Nigerian Journal of Technology (NIJOTECH)
Vol. 41, No. 2, March, 2022, pp.212 –221
www.nijotech.com

Print ISSN: 0331-8443
Electronic ISSN: 2467-8821
http://dx.doi.org/10.4314/njt.v41i2.2

Durability Properties of Cement – Saw Dust Ash (SDA) Blended Self Compacting Concrete (SCC)

S. Ayuba[1, *], O. U. A. Uche[2], S. Haruna[3], A. Mohammed[4]

[1] *Department of Engineering, Federal University Wukari, Taraba State, NIGERIA*
[2, 3, 4] *Department of Civil Engineering, Bayero University Kano, Kano State, NIGERIA*

Abstract

This paper report the durability properties of self-compacting concrete (SCC) modified with Saw dust ash (SDA) exposed to an aggressive media. Saw dust ash (SDA) was used to partially replace OPC in SCC at 0 - 30%. A number of trials mixes were conducted to obtain grade 40 SCC, with a suitable mix proportion varied at 5, 10, 15, 20, 25 and 30 % by weight of the binder as OPC replacement in SCC. Constant water to binder ratio of 0.37 with water reducing admixtures was used in all the mixtures. The research reveals that SDA enhanced the resistance of SCC against Na_2SO_4 attack at 5% replacement but performed poorly in H_2SO_4. The water absorption of SCC decreases with an increase in SDA content. The resistance of SDA-SCC to elevated temperature is reduced with an increase in SDA content. The compressive strength of the SDA-SCC decreases with the age of exposure in an aggressive media. The SEM result revealed the presence of crystal like spikes of SDA particles, which may contribute significantly to the high surface area of the ash particles and results in a porous structure at an early age.

Keywords: Saw dust ash, Self-compacting concrete, Sulphate attack, Elevated temperature, Water absorption

1.0 INTRODUCTION

Concrete is the most useful and diverse construction material the powerful source of infrastructural development of any nation. Engineering practice and construction work around the world depends to a very large extent on concrete[1]. Concrete is the dominant material used for the construction of infrastructures, it is the world most used construction material because of its properties[2]. The use of concrete today cannot be over emphasized, due to its economic and commercial benefit. Concrete is produced by using considerable amount of cement. However, cement production utilizes extensive amount of raw materials at high temperature of 1450˚C combined with emission of harmful gases which pollutes the atmosphere. This contributes to a significant extent of 5–7% of total anthropogenic carbon dioxide emissions [3]. The annual emission of toxic metals, material pollutant and noise are associated with almost all the processes involved in cement production. This is a serious global environmental problem since increase in carbon dioxide in the atmosphere has direct consequences on global warming which contribute to abiotic depletion, acidification, and marine eco-toxicity [4]. Previous reports revealed that besides the environmental friendliness, the use of supplementary cementitious materials (SCMs) such as pulverized fuel ash (PFA), ground granulated blast furnace slag (GGBS), silica fume (SF), metakaolin (MK) and rice husk ash (RHA) lessens the cost of concrete and improves the durability of hardened concrete, thereby enhancing the service life of structures [5-7]. In addition, it has been reported in literatures that Partial replacement of OPC with pozzolans has been highly encouraging as it reduce cement production [8-10]. Pozzolanas such as rice husk ash have gained acceptance as supplementary cementing materials in many parts of the world [11].

Self-compacting concrete SCC is an advanced construction material which is able to flow through heavy and congested reinforcement and consolidate fully under self-weight completely filling the formwork, [12]. It first came to existence in 1980's in Japan to tackle the key factors responsible for poor performance of normal concrete structures due to lack of uniform and complete compaction. previously, attaining a full compaction of concrete on construction site was a challenge as a result, several efforts to achieve concrete with full compaction and without the use of vibrator was carried out which lead to the development of modern SCC [13]. Its highly fluid nature makes it suitable for placing in difficult conditions

*Corresponding author **(Tel:** +234 (0) 8068227651**)**
Email addresses: solos4life@gmail.com (S. Ayuba), uoaustine.civ@buk.edu.ng (O. A. Uche), sharuna.civ@buk.edu.ng (S. Haruna), trophygroup2010@gmail.com (A. Mohammed)

and in sections with complex and congested reinforcements [14]. Consolidation is fully achieved due to its own self-weigh and offers some economic and environmental benefits over the normal vibrated concrete in construction. SCC production required more cement (400 – 600 kg/m^3) [15]. This suggests that SCC production increases the emission of CO_2. Nevertheless, there is a need to comb for alternative methods that can systematically reduce the carbon footprint in concrete using waste material [16].

Sawdust is a waste material from the timber industry; produced as the loose particles or wood chippings obtained as by-products from sawing of timber in to standard usable sizes [17]. Previous research by [18, 19] revealed that Nigeria produce about 5.2 million tonnes of SDA per year. The huge amount of wood waste produced are often discarded as useless material which causes several environmental and landfill related issues as a result of wrong methods of handling. These unselective disposal practices consequently lead to untoward environmental problems and contribution to climate change [20-22]. At the same time contradict sustainable solid waste management which entails various activities that encourage the efficient utilization of the waste produced so that the sustainable development goals are largely achieved [23, 24]. Therefore, to promote green construction technologies and to reduce the environmental problems, a enormous variety of agro wastes have been introduced to the current construction industry for their potential use as a substitute of cement clinker. Recently, many researchers have investigated the role of SDA as a potential supplementary cementitious material in concrete [25–27]. It reveals that, the pozzolanic efficiency of SDA is mainly dependent on its source. At the same time, the chemical composition of ash varies among tree species, growing conditions such as soil type and climate, and combustion methods [28, 29]. From the micrographs obtained after SEM analysis, [30] observed that, ash particles collected from different sources exhibits variations in physical characteristics also method of incineration influences the particle size, shape and several other characteristics. Research also revealed that SDA consist high calcium oxide group and high silicate oxides group and the high loss on ignition was attributed to uncontrolled incineration [31, 32].

