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Properties of self-compacting concrete (SCC) admixing sawdust ash (SDA) cement as replacement

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Abstract

Research on needs of cementatious materials as a substitute for cement in construction industries have been for a time immemorial. Cement is the most useful element in concrete next to water however; its production is energy intensive and produces a lot of CO_2. In this study the Saw dust ash (SDA) was used to partially replace OPC in SCC. A number of trials mixes were conducted to obtain the control grade 40 SCC. Then later a mix proportion varied at 5, 10, 15, 20, 25 and 30 percentages by weight of SDA as OPC replacement in SCC using a plasticizer of 7.49 kg/m^3 in accordance to standard specification. The effects of SDA-SCC on hardened properties were studied at 3, 7, 28, 56 and 90 days curing. The study reveals improvement in the resistance against segregation. While, 0% - 10% and 0% - 15% the satisfied the requirement for slump flow and passing ability of SDA-SCC respectively. Similarly, compressive strength reduces with increase in SDA content at 15 to 30 %.

Keywords: Saw dust ash, fresh and hardened properties of Self-Compacting Concrete

1. Introduction

Self-Compacting Concrete (SCC) can be defined as a special concrete which maintains the consolidation of the material weight and minimize the casting period with the ability to eliminate the problems of passing concrete in difficult conditions and at the same time giving high strength and better durability characteristics as compared to Normal Concrete (NC) (Zende *et-al,* 2014). SCC as the name implies, is a special type of concrete in the construction industry obtained without the application of vibrational effort in the form work with the ability for self-compaction without bleeding or segregation and remain cohesive (Rao and Ravindra, 2010). It is said to be of significance in construction due to the following possessed potentials such as construction time reduction, reduced cost of labour, reduced pollution due to noise, ease to fill the congested and thin section and it enhances casting in congested area of concrete constructions (Memon et-al., 2018). Another advancement of SCC production is the use of lower water cement ratio which yields high strength, low permeability and more durability as compared to compacted concrete produced using vibrators. Its highly fluid nature makes it suitable for placing in difficult conditions and in sections with complex and congested reinforcements (Neville and Brooks, 2010). Consolidation is fully achieved due to its own self-weigh and is found to offer some economic, social and environmental benefits over the normal vibrated concrete in construction.

Self-Compacting Concrete has better composition of fines which strengthen the durability of the material, the composition of Self-Compacting Concrete is similar with normal concrete, some of the essential features between SCC and normal concrete are, SCC contains more cement and admixtures to improve the fresh properties of SCC (Sonebi et-al., 2015). The application of super plasticizers in SCC greatly increases high flow and its ability to resist segregation (Coppola, et-al., 2004). Among the filler materials the most commonly used in SCC are; Silica fume, fly ash, iron slag etc. (Aggarwal et-al., 2008). The use of mineral admixtures as alternative material to cement is cost effective when SCC is used as construction material (Nehdi et-al., 2004). Industrialization in developing countries has resulted in an increase in agricultural output and consequent accumulation of unmanageable waste Sawdust is a waste material from the timber industry; is produce as the loose particles or wood chippings obtained as by-products from sawing of timber in to standard useable sizes Raheem, (2012). Earlier research by (Francescato *et al.,* 2008;

