THE CHARACTERISTIC PROPERTIES OF SELF COMPACTING CONCRETE (SCC) WITH SAW DUST ASH (SDA) AND MILLET HUSK ASH (MHA) AS CEMENT REPLACEMENT TERNARY BLEND.

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Received: May 18, 2023 Accepted: July 10, 2023

Abstract

The quest to minimize the negative effects associated with the high use of natural resources in cement production used in construction industries has been on the increase for age-old. However, despite the environmental hazard, cement production is unaffected. In recent times, research work on the need to find locally available cement replacement material has been at its peak globally. This research presents a comprehensive work on the effect of partial replacement of cement with saw dust ash (SDA) blended with optimum (MHA) as admixture (ternary blend) to improve the strength properties of grade 40 self-compacting concrete (SCC). The SDA and MHA used were obtained at temperature between 600℃−650℃ and used at a varied mix proportion of 0%, 5%, 10%, 15%, 20%, 25% and 30% respectively. To enhance the strength properties of SDA-SCC, optimum dose of MHA was incorporated to produce SDA-MHA-SCC. A number of trials mixed in accordance to standard specification were conducted to obtain grade 40 SCC with plasticizer at 6.24 kg/m^3 and water to binder ratio of 0.37. The hardened properties were evaluated at 3, 7, 28, 56 and 90 days curing to study the effects of the SDA-SCC, MHA-SCC and the effects of optimum MHA-SCC in SDA – SCC. The investigation revealed compressive strength of 44.80N/mm^2 and 40.10N/mm^2 for MHA-SCC at 5% and 10%, and 41.60N/mm^2 at 5% for SDA-SCC and SDA-MHA-SCC as compared to targeted strength of 40N/mm^2 after 28 days.

Keywords: Cement, Millet husk ash, Saw dust ash, Self-compacting concrete.

Introduction

The use of cement in construction of housing as a means of shelter in our built environment has been on the increase and its production affects environmental sustainability globally. However, despite the environmental challenges, cement production has been on the increase (Mohammed, *et al.,* 2021). Research work around the globe in construction industries has been on the need to find alternative material. It was found that agro waste materials offer some benefit when used to improve on properties of concrete (Ajayi *et al.,* 2013). Quite a lot of studies on the use of mineral additives such as; rice husk ash (Habeeb and Fayyadh, 2009; Atan and Awang, 2011; Aboshio *et al*, 2018), fine limestone powder (Ye *et al*, 2007; Esping, 2008, Mohammed, *et al.,* 2021), pulverized-fuel ash (Sukumar *et al.,* 2008; Liu, 2010; Siddique, 2011), silica fume (Yazici, 2008; Mohammed, *et al.,* 2021) confirmed that mineral admixture from waste materials can be used to improve on the properties of concrete when used as a cement replacement mineral.

Self-compacting concrete (SCC) is described as a concrete which has the ability to flow and consolidate under its own weight and fill formwork, even in the presence of congested reinforcement without the requirement of vibration (Mohamed, 2013, Awang *et al.,* 2016). SCC as compared to normal vibrated concrete of comparable properties are more durable, with higher compressive and bond strength (Kapoor, 2012). In addition, SCC has the advantage of reducing labor cost, construction time, quality improvement and good finished surface. These give it advantages over normal vibrated concrete. Though, SCC production requires high cement content which is associated with a number of challenges including increased cost of concrete material and the likely increase in production of cement that lead to increased emissions of carbon (IV) oxide (CO_2) with adverse effect on environmental friendliness. Previous research revealed that cement manufacturing industries give nearly 2.4 % of the global CO_2 emissions (Mohammed *et al.,* 2021, Marland *et al.,* 1989). This to say, higher consumption of Portland cement in SCC mix results in increasing heat of hydration and high autogenous shrinkage (Sabet *et al.,* 2013). Contrariwise, cement production and its utilization can be reduced by utilization of mineral additives in SCC and may possibly, reduce the rate of emission of CO_2, heat hydration and autogenous shrinkage (Awang *et al.,* 2016). These notable effects however, are likely to be reduced by utilization of mineral additives in SCC.