Furthermore; the findings of [33] shows that wood waste ash act more as filler material within the cement paste matrix than as binder material Investigations from previous research work using SDA collected from undisclosed timber species [34,35] revealed that the chemical compositions of SDA is reach in Calcium Oxide (CaO) (50.64, 61.0, 42.5 and 64.47). In addition; the findings of [36], shows that the compressive strength containing SDA, increased with curing age, however decrease in relation to the control as the percentage replacement of cement with SDA increases. Research from previous years have revealed that the agricultural waste can be processed into the mixture of concrete as cementitious supplementary substitution ingredients [37-39] Previously, extensive studies have been carried out on the use of saw dust ash in normal vibrated concrete [32, 35] but, little or no extensive research has been conducted on the durability of saw dust ash (Afara, Ashwale and Iroko) as cement replacement in self-compacting concrete, the research focus on the durability of self-compacting concrete using SDA sourced from Afara, iroko and Ashwale.

2.0 MATERIALS AND METHODS

2.1 Materials

2.1.1 Cement

Cement used in this study is Dangote brand Ordinary Portland cement (OPC) grade 42.5 conforming to BS EN 197 [40] with oxide composition and physical properties presented in Table 1 and 2. The cement has a percentage fineness (% retained on 45µm sieve) of 13%, bulk density of 1448kg/m^3 and a specific gravity of 3.15.

Table 1: Oxides composition of cement and SDA

Oxides	Dangote Cement OPC (%)	SDA (%)
SiO_2	16.42	22.55
AL_2O_3	3.23	3.21
Fe_2O_3	4.42	2.51
CaO	69.93	40.05
MgO	1.36	3.39
SO_3	1.98	1.06
Na_2O	0.32	2.41
K_2O	0.66	16.11
P_2O_5	0.103	0.02
Cl	0.1	0.11
TiO_2	0.31	0.21
Mn_2O_3	-	0.02
BaO	0.18	-
LOI	1.04	5.89

2.1.2 Saw Dust Ash

Saw Dust Ash (SDA) used in this research consist only of Afara, Ashwale and Iroko was collected from timber industries in Kano State, Nigeria, and burned to ash at a controlled temperature of 600 ˚C for 4 hours using incinerator, similar to the work of [26, 41]. The grading of SDA and oxide composition is presented in Table 1 and Figure 1 respectively. The oxide composition did not satisfied the requirement specified in ASTM C-618 for a good pozzolana as the sum of SiO_2+Al_2O_3 +Fe_2O_3 not less than 70% as shown in Table 1, similar to the work of [26, 33, 34, 42]. The morphology of the SDA is presented by a SEM Micrograph shown in figure 6 and 7.

2.1.3 Aggregate

The fine aggregate used in this research was clean river sand with properties as shown in Table 2. The sieve analysis was conducted in accordance with BS EN 933 [43] and the particle size distribution as well as grading limits was determined based on BS EN 882 [44] as shown in Figure 1.

Similarly, it also revealed that the coarse aggregate has a maximum size of 14 mm, fineness modulus of 6.50, specific gravity of 2.76, and bulk density of 1664 kg/m^3 as shown in Figure 1 and Table 2. Potable water was used for mixing and curing the SCC and Super plasticizer of 7.49 kg/m^3 was used to improve the fresh properties of the SCC this is in line with[45-47]

Table 2: Physical Properties of Binders and Aggregates

	Cement	SDA	Fine Aggregate	Coarse Aggregate
Specific gravities	3.15	2.21	2.61	2.76
Fineness (Retained on 40 µm sieve)	13	17	-	-
Fineness modulus	-	-	2.55	6.50
Bulk Density (kg/m^3)	1445	645	1569	1664