Sambo 2009) publicized that Nigeria produce about 5.2 million tonnes of SDA per year and constitutes an environmental nuisance as a result of wrong handling without any commercial used. Similarly, when subjected to heating at a fixed temperature SDA contains some essential mineral such as calcium oxide (CaO), silicon oxide(SiO_2) and iron oxide (Fe_2O_3) in good proportions capable of substituting cement (Arimoro *et al.*, 2007; Nwankwo, 1998; Wihersaari, 2005). These wastes disposal methods refute sustainable solid waste management that encourage the effective utilization of waste generated so that the economic and environmental goals of sustainable development are achieved (Sambo, 2009). Therefore, in order to reduce the enviromental problems to promote green construction technologies huge variety of agro wastes have been used in the current construction industry for their potential use as a substitute of cement clinker. Recently, researchers have affirmed that SDA has a potential of supplementary cementitious material in concrete (Ogork and Ayuba 2014; Subbaramaiah, 2016). And revealed that the pozzolanic efficiency of SDA is depends on the species. Consequently, the chemical composition of ash varies among tree species (Zule and Dolenc, 2012; Van Ryssen and Ndlovu, 2018). Studies of scanning electron microscopic analysis of SDA from different species of SDA waste shows variation in the physical properties such as shape, partcles size and oxide composition, Chowdhury *et-al.*, 2014. Similarly, previous works of (Raheem *et-al.*, 2012, Marthong 2012, Cheah *et-al.*, 2015), affirmed that the use of SDA in concrete improves the compressive strength as curing age increases. However, the strength reduces as SDA content increases. Furthermore; the findings of (Ogork and Ayuba 2014, Cheah *et-al.*, 2015, Abhishek and Kumar, 2017,); revealed that SDA is reach in Calcium Oxide (CaO) (50.64, 61.0, 42.5 and 64.47).

The choice to investigate into the utilization of SDA waste as substitute of cement in construction industries will enrich the economic conditons of wood workers by providing job opportunity from wood waste to wealth creation. Several research works has being conducted using sawdust ash in normal vibrated concreted (Raheem *et-al.*, 2012, Marthong 2012, Cheah *et-al.*, 2015). There is little to no extensive research on the application of SDA sourced from (Afara, Ashwale and iroko) as supplementary material in SCC. If SDA succeeds in replacing cement it will go a long way in mitigating the challenges of waste disporsal from SDA and at the same time eliminate all forms of environment problem related to saw dust waste and cement productions.

2.0 Materials and Methods

2.1 Materials

2.1.1 Cement

The research used Dangote brand Ordinary Portland cement (OPC) grade 42.5 conforming to BS EN 197 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 and the oxide composition and physical properties presented in Table 1 and 2.

2.1.2 Saw Dust Ash (SDA)

Saw dust (Afara, Ashwale and Iroko) used was collected from timber shed in Kano State, Nigeria the sawdust was dried and burned to ash at controlled temperature of 550 ˚C for 4 hours using incinerator, similar to the work of Abdulwahab *et al.*, 2917; Ogork and Ayuba 2014. The ash was then cooled and sieved through 75 µm for used in the SCC. The oxide composition, physical properties and the grading of SDA are presented in Table 1 and 2 below.

Table 1: Oxide Composition of Dangote Cement and SDA

Oxides	Cement (%)	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

Table 2: Physical Properties of Binders and Aggregates

	Cement	SDA	Fine Aggregate	Coarse Aggregate
Specific Gravities	3.16	2.21	2.61	2.72
Fineness (Retained on 45 µm sieve)	13	29	-	-
Fineness modulus	-	-	2.55	6.65
Bulk Density (kg/m^3)	1446	645	1569	1661

2.1.3 Aggregates

The fine aggregate used for the research was clean river sand with the following properties; fineness modulus of 2.55, specific gravity of 2.61 and bulk density 1569 kg/m^3. Sieve analysis was conducted in accordance with BS EN 933. In order to determine the particle size distribution as well as grading limits based on BS EN 882. The result revealed that fine aggregate fall in zone II as shown in Figure 1.

Whereas, crushed granite rock was used as the coarse aggregate with maximum size of 14 mm as shown in Figure 1. The coarse aggregate has fineness modulus of 6.65, specific gravity of 2.72 and bulk density of 1665kg/m^3 respectively as was presented in Table 2.

