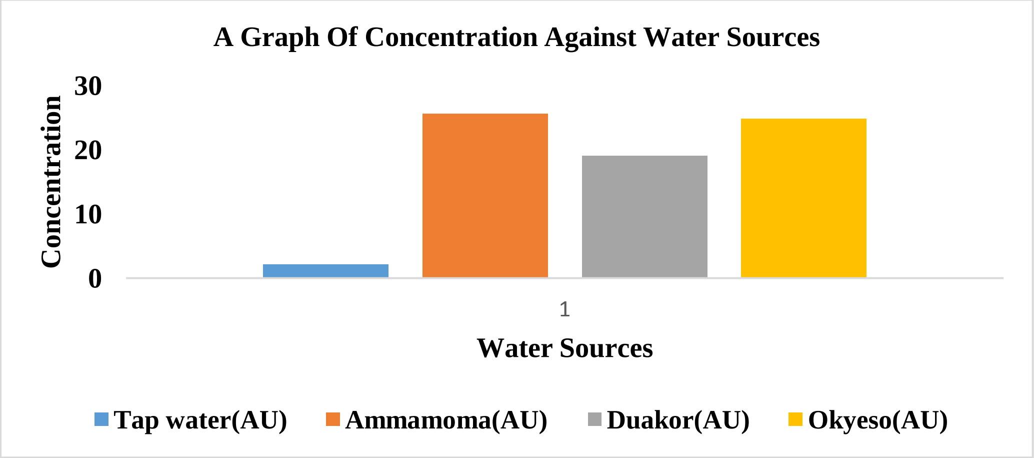

Fig. 3. Shows a graph of concentration (mg/L) against water sources

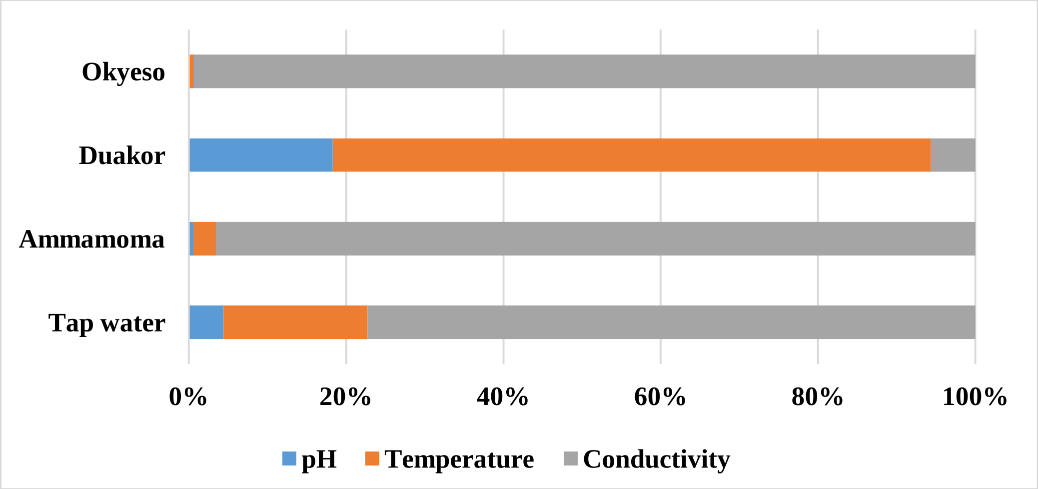

Fig. 4. Shows a graph of water sources against (pH, Temperature and Conductivity)