About 29.87 million tons of millet is produced yearly in the world out of which 16.74 % is produced in Nigeria (Worldatlas, 2017; Muhammed *et al.,* 2012). Researches into the use of millet husk ash in concrete show that the ash is pozzolanic in nature (Jimoh *et al,* 2013) and can be used as partial replacement of cement to improves the properties of the concrete (Uche *et al.,* 2012). The findings of Auta *et al.*, (2015) shows that, 10 % or less of MHA can be used as replacement in normal vibrating concrete (NVC). The finding of Jimoh *et al.,* (2013) also shows that up to 10 % MHA can be used to improve NCC blended with lateritic soil. However, limited or no information is available on utilization of MHA in SCC.

Sawdust is an industrial byproduct in the timber industry which litters the environment due to current mode of disposal. The volume of pollutant emanating from saw dust waste is a cause of concern on the environmental sustainability. Previous studies by Ogork and Ayuba (2014) reveals that partial replacement of cement with sawdust ash in concrete is effective reducing the cost of concrete production at the same time offers a large potential for the utilization of sawdust ash concrete as a cost-effective alternative to current disposal method of waste. Also, Mindess *et al.,* (2003); Bheel *et al.,* (2021) reveals that the compressive strength of mixtures containing SDA increases with curing age and subsequently decreases with higher dosage of SDA in the mixture. Several researches has been conducted using SDA in NVC but, research admixing SDA with MHA as ternary blend in SCC has not been conducted. Furthermore the findings of Shahbeyk *et al.,* (2011); Ogork and Ayuba (2014) revealed SDA has some shortcoming with its reactive element such as Silicon Oxide (SiO_2) but has high CaO, on the other hand, the works of Ayuba *et al.,* (2022), Abubakar and Aaron. (2021) confirms that MHA has high silicon oxide (SiO_2) content. Hence, admixing with MHA in SDA-SCC will convert calcium hydroxide to calcium silicate hydrate and is likely to improves the strength properties of SCC and reduce the bulk of waste.

Materials and Methods

Materials

In this research, Ordinary Portland cement (OPC) Dangote 3X cement type CEMII 42.5N (A-L), was used as binder, in accordance with the recommendation of BS EN 197-1. The Millet Husk and Sawdust (Afara, Iroko and Ashwale) obtained from Yola Adamawa state Nigeria, were incinerated at a control temperature ranging 550 – 600˚C for 3hours at a constant temperature to produce the required ash. The chemical oxides of OPC, MHA and SDA were studied using X-Ray Fluorescence (XRF) analyses and are presented in Table 1. The fine aggregates used was clean river sand obtained from Chuchi River Yola South Adamawa State, which conforms to BS EN 12620 with a specific gravity of 2.63 as shown in Table 2. The sieve analysis of the fine aggregate was conducted in accordance with BS EN 933-1 to determine particle size distribution as well as grading limits based on BS EN 882 and BS 1377:1 (1990), and was classified as Zone 2 fine aggregates as shown in Figure 1. Also, crushed granite of 20 mm nominal diameter with aggregates crushing value of 22% and specific gravity of 2.7 was used as the coarse aggregates to BS EN 196 -3 (2005) as shown in Table 2. While the water used for mixing and curing the SCC is potable tap water, which satisfied ASTM C1602-12 water specification for use in concrete mixtures, the superplasticizer used is a (Conplast SP430) which was chloride free, super-plasticizing admixture based on selected sulphonated naphthalene polymers. It is a brown solution that instantly disperses in water. It was used in compliance with BS 5075-3:1985, BS EN 934-2 and ASTM C494. It has a specific gravity of 1.12 @ 25℃.