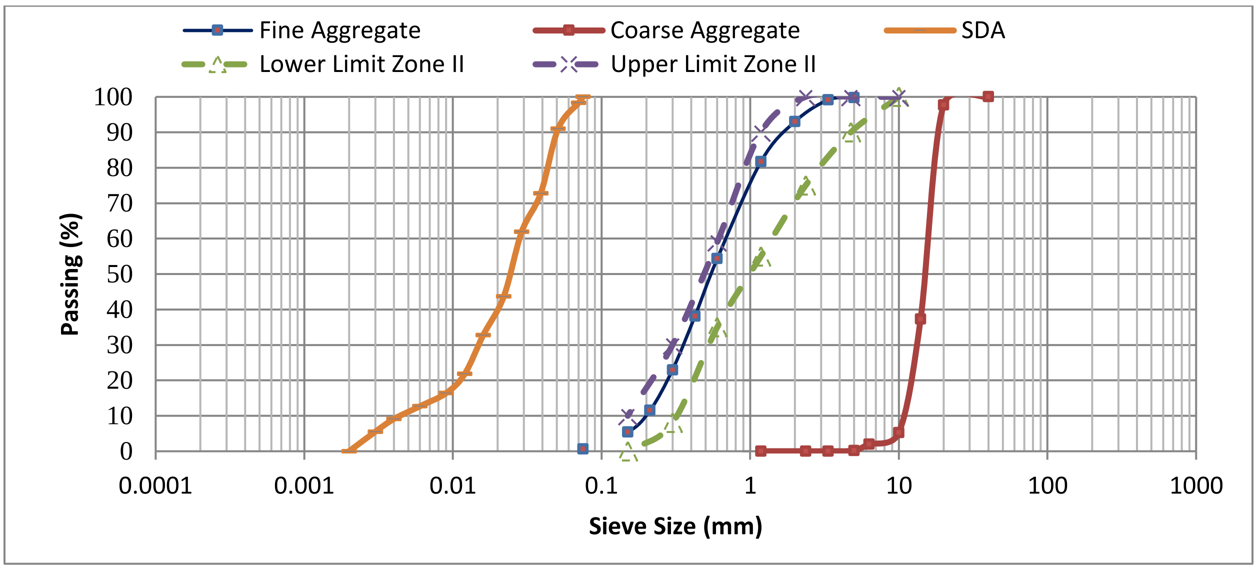

Figure 1: Grading of Aggregates and Saw dust Ash

2.1.4 Super plasticizer

The research was conducted using Super plasticizer of 7.49 kg/m^3 to increases high flow to resist segregation of SCC, a chloride free super plasticizing and water reducing admixture produced by Fosroc based on selected sulphonated naphthalene polymers was used in this research. This is within the acceptable specified limit provided by the manufacturer and in line with the work of Mohammed and Aaron 2021.

2.1.5 Water

Clean water suitable for drinking available in the laboratory was used for mixing and curing the SCC during the research.

2.2 Methods

2.2.1 Mix design of self-compacting concrete

Guidelines laid out in BS EN 12390-6: (2000) was used in designing mix for self-compacting concrete which involving the selection and proportioning of SCC constituents materials. The mix design for the control (SCC without SDA) was obtained via trial mixes using 0.37 as water – cement ratio and Grade 40 SCC was considered for the research as shown in table 3. The control mix obtained was used for the other SCC mixes containing 5, 10, 15, 20, 25 and 30 percentages replacement SDA by weight of cement. The constituent materials for the SCC – SDA are presented in Table 4.

Table 3: Summary of Mix Design Proportion of grade 40 SCC by trial

Trial	cement (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	water	Passing Ability	Slump Flow (mm)	Segregation Resistance	Compressive strength (N/mm^2)	Super-plasticizer (kg/m^3)
TM1	520	840	890	182	0.73	531	5.9	38.4	7.49
TM2	520	860	870	182	0.78	544	7.4	40.39	7.49
TM3	520	880	850	182	0.81	651	9.4	41.36	7.49
TM4	520	900	830	182	0.84	658	11.7	43.87	7.49
TM5	520	920	810	182	0.85	682	17.6	42.81	7.49
TM6	520	840	890	192.4	0.78	584	6.6	40.22	7.49
TM7	**520**	**860**	**870**	**192.4**	**0.81**	**657**	**9.2**	**44.42**	7.49
TM8	520	880	850	192.4	0.83	672	12.6	42.68	7.49
TM9	520	900	830	192.4	0.84	689	15.1	44.89	7.49
TM10	520	920	810	192.4	0.87	722	18.6	45.52	7.49

Trial mix TM7 meet the requirement for the design strength of grade 40 concrete the requirement for fresh properties of SCC are slump flow 550mm-850mm, passing ability of 0.8-1.0, and segregation not greater than 15.