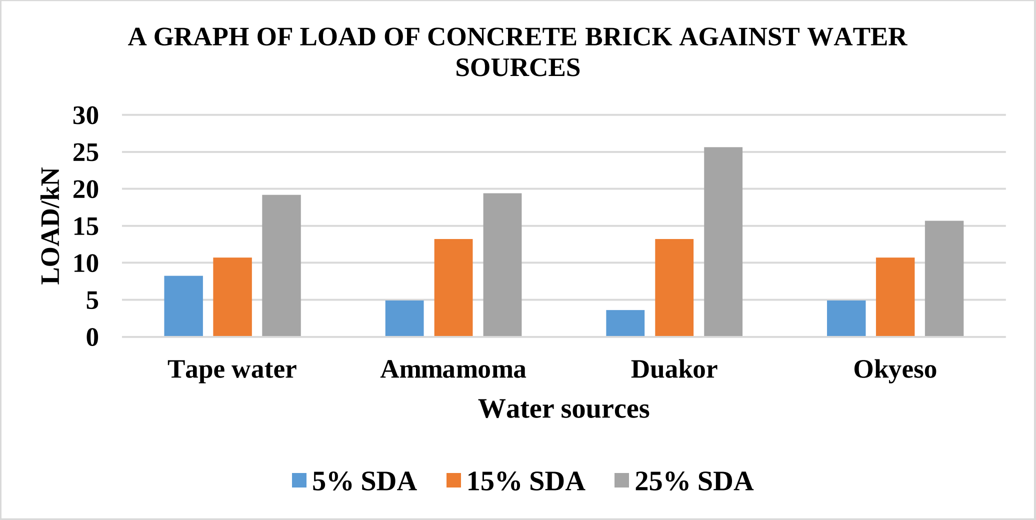

Fig. 5. shows loads of concrete bricks against water source (no curing) for 28 days immersion period

Table 2. Compressive strength of concrete brick with percentage replacements of sawdust ash (no curing) at 28days immersion period. 5% mix Control (0.019KN/mm^2), 15% mix control (0.021KN/mm^2) and 25% mix control (0.023KN/mm^2)

% Replacements	Tap water (KN/mm^2)	Ammamoma (KN/mm^2)	Duakor (KN/mm^2)	Okyeso (KN/mm^2)
5	0.0032	0.0019	0.0014	0.0019
15	0.0042	0.0051	0.0051	0.0042
25	0.0074	0.0075	0.0099	0.0060

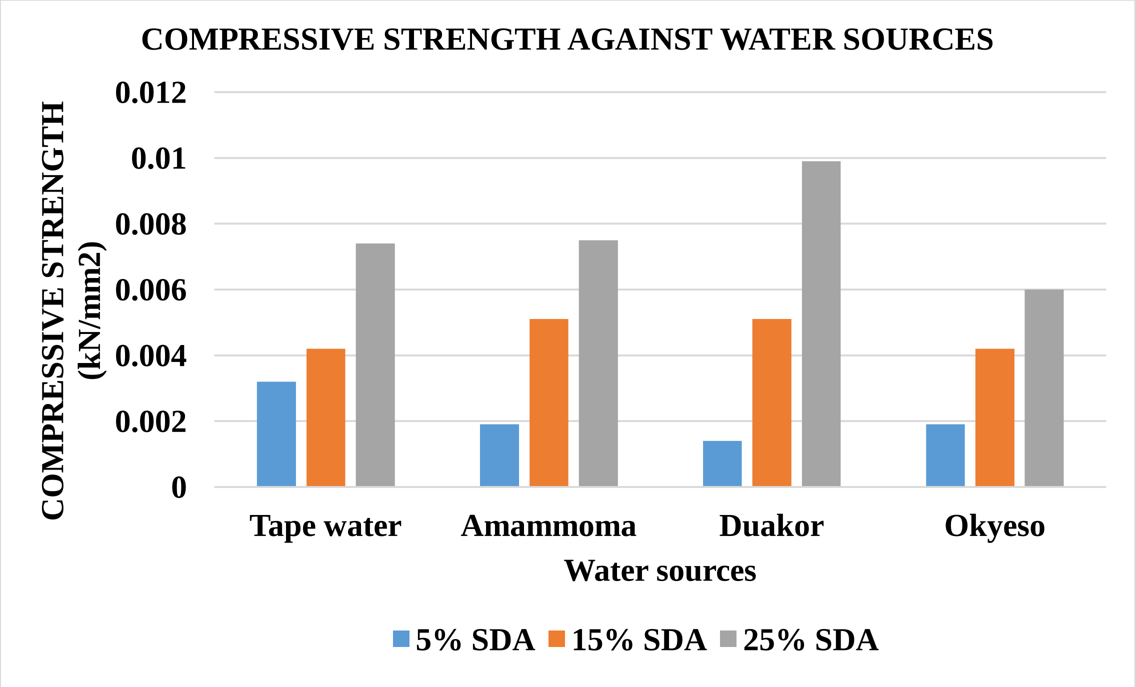

Fig. 6. shows compressive strength of concrete brick with percentage replacements of sawdust ash against water sources (no curing) for 28 days immersion period

From the Fig. 6 it can deduced that, increased in compressive strength with respect to SDA replacement might be due to the fact that the sawdust ash fill the porous spaces of the cement paste on hydration hence making it impervious for ground water intrusion.