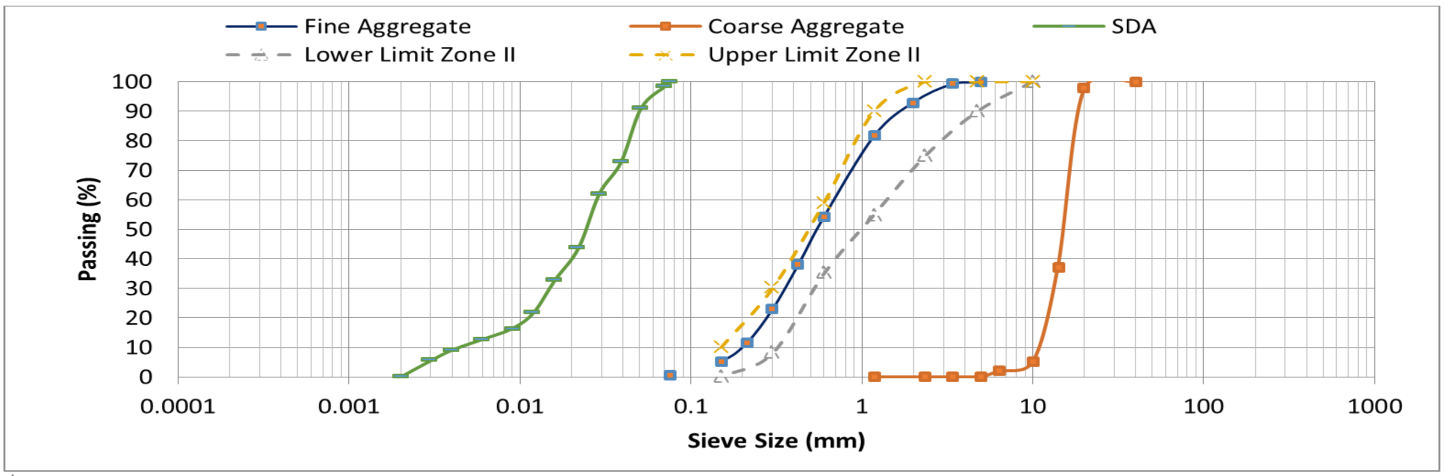

Figure 1: Grading of aggregates and saw dust ash

2.2 *Mixing and Test Methods*

2.2.1 Mix design of self-compacting concrete

The mix design was obtained using the principles for selecting and proportioning SCC constituents in accordance with BS EN 206 (2013) [48]. Grade 40 SCC was obtained by trial mixes using a 0.37 water-cement ratio as shown in Table 3. The control mix was used for the other SCC mixes containing 5, 10, 15, 20, 25 and 30 percentages by weight of SDA in cement replacement. The constituent materials for the SCC – SDA are presented in Table 3.

Table 3: Materials Batching of SCC with SDA

Mixtures	SDA (%)	Cement (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	Super plasticizer (kg/m^3)	SDA (kg/m^3)	Water (kg/m^3)
TM1	0	510.0	870	890	7.49	0.0	180
TM2	5	484.5	870	890	7.49	25.5	180
TM3	10	459.0	870	890	7.49	51.0	180
TM4	15	433.5	870	890	7.49	76.5	180
TM5	20	408.0	870	890	7.49	102.0	180

Mixtures	SDA (%)	Cement (kg/m³)	Sand (kg/m³)	Granite (kg/m³)	Super plasticizer (kg/m³)	SDA (kg/m³)	Water (kg/m³)
TM6	25	382.5	870	890	7.49	127.5	180
TM7	30	357.0	870	890	7.49	153.0	180

2.2.2 Sample preparation

The SCC was achieved by first mixing the fine and coarse aggregates with 10% of the required water. The cement and SDA were added and mixed homogeneously. About 60% of the water was added and mixed uniformly. The plasticizer was added to the remaining water and mixed with the concrete until a homogenous and uniform mixture of saw dust ash self-compacting concrete (SDA-SCC) was achieved. The SDA-SCC was cast in 100mm diameter and 200mm height cylinder and 100 mm x 100mm x 100 mm cube molds. The specimens were cured in clean water for 28 days before testing for durability.

2.2.3 Testing methods

The durability test was carried out on SDA-SCC samples to study the physical characteristics under the effect of different conditions such acid, salt and temperature. SDA-SCC Concrete of (100mm x 200mm) was initially cured in water for 28 days and the concrete cubes were later immersed into a 5% concentrated solution of hydrogen tetraoxosulphate (VI) acid (H_2SO_4). The concrete samples were submerged in the acid solution for a period of 3, 7, 28, 56 and 90 days. At the end of the exposure periods, the concrete samples were removed the surface was washed with clean water, air-dried and reweighed to enable assess the effect of the acid on the weight loss. The calculation of weight loss was conducted using Equation 1. Thereafter the test was repeated using a 5% concentrated sodium tetraoxosulphate (V) salt (Na_2SO_4).

$$\text{Percentage weight loss} = \frac{loss\ in\ weight}{original\ weight} x100\% \quad (1)$$

For elevated temperature exposure, SDA-SCC specimens of (100 x 100 x 100) mm concrete cubes were used in this test. After 28 days of curing in water, the samples were air-dried, weighed and then subjected to heat at elevated temperature 200, 300, 400, 500, and 600 ˚C respectively for one hour using CARBOLITE CWF1100 model furnace and thereafter was allowed to cool and then reweighed before crushing. The effects of increase in temperature on the SDA-SCC samples were evaluated in relations to percentage weight loss and percentage loss in strength as shown in Equation 2. The schedules of durability test specimens cast is shown in Table 4.

$$\text{Percentage loss in strength} = \frac{s_{bh}-s_{ah}}{s_{bh}} x100\% \quad (2)$$

Where, s_{bh} = Strength before heating, and s_{ah} = Strength after heating

Water absorption test was performed in compliance with [49] and BS 1881-122: (2011) using SCC containing 0, 5, 10, 15, 20, 25 and 30 SDA as partial replacement of cement in SCC. SDA-SCC specimens (100 x 100 x 100) mm cubes were cast and cured for 28 days. The cured samples were dried in the D81L201 multipurpose oven at about 60 ˚C, then cooled for 24 hours, and then was totally immersed in the water for 30min. The water absorption was calculated in percentage as given in Equation (3).

$$\text{Water absorption} = \frac{m2-m1}{m1} x100\% \quad (3)$$

Where, m_1 = mass of saturated sample when suspended in air, and m_2 = mass of dry weight sample.

Table 4: Schedules of Durability Test Cast

Test	Materials	Sample	Dimension (mm)	No Per Sample	Mix proportions (%)	Total
Effect of Heat at 200℃ - 600℃	SDASCC	Cube	100 x 100 x 100	3	0,5,10,15,20,25,30 SDA	105
Water Absorption	SDASCC	Cube	100 x 100 x 100	3	0,5,10,15,20,25, 30 SDA	21
H_2SO_4	SDASCC	Cylinder	100 x 200	3	0,5,10,15,20,25,30 SDA	21
Na_2SO_4	SDASCC	Cylinder	100 x 200	3	0,5,10,15,20,25,30 SDA	21