Table 4: Material Batching for Self –Compacting (SCC) – Saw dust Ash (SDA)

Mix No	% MHA	Cement (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	SDA (kg/m^3)	Water (kg/m^3)	Super Plasticiser (kg/m^3)
MC0	0	520	870	890	0	192.5	7.49
MC1	5	494	870	890	24.7	192.5	7.49
MC2	10	468	870	890	46.8	192.5	7.49
MC3	15	442	870	890	66.3	192.5	7.49
MC4	20	416	870	890	83.2	192.5	7.49
MC5	25	390	870	890	97.5	192.5	7.49
MC6	30	364	870	890	109.2	192.5	7.49

2.1.2 Fresh properties assessment of self-compacting – millet husk ash concrete

The following tests; slump flow, passing ability (L-box) and segregation resistance was carried out in the assessment of the self-compacting – Saw dust ash concrete in its fresh state. The tests were conducted in accordance with (BS EN 206–9: 2010).

2.1.3 Hardened properties assessment of self-compacting – Saw dust ash concrete

The test on the hardened properties self-compacting concrete – Saw dust ash carried out on following; compressive, flexural and splitting tensile strengths. The tests were conducted in accordance to BS EN 12390-3; BS EN 12390-5; BS EN 12390-6 and BS EN 12350-8 respectively, at a curing ages of 3, 7, 28, 56 and 90 days. The compressive strength test was carried on 100 mm diameter and 200 mm height concrete cylinders using ELE digital compression machine at a loading rate 5 kN/s. The flexural strength was conducted using two points loading method was evaluated using rectangular prism 500 x 100 x 100 mm. The splitting tensile strength was conducted using 100mm diameter and 200mm length cylinders. The flexural and splitting tensile strength tests were conducted using Avery Denison Universal testing machine at a loading rate 0.4kN/s.

Figure 2: Compressive strength

Figure 3: Splitting Tensile

Figure 4: Flexural Strength Test

3.0 Results and Discussion

3.1. Passing ability of SDA- SCC

The passing ability of SDA- SCC for MC0, MC1, MC2, MC3, MC4, MC5 and MC6 is shown in figure 2, the result reveals that only 5%SDA, and 10%SDA has values between 0.8-1.0mm that satisfied the requirement giving by Elinwa and Mahmood (2002) for passing ability (0.8mm-1.0mm). The reason for decrease in the passing ability of fresh concrete blended with increase in SDA content may be due to lost in consistency as a result of higher specific surface area of porous wood waste ash particles. This view agrees with (Udoeyo, *et al.*, 2006), who reveals that the workability of SDA concrete reduces with increase in SDA content. Equally, the decline in passing ability could also be as result of increase in the amount of calcium oxide which increases with increase in SDA content leading to harsh concrete mix. The submission is in line with (Chowdhury *et-al.*, 2015).