Table 1 Oxides composition of ash and binder

Oxides	Dangote Cement (%)	BSEN197-1(2000) ASTM C618(2005)	Waste Materials		BS EN 197-1(2000) ASTM C 618 (2005)
			MHA	**SDA**	
SiO_2	16.42	$CaO + SiO_2 \geq 50\%$	65.01	22.55	$CaO + SiO_2 + Fe_2O_3 > 70\%$ $LoI \leq 12\%$
Al_2O_3	3.23	$CaO/SiO_2 \geq 2\%$	5.12	3.21	
Fe_2O_3	4.42		3.03	2.51	
CaO	69.93	$SO_3 \leq 3.5\%$	6.03	40.05	
MgO	1.36	$MgO \leq 5.0\%$	2.81	3.39	
SO_3	1.98		1.21	1.06	
Na_2O	0.32	$Cl \leq 0.1\%$	1.06	2.41	
K_2O	0.66		5.13	16.11	
P_2O_5	0.103	$LoI \leq 5\%$	3.11	0.02	
Cl	0.1		0.16	0.11	
TiO_2	0.31		0.15	0.21	
Cr_2O_3	-		0.01	-	
Mn_2O_3	-		-	0.02	
BaO	0.18		0.02	-	
LOI	4.04		6.01	5.89	

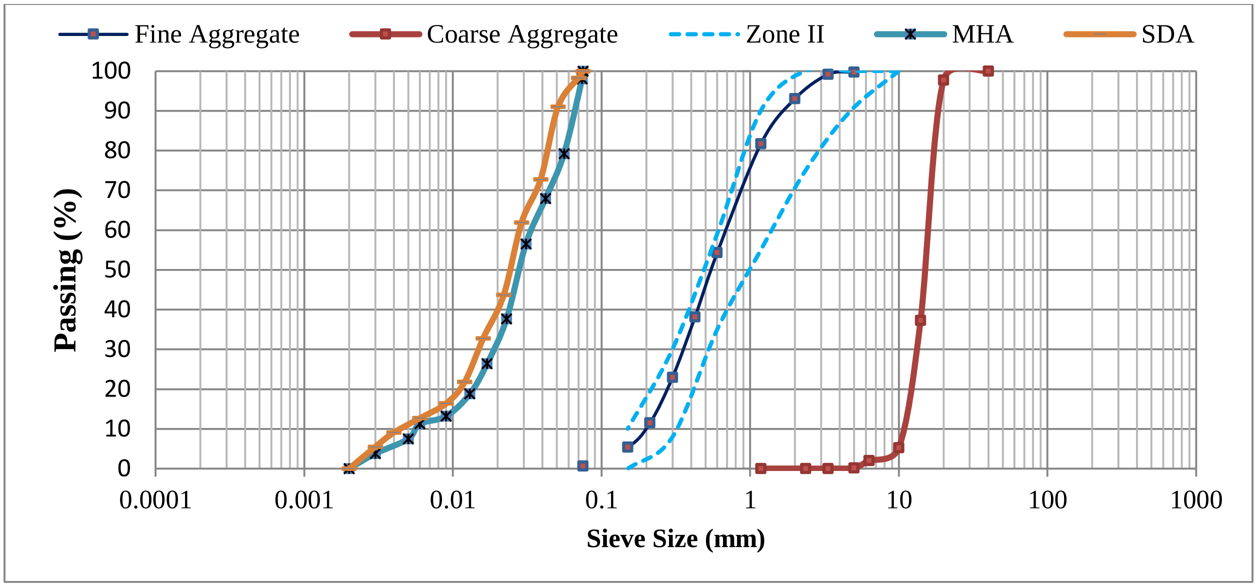

Figure 1 Particle Size gradation of aggregate, MHA and SDA

Table 2 Physical properties of aggregate and binder materials

Properties	Materials				
	Cement	MHA	SDA	Sand	Gravel
Moisture content (%)	0.68	2.56	2.98	2.37	
Specific gravity	3.14	2.24	1.22	2.63	2.70
Fineness modulus	-	-	2.55	6.65	1665
Loss on ignition (%)	1.30	6.01	5.89	-	-
Fineness (% Passing BS Sieve 45 µm	15	28.7	29.8	-	-
Colour	Dark grey	Dark grey	Grey	-	-