3.0 RESULTS AND DISCUSSION

3.1 Effect of H_2SO_4 on the properties of SDA in SCC

The effect of 5% concentration of sulphuric acid (H_2SO_4) on SDA-SCC shown in terms of weight loss, in Figure 2, revealed that the weight of concrete cubes was gradually reducing and increases with increase in SDA compared to the control (OPC). At the early age of 3 and 7 days, there appear to be minimal change in the weight of the concrete cubes, but as the age increases, the weight also decreases. It was observed that the weight loss of SDA-SCC has similar values with the control at 5% replacement in 5% H_2SO_4 solution. This development in weight may be attributed to low CaO available in the mix due to the effect of percentage replacement for reaction with acids since low calcium hydration products have more durability towards acid attack [24]. However, rapid decrease was observed as SDA content increases beyond 5%, at a higher % replacement of SDA with high CaO (40.05 %) may possibly produce additional $Ca(OH)_2$ for reaction with H_2SO_4 to produce weaker compound (gypsum) that is formed as a result of neutralization reaction between H_2SO_4 and $Ca(OH)_2$. The formation of calcium sulfate (gypsums) leads to softening of the concrete specimens, thus decrease its density. The acid attack damages the concrete surface causing expansion and weight loss of specimens which is the major indicator of deterioration of the concrete [25]. In addition, OPC is rich in calcium (Ca) and four major phases of OPC which are alite (Ca_3SiO_5), belite (Ca_2SiO_4), aluminate ($Ca_3Al_2O_6$) and ferrite (Ca_2AlFeO_5) which are considerably composed of calcium, this react with acetic acid producing a gel-like precipitate. Calcium acetate is soluble and leaves the OPC paste [50] The H_2SO_4 attack on SDA-SCC is shown in the chemical reaction in equation 4 and 5.

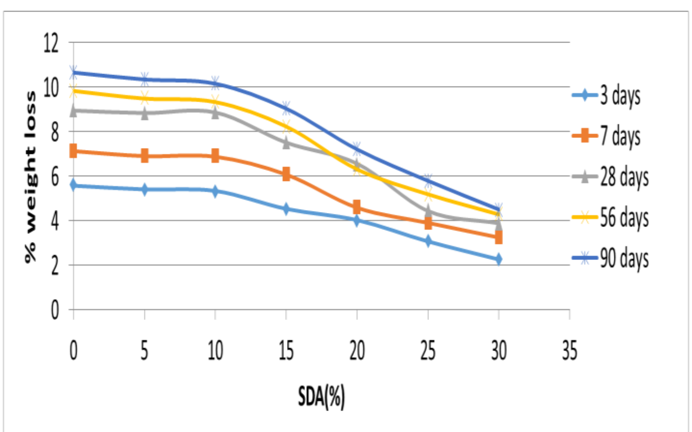

Figure 2: Effect of H_2SO_4 on property of SDA in SCC

$$H_2SO_4 + Ca(OH)_2 \rightarrow CaSO_4.2H_2O \text{ (gypsum)} \quad (4)$$

$$3CaSO_4+3CaO.Al_2O_3.6H_2O+25H_2O \rightarrow 3CaO.Al_2O_3.3CaSO_4.31H_2O \text{ (ettringite)} \quad (5)$$

Equally, the high content of K_2O (16.11%) in SDA may react with H_2SO_4 to produce potassium sulphate (K_2SO_4) as shown in equation (6) to initiate the formation of monosulfoaluminate and enttringite which leads to stresses and deformations causing decrease in the strength of concrete, similar to the work of [51].

$$K_2O + H_2SO_4 \rightarrow K_2SO_4 + H_2O \quad (6)$$

3.2 Effect of Na_2SO_4 on properties of SDA in SCC

Figure 3 show the effect of weight loss of SDA-SCC in 5% Na_2SO_4 immersion, the reveals that the weight of SDA- SCC cubes reduces with increase in SDA. The weight loss of SDA at 5% and 10% was lower than the weight loss of SDA at 15% -30% this could be as a result of ettringite formation. cements blended fly ash and natural pozzolan reduced the potential for the formation of ettringite due to the reduction in the quantity of calcium hydroxide and C_3A as explained by [52]. In addition, the increase in loss weight of SDA, could be as result of the mechanism of Na_2SO_4 reaction with sulfate ions diffuse in pores of the concrete, which cause chemical reaction between cement hydration and sulfate ions. Na_2SO_4 react with $Ca(OH)_2$ while mono-sulfate develop gypsum and ettringite in the concrete pores as reported by [53, 54]. The SO_4^{2-} ions interact with calcium hydroxide $Ca(OH)_2$, tricalcium aluminate (C_3A), or aluminum-phase water in the cement base. The chemical products react to produce ettringite and gypsum crystals which fill the pores and cracks in the concrete [55]. Therefore, it was deduced that 5% SDA is found to be the optimum when exposed to Na_2SO_4 medium.

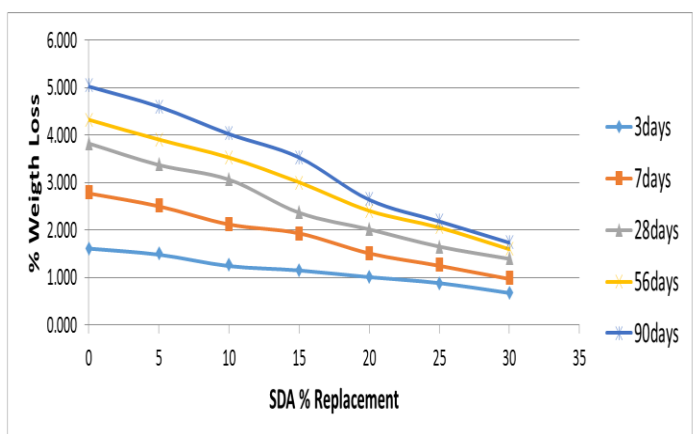

Figure 3: Effect of Na_2SO_4 Salt on the properties of SDA in SCC

3.3 Effect of Elevated Temperature on SDA-SCC

Figure 4 illustrate the typical development of SDA-SCC and the control subjected to a temperature range between 200 ˚C to 600 ˚C for two hours. The result shows loss in weight of SDA-SCC as percentage replacement of SDA content increases, the weight loss could result from the expulsion of the excess pore water in SDA–SCC as revealed in the work of [56,57]. Similarly, it was deduced that weight loss was less significant at lower temperature in SDA-SCC. However, more weight loss was observed at temperatures extending from 400℃ – 600℃, for all cubes samples. This could be due to the fact that when cement paste is heated at a temperature the portlandite content rapidly drops, as it decomposes as shown in equation (7)