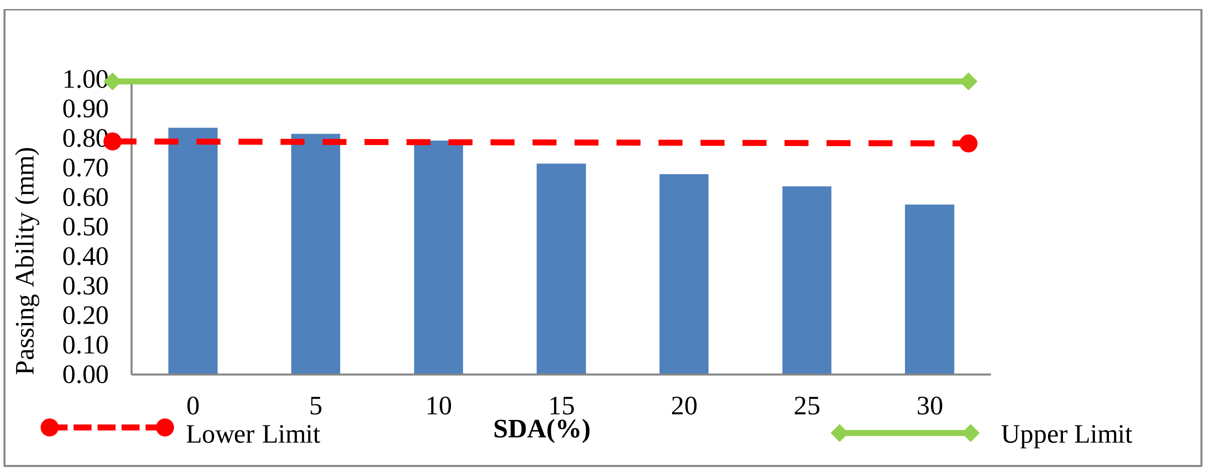

Figure 2 Passing ability of SDA with Cement Paste

3.2. Slump flow of SDA- SCC

Figure 4.3 show the results slum flow of fresh in SCC with and without addition of SDA as replacement for OPC and reveals the average slump as 748mm, 715mm, 646mm, 578mm, 541mm, 503mm, and 487mm for MC0, MC5, MC10, MC15, MC20, MC25 and MC30 respectively. Though, MC0, MC5, MC10, MC15, satisfied the requirement of BS EN 206-9 2010 for slump flow (550mm-850mm) this is possible as a result of the super plasticizer used but, at 20%SDA and above the slump could not satisfied the requirement of BS EN 206-9 2010 for slump flow (550mm-850mm). Figure 4.3 shows that the slump flow of the fresh concrete dropped with increasing the amounts of SDA as replacement for PC in concrete. The decrease in slump with increase in SDA content may be attributed to high specific surface area and high carbon content of the SDA. These explanations correlate with the work of (Aquib *et-al.*, 2020; Elyamany *et-al.*, 2014). This shows that the use of sawdust ash requires more water in concrete to maintain the workability of the mix, (Olawuyi, and Olusola 2010).