Methods

A. Mix design of self-compacting concrete

The self-compacting concrete was produced based on BS EN 206 (2013). The mix design for the control (SCC without SDA and MHA) was obtained via trial mixes using 0.37 as water – cement ratio and Grade 40 SCC considered for the research. The best mix or optimum values (44.55N/mm^2) of SCC obtained as was adopted and used at a varied mix proportions of 5%, 10%, 15%, 20%, and 25% and 30% SDA (Afara, Iroko and Ashwale) as partial replacement of cement in SCC same mixes were adopted for MHA as partial replacement of cement in SCC and the effect of Optimum MHA-SCC admixed with SDA-SCC as shown in Table 3.

Table 3 Summary of Trials Mix Design Proportion of grade 40 SCC

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	185	0.75	534	5.8	36.7	6.24
TM2	520	860	870	185	0.77	546	7.3	40.56	6.24
TM3	520	880	850	185	0.84	653	9.2	41.26	6.24
TM4	520	900	830	185	0.86	656	11.6	42.76	6.24
TM5	520	920	810	185	0.86	684	17.4	41.51	6.24
TM6	520	840	890	195.2	0.79	586	6.4	41.11	6.24
TM7	**520**	**860**	**870**	**195.2**	**0.83**	**658**	**9.5**	**44.55**	**6.24**
TM8	520	880	850	195.2	0.84	674	12.7	41.78	6.24
TM9	520	900	830	195.2	0.84	688	15.4	44.66	6.24
TM10	520	920	810	195.2	0.88	724	18.5	44.87	6.24

Table 4 Materials Batching of SCC with SDA and MHA

Mixtures	% MHA	Cement (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	MHA (kg/m^3)	Water (kg/m^3)	Super plasticizer (kg/m^3)
TM1	0	520	860	870	0	195.2	6.24
TM2	5	520	860	870	26	195.2	6.24
TM3	10	494	860	870	26	195.2	6.24
TM4	15	468	860	870	26	195.2	6.24
TM5	20	442	860	870	26	195.2	6.24
TM6	25	416	860	870	26	195.2	6.24
TM7	30	490	860	870	26	195.2	6.24

B. Fresh properties of the mixtures

Slump flow, passing ability and segregation resistance were carried out in compliance with BS EN 206 (2013).

C. Hardened properties of the SCC

Concrete cylinder of 100mm x 200mm size was cast with SCC, SDA-SCC, MHA-SCC and SDA-MHA-SCC. The compressive strength test was carried out according to BS EN 12390-2 (2002) at ages of 3, 7, 28, 56 and 90 days using ADR1500 branded ELE digital compression machine at a loading rate 0.5 kN/s. Total of 105 numbers of cylinders were used with 3 samples from each % replacement.

Results and Discussion

A. Compressive Strength of MHASCC

The results of compressive strength of MHA-SCC increased with curing age but decreased with increase in MHA content at all curing ages. The 28 days compressive strength has maximum strength of 44.55 N/mm^2 at 5%MHA and minimum strength of 26.7 N/mm^2 at 30% MHA, It was however observed that the 28 days compressive strength of SCC increase with up to 10 % MHA content meeting the design characteristic strength of 40N/mm^2, this is also obtainable at 15% and 20% MHA at 56 and 90 days curing respectively as shown in Figure 2. The improvement in strength could be due to high content of silica available in MHA and its fineness during hydration process convert calcium hydroxide and improves its properties (Mindess *et al.*, 2003).