$$Ca(OH)_2 \rightarrow CaO + H_2O \quad (7)$$

The portlandite decomposition reaction explains the possible increase in CaO content in cement paste at high temperature 550◦C approximately [58]. The dehydration process of the C-S-H gel reduces its volume, which in turn increases the porosity of the cement matrix. The compressive strength of SDA-SCC decrease with increase in temperature as shown in Figure 4 similar to the findings of [59,60]. This is as result of the portlandite, formed from the hydration of tricalcium silicate and dicalcium silicate, occupies about 15-25% volume of ordinary Portland cement paste. At temperature between 450˚C to 550 ˚C, the portlandite decomposes abruptly and transformed into CaO [61]. This transformation is accompanied by expansion followed by shrinkage of the ordinary Portland cement (OPC) paste. As a result, cracking followed by decrepitating the concrete surface that result in significant loss of strength at higher temperature in OPC concrete specimens.

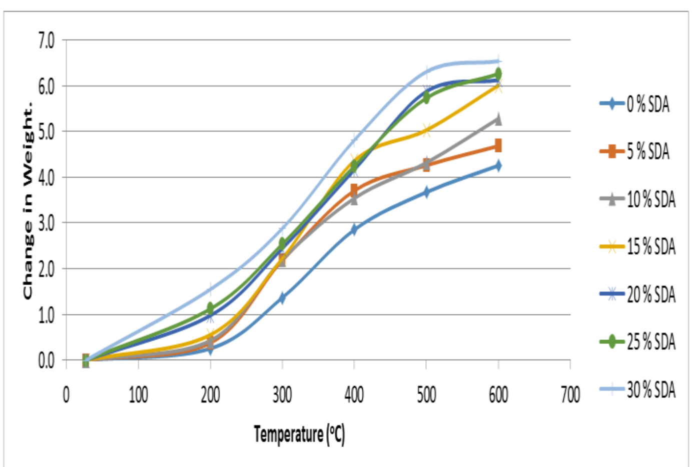

Figure 4: Effect of Elevated Temperature on the properties of SDA in SCC

3.4 Water Absorption of SDA-SCC

Figure 5 shows the water absorption of SDA-SCC, the results revealed that the water absorption reduced with increase in SDA content at 28 days up to 15% but, increases at 20% -30%. The reduction in water absorption up to 15% may be linked with the fineness and high surface area of the samples as per the specific gravity and during hydration process form dense concrete with less void and reduced water absorption. This claim is in line with [62]. Who revealed that hydration products gel gradually fills the original water filled spaces this makes it impervious to water**.** In addition, comparing this results with that obtained by [63], at higher replacement level pozzolanas reduces the available spaces to be filled with water and results in decrease in porosity of the mortar as per the SEM in Figure 7. It was however, observed that the water absorption of SDA-SCC was within the limits of BS EN 998-2 for structural mortar [64].

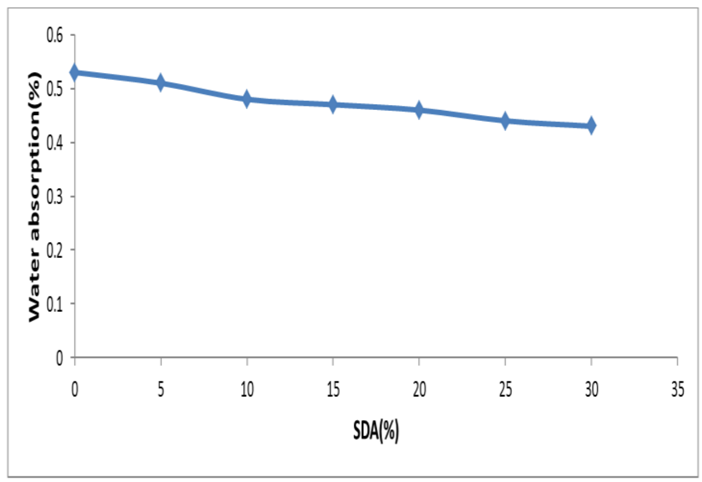

Figure 5: Water absorption of SDA in SCC.

3.5 The Microstructure Study of SDA-SCC

SEM analysis on residual ash produced from the incineration of saw dust ash at a temperature of 600ºC the result reveals that SDA at 7 and 28 days curing consists of particles which are highly irregular in shape as shown in Figure 6 and Figure 7. This confirms with [26, 64] who opined that high specific surface area of the SDA is due to higher degree of irregularity in particle shape. In addition, crystal like spikes were also observed to be present on the surface of SDA particles which may contribute significantly to the high surface area of the ash particles [55]. This trend justified the reason that SDA particle acts more as a filler material within the cement paste matrix than in the binder material. As the replacement percentage is increased, surface area of filler material to be bonded by cement increases, thereby reducing strength [64]