The analysis from the Fig. 7, can be deduced that the load pressure decreased in tape water and Ammamoma water source with respect to increase in SDA percentage replacements whilst in Duakor and Okyeso water source, it decreased from 5% to 15% of SDA replacements and hence an increase in Duakor water source. From the graph, concrete bricks fully immersed in Ammamoma water was found to have suffered greater damage even with an increase in SDA contents.

The analysis from the Table 3 when compared to Table 2. Making reference to Ammamoma water source. At 5% SDA replacement,the compressive strength of the concrete brick increased by a factor of 0.0091 and then showed a decrease in strength with SDA replacements at 25%.Henceforth,3days curing of concrete brick was more vulnerable to sulphate ion attack when compared to concrete bricks of no curing days and thus the additional reduction in compressive strength at 25% SDA replacement was 0.0015.

From the Fig. 8, it can be summarized that, removal of voids by full hydration of the binder to achieve a high quality concrete brick and least possible permeability by curing are objectives well known to concrete practitioners but all too rarely achieved in practice.Hence,when the Fig. below was compared to Fig. 6 it could be deduced that, the 3 days curing of concrete brick performed poorly after the 28 days immersion period in the ground waters.

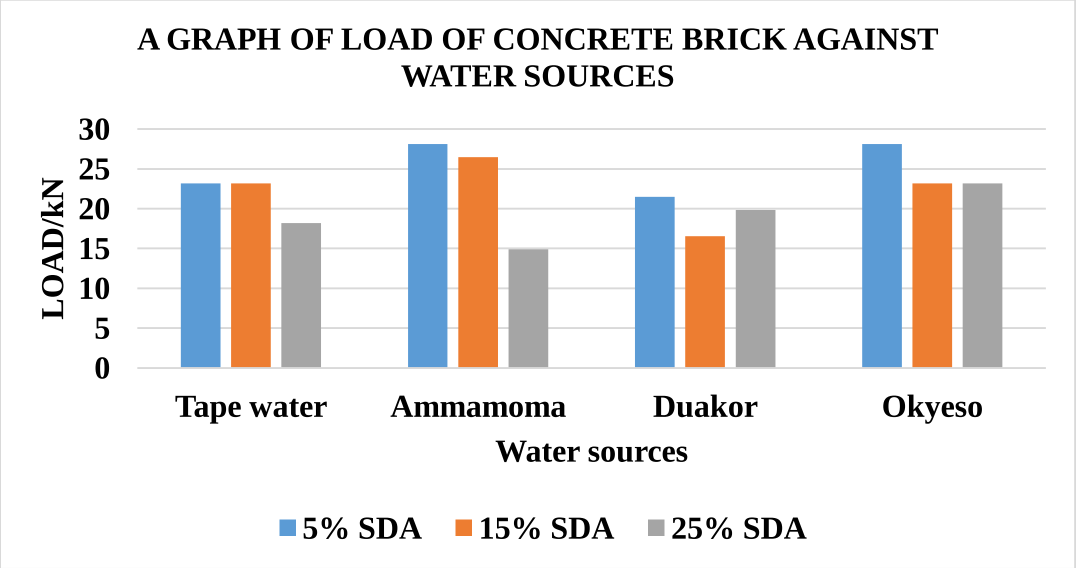

Fig. 7 Shows Loads of concrete brick with percentage replacements of sawdust ash against water sources (3 days curing) for 28 days immersion period

Table 3. Compressive strength of percentage replacements of concrete brick (3days curing) at 28days immersion period. (5% mix Control (0.018KN/mm^2), 15% mix control (0.022KN/mm^2) and 25% mix control (0.024KN/mm^2)

% replacements	Tap water(KN/mm^2)	Ammamoma(KN/ mm^2)	Duakor(KN/ mm^2)	Okyeso(KN/ mm^2)
5	0.009	0.011	0.008	0.011
15	0.009	0.010	0.006	0.009
25	0.007	0.006	0.007	0.009