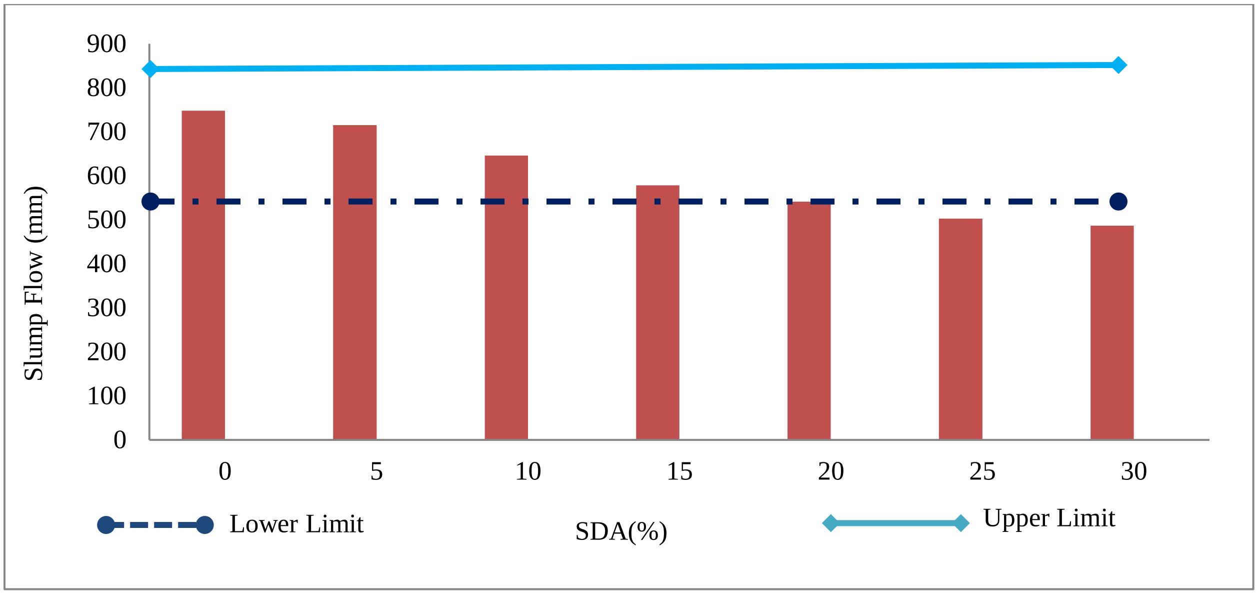

Figure 3: Slump flow of SDA - SCC

3.3. The Segregation resistance (SR) of SDA- SCC

Figure 4 show the segregation resistance of SDA-SCC mix the study shows that the (SR) increases significantly with increase in SDA content, this may implies loss in consistency of the paste due to lack of sufficient amount of water to produce standard consistency. This trend is in line with sugestion of (Olusola and Opeyemi, 2012) working on the effect of filler types on the properties of self compacting concrete however, all the mixes satisfied the limit set by (Elinwa and Mahmood (2002) $\leq 15\%\ for\ segregation\ resistance$

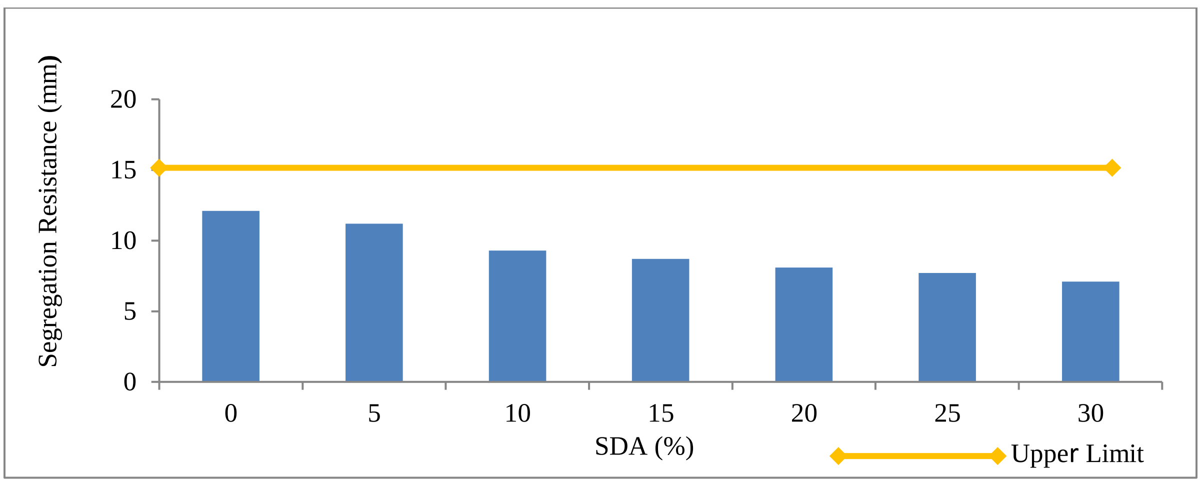

Figure 4: Segregation resistance of SDA - SCC

3.4 Compressive Strength of SDA- SCC

Figure 5 shows the effect of curing age on the compressive strength of SDA-SCC and attests that the compressive strength of SDA-SCC decreased with increase in ash content but, increases with curing age. However, the plot shows that at 28 days, compressive strength of SDA-SCC increases up to 10% and meet up the design strength 40N/mm^2 though, less than that of control but decreases with as replacement levels increase. This trend could be as a result that the wood waste ash particles act more as filler material within the cement paste matrix than as binder material. Therefore, increasing the ash content as cement replacement could lead to increase in surface area of filler material to be bonded by decreasing the amount of cement which causes a decline in strength, this observation agrees with the findings of (Udoeyo *et-al.*, 2006) who worked on Potential of wood ash waste as an additive in concrete. This is also in accordance with the works of (Raheem *et-al.*, 2012, Cheah *et-al.*, 2015), who reveals that the compressive strength development of concrete containing SDA, though increased with curing ages, nonetheless deceased in relation to the control with increase in the percent replacement of cement with SDA. Similarly, the increased in compressive strength with curing age due to the hydration reaction of Portland cement and reduced with increasing SDA content due to the decreasing content of the cement. This statement is in line with (Ettu *et-al*., 2013, Naik, 2002, Rajamma *et-al*., 2009).