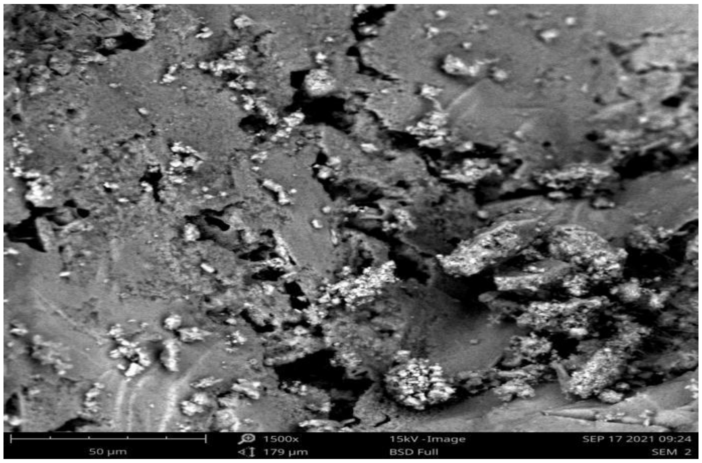

Figure 6: SEM of SDA-SCC at 7 days

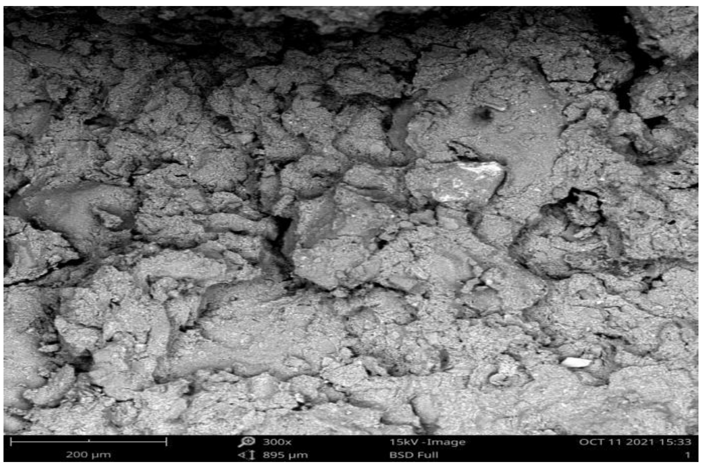

Figure 7: SEM of SDA-SCC at 28 days

4.0 CONCLUSIONS

The following conclusions were deduced based on the experiment investigations.

1. SDA (Afara, Ashwale and Iroko) have not satisfied the minimum requirement of a good pozzolana since the combined SiO_2 + Al_2O_3 + Fe_2O_3 is less than 70%, but has cementitious properties as recommended by ASTM C618.
2. SDA enhanced the resistance of SCC against Na_2SO_4 attack at 5% replacement but performed poorly in H_2SO_4. The resistance of SDA-SCC to heat is reduced with an increase in SDA content and increased temperature.
3. The pozzolanic efficiency of SDA is mainly dependent on its source. Hence, the chemical composition of SDA varies among tree species.
4. The lower calcium hydroxide content in pozzolanic concrete leads to improved sulfate resistance.
5. The cement industry is responsible for up to 10% of global CO_2 production.

REFERENCES

[1] Olafusi, O.S and Olutoge, F.A. "Strength properties of corn cob ash concrete". *Journal of Emerging Trends in Engineering Applied Sciences*, 3(2), 2012, pp.297-301.

[2] Mehta, P.K. "Greening of the concrete industry for sustainable development". *Concrete international*, 24(7), 2002, pp.23-28.

[3] Lei, Y. Zhang, Q and Nielsen, C. "An inventory of primary air pollutants and CO_2 emissions from cement production in China". *Atmospheric Environment*, 45(1), 2011 pp,147-154.

[4] Dunuweera, S. and Rajapakse, "Cement types, composition, uses and advantages of nanocement, environmental impact on cement production, and possible solutions". *Advances in Materials Science Engineering*, 2018.

[5] Bapat, J.D."Mineral admixtures in cement and concrete". *CRC Press*, 2012.

[6] Mohammed, O.H Hamid, R.B, Taha, M.R. "A review of sustainable supplementary cementitious materials as an alternative to all-portland cement mortar and concrete". *Australian Journal of Basic & Applied Sciences*, 2012.

[7] Ash A, John K, Jonida P, Fraser H and Heni F. ‘‘Chemical Reactions in Pozzolanic *Concrete’’ Modern Approaches on Material Science*, *2019, pp 128-133.* Lupine publisher DOI: 10.32474/MAMS.2019.01.000120, ISSN: 2641-692.

[8] Arum, C. Ikumapayi, C.M. Aralepo, G.O." Ashes of Biogenic Wastes—Pozzolanicity, Prospects for Use, and Effects on Some Engineering Properties of Concrete". *Materials Sciences and Applications* 4, 2013, pp 521-527. ASTM C618 - 12a (1999).

[9] Rojas, M.F and Cabrera J. "The effect of Temperature on the Hydration rate and Stability of the Hydration Phases of metakaolin-lime – water systems". *Cement and Concrete Research*, 32, 2002, pp133-138.

[10] Ikumapayi, C.M, Arum C, Oguntunde P.G. "Making Durable Concrete through Inhibition of Chloride Ion penetration by Pozzolanic Action". *Proceedings of the 1st symposium of Knowlegde Exchange for Young Scientists (KEYS): Sub- Saharan African Standards for Cement and Concrete Research & Raw materials, Quality Control and Maintenance of Cementitious products held in Dares Salaam Tanzania*, 9 -11th June, 2015: pp 145-149.

[11] Adole, M.A, Dzasu, W.E, Umar, A Oraegbune, O.M. "Effects of Groundnut Husk Ash-blended Cement on Chemical Resistance of Concrete". *ATBU*

Journal of Environmental Technology 4(1), 2011, 23-32..