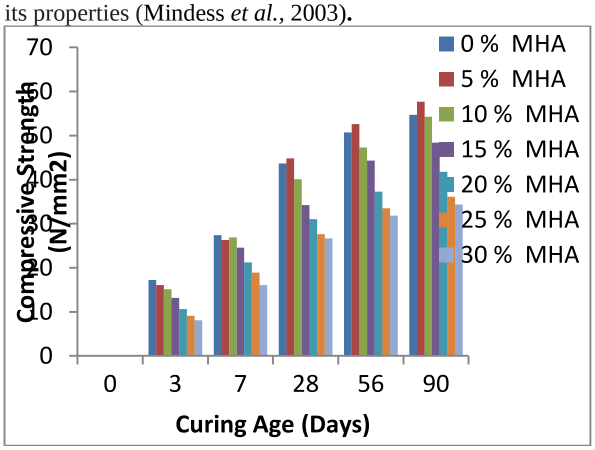

Figure 2: Compressive strength vs. curing age of MHA – SCC

B. Effect of MHA on Compressive Strength of SDA-SCC

The compressive strength of SDA-SCC admixed with optimum MHA is shown in Figure 3. The result attests that the compressive strength decreased with increase in SDA content and subsequently increases with curing age. At 28 days, the compressive strength of SDA-SCC blended with 5% MHA improves significantly; this could be as a result of high silica content in MHA (Morsy *et al.*, 2010). However, compressive strength gradually reduced with SDA contents higher than 10% possibly due to the dilution effect of SDA and MHA in cement. This is consistence with the work of Bheel *et al.*, (2021) and Jimoh *et al.*, (2013). Equally, it could be due to the fact that wood waste ash particle acts as a filler material rather than a binder material within the cement paste matrix. Therefore, increasing the ash content as a cement replacement material could arise in an increase in the surface area of the filler material to be bonded by reducing the amount of cement, resulting in a decrease in strength., this observation agrees with the findings of Udoeyo *et al.*, (2006) and in agreement with the works of Raheem *et al.*, (2012), Part *et al.*, (2015), who stated that the compressive strength development of concrete containing SDA, increased with curing ages, deceased in relation to the control as replacement of cement with SDA with increases.

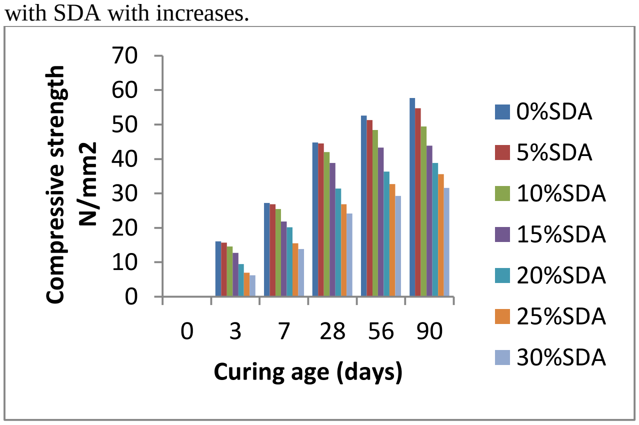

Figure 3: Compressive strength vs. curing age of MHASDA-SCC.

C. Effect of MHA on Splitting Tensile Strength of MHA-SCC

The splitting tensile strength result of MHA-SCC samples at 28 days is shown in Figure 4. The result shows high tensile strength of 4.68 N/mm^2 at 5% MHA greater than the control and minimum splitting tensile strength equals to 2.04 N/mm^2 for 30 % MHA replacement. Also the Figure show that the splitting tensile strength decreases with increasing MHA content at early curing age, this may be due to delay in strength development caused by the delay in setting time and the dilution effect of OPC with MHA (Bheel *et al.,* 2021)**.** This is in line with the work of (Foong *et al.*, 2015)**.** Similarly, Wasiu *et al.*, (2020) stated that the tensile strength for MHA increases with an increase in curing days. The improvement in strength over the conventional SCC was attributed to the presence of pozzolanic action of silicon oxide, alumina and lime in the ash, thereby enhancing the cementitious reaction of the concrete mixes.