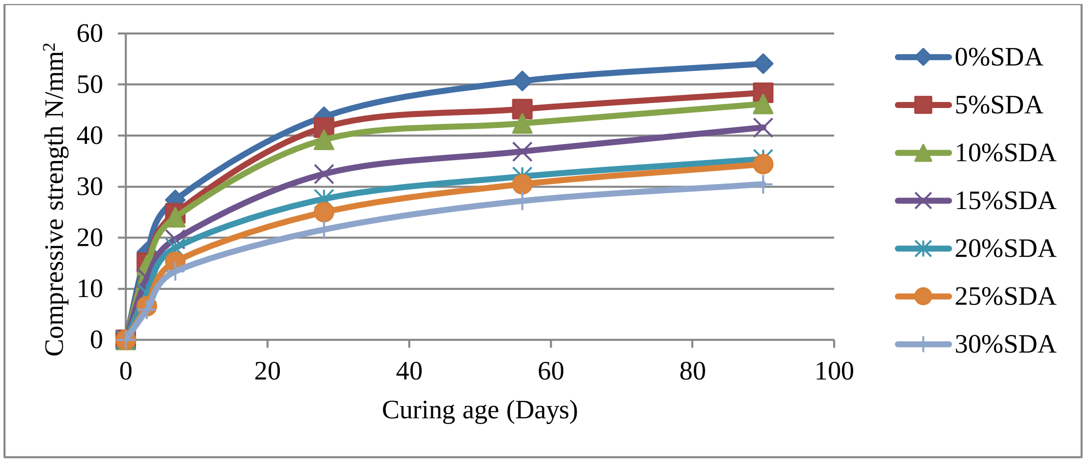

Figure 5: Effect of Curing Age on Compressive strength of SDA-SCC

3.5 Effect of SDA on Splitting Tensile Strength of SDA-SCC

Figure 6 shows the splitting tensile strength of SDA-SCC, as expected the result shows that splitting tensile strength increases with curing age but decrease with increase content of SDA from 5% - 30% SDA. It was observed SDA successfully replace up to 10% of cement in SCC and give same strength with control strength. At 5% cement replacement by SDA, the tensile splitting strength gotten as 1.04 to 4.84 between 3 to 90 days of curing and 10% had a range of 1.20 to 4.88N/mm^2. The increase in strength with age of curing is due to continuous hydration of cement and pozzolanic reaction of SDA. This is in consistent with conclusion of (Elyamany *et-al.*, 2014). The decrease in strength could be due to the effect of increasing SDA replacement having low cementitious properties reduces cement composition which lead strength reduction. This submission is in line with the work of (Rajamma *et-al*., 2009) who studied the effect of SDA at early ages up to 28 day curing on the splitting tensile strength of concrete and revealed the strength decreases with increasing content of SDA.