[12] Anwar, F.H., Analyzing the setting behaviour of self-compacting concrete manufactured in north cyprus. 2014, *Near East University*.

[13] Okamura, H. and Ouchi, M. "Self-compacting concrete". 1(1),2003, pp.5-15.

[14] Krauss, P. and Paret, T. "Review of Properties of Concrete, by AM Neville". *American Society of Civil Engineers,* 2014.

[15] EFNARC, *Specification and guidelines for self-compacting concrete.* 2002.

[16] Awoyera, P. and Adesina, A. "Plastic wastes to construction products: Status, limitations and future perspective". *Case Studies in Construction Materials*, 12, 2020, pp.e00330.

[17] Raheem, A.B. Olasunkanmi, and Folorunso C. "Saw dust ash as partial replacement for cement in concrete". *Organization technology management in construction: an international journal*, 4(2), 2012, pp.474-480.

[18] Sambo, A.S "The Place of Renewable Energy in the Nigerian Energy Sector''. *World Future Council Workshop on Renewable Energy Policies, Addis Ababa, Ethiopia*. 2009.

[19] Francescato, V. Antonini, E. Bergomi, L.Z. Metschina, C. Schnedl, C. Krajnc, N. Koscik, K. Gradziuk, P. Nocentini, G. and Stranieri, S. " Wood Fuels Handbook. AIEL", *Italian Agriforestry Energy Association, Legnaro* (2008).

[20] Arimoro, F.O, Ikomi, R.B, Osalor, E.C, The impact of sawmills wood wastes on the water quality and fish communities of Benin River, Niger Delta area, Nigeria. *International Journal of Science and Technology,* 2(1), 2007, pp 1–12.

[21] Nwankwo, DI. "The influence of sawmill wood waste on diatom population at Okobaba. Lagos,Nigeria". *Nigerian Journal of Botany.* 11, 1998, pp 15–24.

[22] Wihersaari, M. "Evaluation of Greenhouse Gas Emissions Risk from Storage of Wood Residues", *Biomass and Energy*, 28, 2005, pp 444-453.

[23] Pianosi, M. "Sustainable waste management". https://torinobyveg.wordpress.com /2012/11/19/ sustainablewastesustainablewastemanagement/

[24] Akhator, P. Obanor A. and Ugege, A. ''Nigerian Wood Waste: A Potential Resource for Economic Development'' *Appl. Sci. Environ. Manage.* 21 (2), 2017,pp 246-251, JASEM ISSN 1119-8362.

[25] Garcia, M., Sousa-coutinho, J. Strength and durability of cement with forest waste bottom ash. Construction and Building Materials, 41, 2013, pp 897–910.

[26] Ogork, E. N., Ayuba, S. Influence of sawdust ash (sda) as admixture in cement paste and concrete. IJISET – International Journal of Innovative Science, Engineering & Technology, 1(10), 2014, pp. 736 – 743.

[27] Subbaramaiah, G. Strength and durability studies on wood waste ash structural grade concrete. *A PhD Thesis submitted to Jawaharlal Nehru Technological University Anantapur, Ananthapuramu,* India. 2016 (http://shodhganga.inflibnet.ac.in/bitstream/.pdf assessed 6– 10 – 2017).

[28] Zule, J. & Dolenc, J. "Distribution of mineral substances in different wood tissues of European Larch" (*Larix decidua* Mill.). *Drvna Industrija*, 63,2012, pp19-25.

[29] Van Ryssen, J. B. J., and H. Ndlovu, "Wood ash in livestock nutrition: 1. Factors affecting the mineral composition of wood ash." *Appl. Anim. Husb. Rural Dev* 11 (2018): 53-61.

[30] Chowdhury S, Mishra M, Suganya O. ''The incorporation of wood waste ash as a partial replacement material for making structural grade concrete". *An Overview. Ain Shams Engineering Journa*l, 6, 2014, pp. 429 – 437.

[31] ASTM C618-05 ''Standard specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete". *American Society for Testing and Materials International West Conshohocken Philadelphia* 2005.

[32] Elinwa, A. U, Ejeh, S. P. ''Effects of incorporation of sawdust incineration fly ash in cement pastes and mortars". *Journal of Asian Architecture Building Engineering*, 3(1) 2004, pp. 1–7.

[33] Udoeyo, F. F., Inyang, H., Young, D. T., & Oparadu, E. E."Potential of wood waste ash as an additive in concrete". *Journal of materials in civil engineering*, *18*(4),2006,pp 605-611.

[34] Fapohunda, C. Bolatito, A and Akintoye, O. "A Review of the Properties, Structural Characteristics and Application Potentials of Concrete Containing Wood Waste as Partial Replacement of one of its Constituent Material. YBL Journal of Built Environment 6(1), 2018, pp 63-85.

[35] Cheah, C.B. and Ramli, *The implementation of wood waste ash as a partial cement replacement material in the production of structural grade concrete and mortar: An overview.* Mahyuddin Resources, Conservation Recycling, 55(7), 2011, pp.669-685.

[36] Marthong, C., *Sawdust ash (SDA) as partial replacement of cement.* International Journal of

Engineering Research Applications, 2012. 2(4): pp.1980-1985.

[37] Chindaprasirt P, Sujumnongtokul P, Posi P. "Durability and mechanical properties of pavement concrete containing bagasse ash". *Materials Today: Proceedings*. 2019 Jan 1;17: pp 1612-1626.

[38] Ikponmwosa EE, Ehikhuenmen S, Emeshie J, Adesina A. Performance of coconut shell alkali-activated concrete: experimental investigation and statistical modelling. *Silicon*. 2021.13(2):pp 335-40.