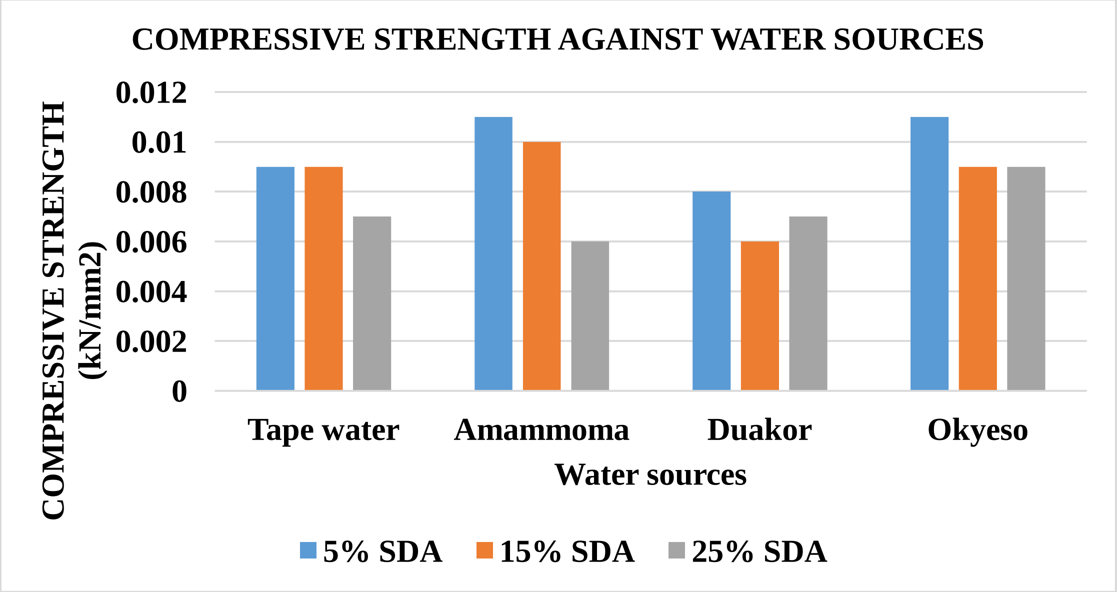

Fig. 8 shows compressive strength of concrete brick with percentage replacements of sawdust ash against water sources (3 days curing) for 28 days immersion period

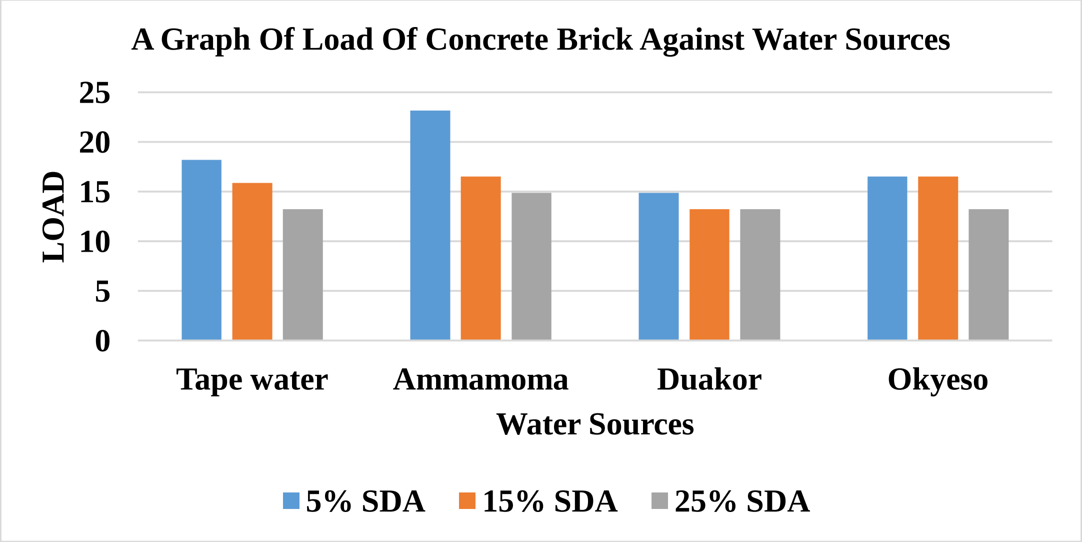

Fig. 9. shows Loads of concrete brick with percentage replacements of sawdust ash against water sources (7days curing) for 28days immersion period

Table 4. Compressive strength of percentage replacements of concrete brick (with 7days curing) at 28days immersion period. (5% mix Control (0.019KN/mm^2), 15% mix control (0.023KN/mm^2) and 25% mix control (0.025KN/mm^2)