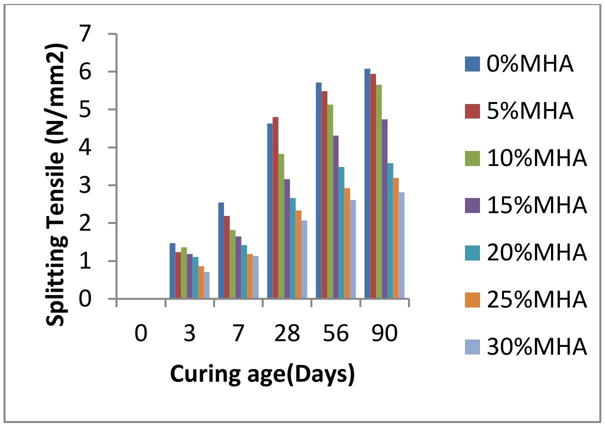

Figure 4: Splitting tensile Strength vs. curing age of MHA-SCC

D. Effect of MHA on Splitting Tensile Strength SDA-SCC

Figure 5, shows the splitting tensile strength results of MHASDA-SCC samples, it show that the maximum splitting tensile strength is 4.21 N/mm^2 at 5% MHA and the minimum splitting tensile strength of 2.02 N/mm^2 was obtained at 30% MHA at 28 days, which is less than the control. The improvement in strength over the control due to the presence of pozzolanic effect of silica oxide, alumina and lime in the ash, which enhances the cementitious reaction of the concrete mix this corresponds with the work of Wasiu *et al.*, (2020). The increase in strength with age of curing is due to continuous hydration of cement and silicon oxide (SiO_2) in MHA mixed with SDA during hydration and lead to strength increase. This is in line with the work of Chowdhury *et al.*, (2015). The decrease in strength with increase in SDA content implies that less content of SiO_2 in SDA leads to slower strength development, which is responsible for the reduction in strength. This assertion is similar to the work of Naik *et al.*, (2002).

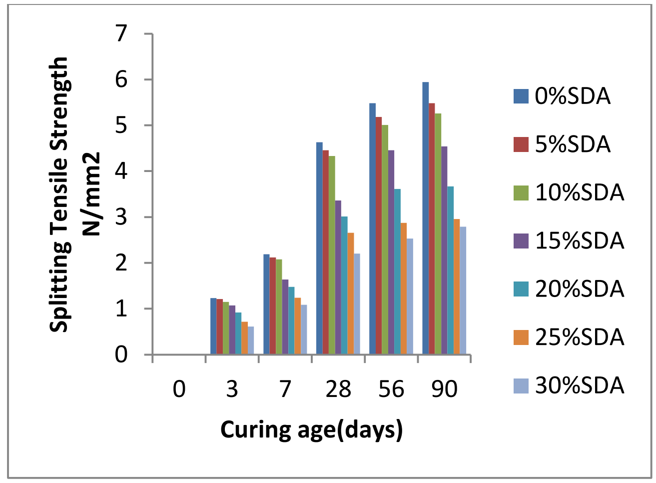

Figure 5: Splitting Tensile Strength vs. curing Age of MHASDA-SCC.

E. Effect of MHA on Flexural Strength of MHA-SCC

Figure 6 shows flexural strength results of MHA-SCC. The outcome of the flexural strength varied from 5.82 N/mm^2 at 5% to 3.31 N/mm^2 at 30%. However, at 5% MHA the flexural strength tends to be higher than that of control mixture. From Figure 6 it can be observed that the flexural strength increased with the curing age however, decreased with increased in MHA content, following a similar trend to tensile strength. A similar result was observed by Vasanthi and Selvan (2021). This boost in strength of the SCC is due to improvement of concrete properties owing to the particle size of MHA having a dominant silicon oxide (SiO_2) content reduces void during hydration and improves the strength properties (Jimoh *et al.*, 2013). At 10% MHA the strength tend to deteriorate, this can be attributed to the limiting binding characteristics of MHA as compared to cement. The decrease in flexural strength with increase in MHA at 10% replacement and above could be due to slower strength development from the pozzolanic reaction which is responsible for the reduction in strength (Prasanphan *et al.*, 2010).