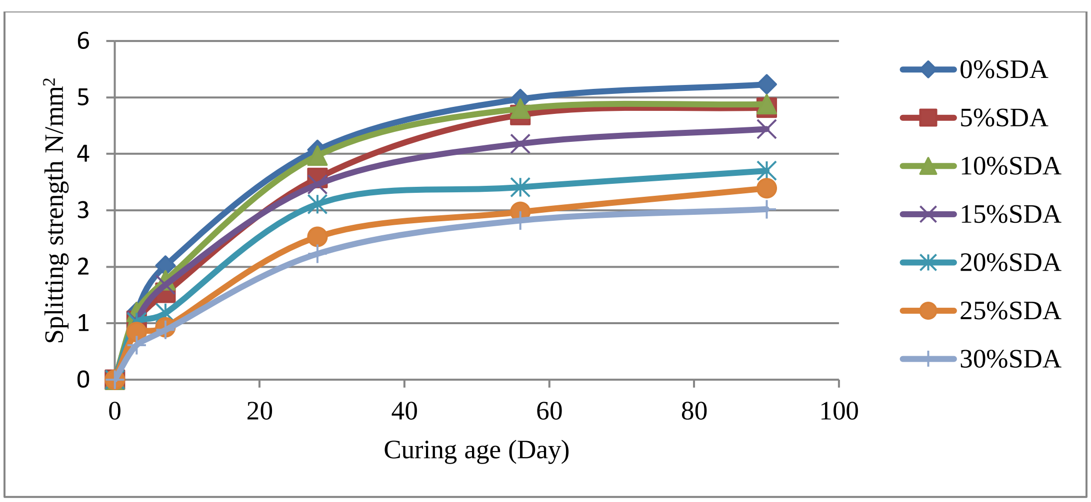

Figure 5: Effect of Curing Age on Splitting Tensile strength of SDA-SCC

3.6 Effect of SDA on Flexural Strength of SDA-SCC

The flexural strength of SDA-SCC samples deceased with increase content of SDA and increase with curing age. The trend was proven by the works of (Abhishek and Kumbar 2017; Rajamma *et-al.*, 2009 and Naik *et-al.*, (2002)). However, the inclusions of SDA to SCC as a replacement for cement, the flexural strength of SCC increases up to 5% and after which it started declining. Maximum reduction in strength was recorded at 30% SDA at all ages of curing, while the maximum increase was shown at 10% replacement of cement with SDA throughout the ages of curing.

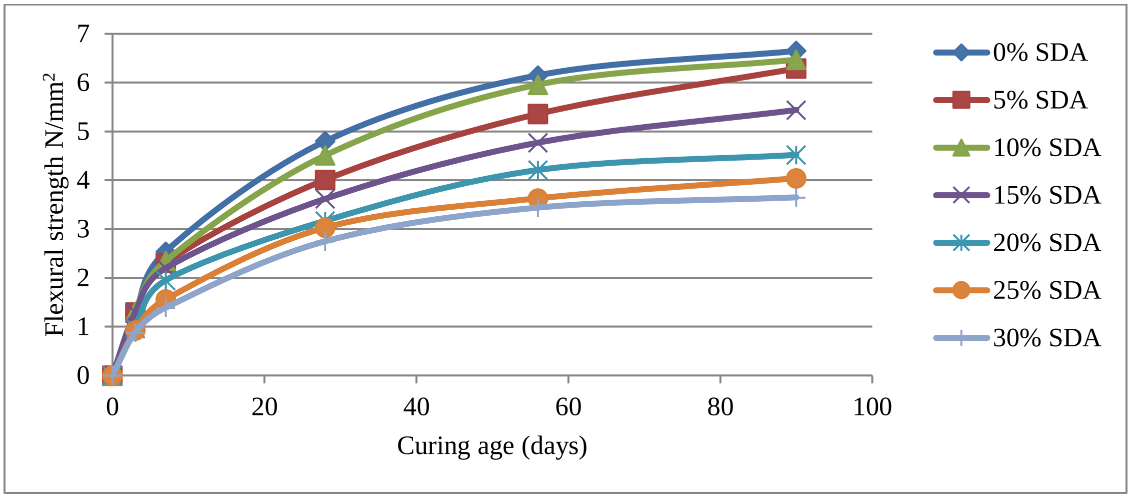

Figure 6: Effect of Curing Age on Flexural Strength of SDA-SCC

4.0 Conclusions

Based on the study conducted to evaluate the properties of saw dust ash in self-compacting concrete, the following conclusions are drawn;

1. Saw Dust Ash (SDA) has cementitious properties having CaO (40.5%) but could not satisfies the requirement for minimum content of SiO_2, Al_2O_3 and Fe_2O_3 recommended by ASTM C618 and as a pozzolana.
2. Up to 10 % SDA replacement of cement by weight in SCC satisfied all the requirement for passing ability and Slump flow of SCC as provided by BS EN 12350 (2010) while, the segregation resistance increase with increase in SDA content but all the mixes satisfied the requirement of the BS.
3. Grade 40 SCC can be satisfactorily produce using 10 % SDA (optimum SDA content) replacement of cement by weight.
4. The splitting tensile strength and flexural strength of MHA-SCC decreased with increase in SDA content beyond 10 % MHA content.
5. The cement industry is responsible for up to 10% of global CO_2 production.

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