% replacements	Tap water(KN/mm^2)	Ammamoma(KN/ mm^2)	Duakor(KN/ mm^2)	Okyeso(KN/ mm^2)
5	0.0070	0.0090	0.0058	0.0064
15	0.0061	0.0064	0.0051	0.0064
25	0.0051	0.0058	0.0051	0.0051

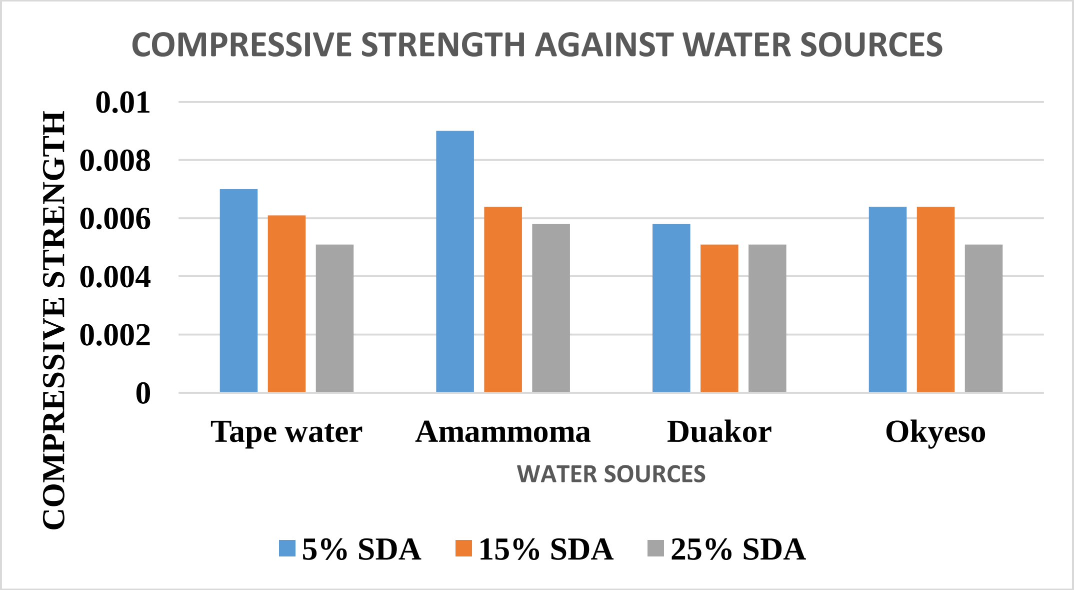

Fig. 10. A graph showing the Compressive strength of concrete brick with percentage replacements of Sawdust ash against water sources (7days curing) for 28 days immersion period

The analysis from the Fig. 9, can be deduced that the load pressure decreased in tape water and Ammamoma water source with respect to increase in SDA percentage replacements. In Duakrow water source, it decreased from 5 % to 15 % of SDA replacements and remained constant from 15 % to 25 % increment in SDA. In Okyeso water source,it remained constant from 5 % to 15 % and then decreased from 15 % to 25 % SDA replacements.

The analysis from the Table 4, can be deduced that the compressive strength of the concrete brick decreased with respect to increase in SDA percentage replacement.Henceforth,7days curing of concrete brick was even more vulnerable to sulphate ion attack when compared to 3 days curing of concrete brick and thus the additional reduction in compressive strength at 25% SDA replacement was 0.0002 with reference to Ammamoma water source.

From the Fig. 10, it was observed that, the additional reduction in compressive strength might be due to the fact that sawdust ash is porous and might have absorbed more water during the 28days immersion in the ground waters causing unstable volume and subsequent poor cohesion between the cement-matrix interface.

4. CONCLUSION

5% replacements of sawdust ash, concrete brick (no curing) was found to have suffered greater attack at 28 days immersion period as compared to concrete bricks cured for 3 days and 7 days. 3 days curing and no curing of concrete brick showed a greater resistance against sulphate intrusion with 25% sawdust ash replacements at 28 days immersion period. Premature curing of concrete brick for 7 days, with an increase in sawdust ash replacement were even more vulnerable to sulphate ion attack than concrete brick with 3 days curing and no curing.

Conclusively, this research work has demonstrated that sawdust ash been industrial waste, non-toxic and bio-degradable material could be used as an admixture to produce concrete brick with good cementitious properties.

5. RECOMMENDATION

Further research should be carried on curing ages at which concrete brick with admixture of sawdust ash can be able to resist sulphate ion in ground water.

DATA AVAILABILITY

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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