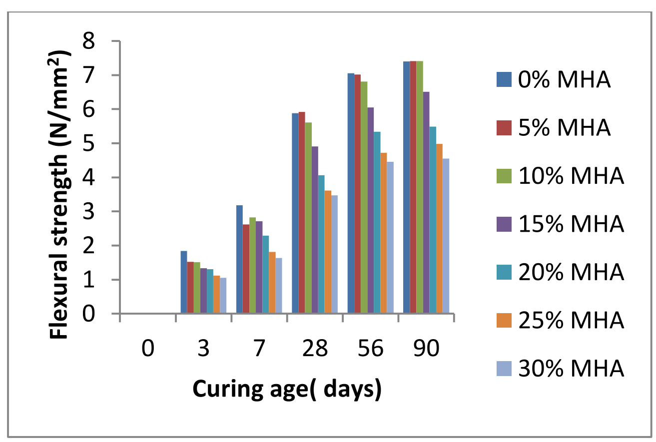

Figure 6: Flexural Strength vs. Curing Age of MHA-SCC

F. Effect of MHA on Flexural Strength of SDA-SCC

Figure 7 shows flexural strength results of SCC with addition of 5% MHA on SDA-SCC and reveals that flexural strength increased with the increase in curing age but decrease with increase in SDA content. The maximum strength was observed at 10 % SDA replacement, though less than the control. Similar results were observed by (Vasanthi *et al.*, 2021). This boost in strength is as a result of the fineness of MHA which improves concrete properties (Jimoh *et al.*, 2013). The decrease in flexural strength with increase in SDA at 15% replacement and above could be due to limited binding properties of SDA as the replacement levels increase reducing the chemical composition of cement and causes slower reaction leading to reduction in strength (Prasanphan *et al.*, 2010).

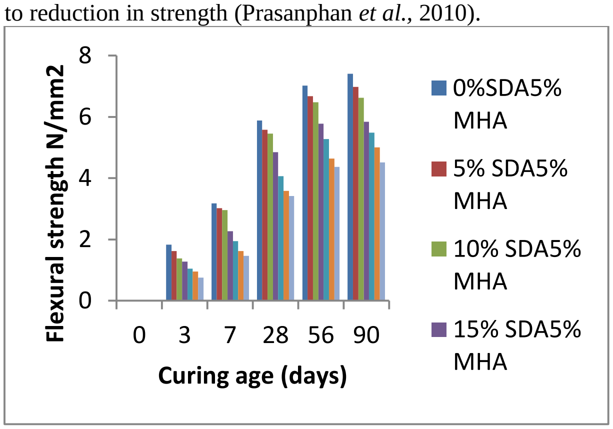

Figure 7: Flexural Strength vs. Curing Age of MHASDA-SCC

Conclusions

This study focuses on the effect of saw dust ash as a partial replacement of cement admixed with millet husk ash on the hardened properties of self compacting concrete. Based on the experimental investigations the following conclusions are drawn.

A. MHA is a good pozzolana as it has satisfied the requirement for BS EN 197-1 (2000) and ASTM C 618 (2005) for (SiO_2, Al_2O_3 and Fe_2O_3) while, SDA have not meet the requirement for BS-EN 197-1 (2000) and ASTM C 18 for SiO_2, Al_2O_3 and Fe_2O_3. Hence not a good pozzolana but has cementitious properties.

B. MHA and SDA successfully replace up to 10% cement to produces grade 40 SCC, grade 40 SCC can also be achieved at 15% and 20% replacement of cement with MHA and SDA at 56 and 90 days curing respectively.

C. MHA improves the tensile strength at 5% replacement. However, the flexural strength, splitting tensile strength of SDA-SCC-MHA decreases with increase in ash content but increase with curing age.

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