[39] Bheel N., Ali M.O., Kirgiz M.S., de Sousa Galdino A.G., Kumar A. "Fresh and mechanical properties of concrete made of binary substitution of millet husk ash and wheat straw ash for cement and fine aggregate". *Journal of Materials Research and Technology*. 2021. 13:872-893.

[40] BS EN 197, "Part 1, Composition, specification and conformity criteria for common cements". *British Standard Institution, London*, (2000).

[41] Abdulwahab, M. T., Uche, O. A. U. and Suleiman, G. "Mechanical Properties of Millet Husk Ash Bitumen Stabilized Soil Block". *Nigerian Journal of Technological Development*, 14(1), 2017, pp 34 – 38.

[42] Adamu, M, Tifase, A. S, Uche, O. A. U. Engineering properties of industrial wood waste ash-concrete. *International Journal of Advances in Construction Engineering*, 1(1),2017. pp. 1 – 10.

[43] BS EN 933-1, "Test for geometrical properties of aggregates - determination of particle size distribution (sieving method)". *British Standard Institute, London*, (1997).

[44] BS EN 882, "Specification for Natural Aggregates from Natural Sources". *British Standard Institute, London*, (1992).

[45] Akiije, I., *Effects Of CONPLAST SP 430 Superplasticizer Using Four Nigerian Produced Cements Individually In Concrete Production For Highway Pavement.* Journal of Multidisciplinary Engineering Science Technology, 4(6), 2017.

[46] Kabir, N., A. Sallau, and A.U. Chinade, *Experimental Study of Conplast SP430 in Concrete Using Selected Brands of Portland cement.*

[47] Mohammed, A. and A. Aboshio, *Durability characteristics of millet hush ash: A study on self-compacting concrete.* Teknika: Jurnal Sains dan Teknologi, 17(1), 2021, pp.106-112.

[48] BS EN 206. "Additional Rules for Self-compacting concrete (SCC)". *British Standards publication*, 2013.

[49] BS 1881-122, (2011). "Method for determination of water absorption". *British Standard Institution London.*

[50] Izzat, A.M., Al Bakri, A.M.M., Hussin K., Andrei V. S., Ghazali C. M. R., Mohd T.M.F., Ligia M.M, *"Sulfuric acid attack on ordinary Portland cement and geopolymer material"*. Revista de Chimie, 64(9), 2013, pp.1011-1014.

[51] Zivica, V.R. and Bajza, A. "Acidic attack of cement based materials—a review.: Part 1. Principle of acidic attack". *Construction Building materials*, 15(8), 2001, pp.331-340.

[52] Sahmaran M., Kasap O., Duru K, Yaman I.O., Effects of mix composition and water–cement ratio on the sulfate resistance of blended cements. *Cement and Concrete composites*. 2007 29(3):159-167.

[53] SARIBAŞ, İ. and Ö. ÇAKIR, *Short-term effects of sodium sulfate and sodium chloride solutions on the strength and durability properties of hardened mortars.* Avrupa Bilim ve Teknoloji Dergisi, 6(10), 2017, pp.38-47.

[54] Le, D.-H., Y.-N. Sheen, and M.N.-T.J.C. Lam, *Fresh and hardened properties of self-compacting concrete with sugarcane bagasse ash–slag blended cement.* Construction and Building Materials, 185, 2018, pp.138-147.

[55] Wang, X.-Y. and Park, K.-B.J.C. "Analysis of compressive strength development of concrete containing high volume fly ash" *Construction Building Materials*, 98, 2015 pp.810-819.

[56] Janotka, I. and T. Nürnbergerová, "Effect of temperature on structural quality of the cement paste and high-strength concrete with silica fume". *Nuclear Engineering design*, 235(17-19), 2005, pp.2019-2032.

[57] Mwilongo, K.P., Machunda, R.L. and Jande, Y.A.C. "Effect of Elevated Temperature on Compressive Strength and Physical Properties of Neem Seed Husk Ash Concrete". *Materials*, 13(5), 2020, pp.1198.

[58] Castellote,M. Alonso, C. Andrade, C. Turrillasa, X. and Campoc, J, "Composition and microstructural changes of cement pastes upon heating, as studied by neutron diffraction", *Cement and Concrete Research* 34, 2004, pp1633–1644.

[59] Morsy, M. Alsayed, S. and Aqel, M. "Effect of elevated temperature on mechanical properties and microstructure of silica flour concrete". *International journal of civil environmental engineering*,10 (1), 2010. pp.1-6.

[60] Nimyat, P.S. and Y. Tok, Y, "Effect of Saw Dust ash (SDA) Pozzolana on the Performance of Blended Cement Paste Concrete at High Temperatures" *Journal of Civ. Environ. Res*, 3(11), 2013, pp.22-29.

[61] Sarker, P.K. Kelly, S. Yao, Z. ‘’Effect of fire exposure on cracking, spalling and 625 residual strength of fly ash geopolymer concrete’’. *Materials & Design*, 63,2014, pp 584-592.

[62] Abhishek, D. S, Kumbar, P. K. "An experimental study on durability aspects of concrete with partial replacement of cement by sawdust ash". *International Journal of Scientific Research Organization*, 1(5), 2017, pp. 36 – 41.

[63] Kim, H.K. Jeon, J. and Lee, H.K. "Flow water absorption and mechanical characteristics of normal- and high-strength mortar incorporating fine bottom ash aggregates". *Construction Building Materials*, 26(1), 2012, pp.249-256.

[64] Rajamma, R, Ball, R. J, Tarelho, L.A.C, Allen, G. C, Labrincha, J.A, Ferreira, V.M. "Characteristics and use of biomass fly ash in cement-based materials". *J Hazard Mater*, 172, 2009, pp.1049–60