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Mechanical strengths of self compacting concrete containing sawdust-ash and naphthalene sulfonate

Elinwa, Augustine U*, Mamuda and Ahmed M.

Civil Engineering Programmme, Abubakar Tafawa Balewa University, PMB 0248, Bauchi, Nigeria

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Abstract. The present research work is on the effect of sawdust ash (SDA) on the mechanical strengths of self compacting concrete (SCC) using naphthalene sulfonate (NS) as a plasticizer. Experiments on compressive, flexural and splitting tensile strengths are conducted and the data analyzed using the Minitab 15 software. The results showed that SDA can defer the reaction of cement hydration and prolong the setting times of cement paste. This was very much pronounced on the flexural and splitting tensile strengths at 90 days of curing which are 36 % and 33 % higher than the control strengths, respectively. The study has proposed strength relations of mortar compressive strength with the flexural and splitting tensile strengths and these are, 5 and 7 times respectively. The flexural strength is 1.5 times that of the splitting tensile. Finally, linear models were developed on these relationships.

Keywords: compressive strength; mechanical strengths; flexural strengths; splitting tensile; sawdust ash; plasticizers

1. Introduction

SCC is a form of concrete that is able to flow under its own weight and completely fills the formwork even in the presence of dense reinforcement, without the need of any vibration, whilst maintaining homogeneity (EFNARC 2002). It was originally developed in Japan some years ago to off-set a growing shortage of skilled labour. The interest in this area of research has taken a tremendous limp in recent years. The development and use of SCC in many countries today have shown that it can successfully be produced from a wide range of component materials, notably cement replacement materials (mineral admixtures) and super plasticizers (high range water reducers)(Elinwa *et al*. 2008). SDA is an industrial waste from the timber industry and identified as a mineral admixture with potentials for use as a pozzolana and powder material in the production of SCC (Elinwa 2008, Elinwa and Mamuda 2001). Elinwa and Mamuda (2014) using SDA as powder material, achieved saturations at a water-cementitious material of 0.4 and 0.42, when the dosages of the super plasticizer (naphthalene sulfonate) was 3.5% and 2 % respectively. The optimum replacement level in their study was 10 wt % of cement by SDA and 2 % of super

∗Corresponding author, Professor Augustine U Elinwa; auelinwa@gmail.com

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plasticizer dosage.

Saturation was also achieved at 10 % wt. of fly ash addition and 3 % of super plasticizer dosage by (Ahmed *et al*. 2013). In their work, they used a range of water-cement ratios of between 0.28 to 0.38, and their results satisfied the requirements of SCC production. Good performances in the production of SCC have also been achieved using quarry dust (Johnsirani *et al*. 2013), hydrated and silica fume (Kumar and Rajeev 2012), and rice husk (Pedro and Jorge 2013).

Silva and Brito (2013) worked on the electrical resistivity and capillary of SCC with incorporation of fly ash and limestone filler. They used 11 mixes produced according to the NP EN 206-9 (2010) and four reference concretes according to the NP EN 206-1 (2007), and concluded that all the mixes produced reached the required workability parameters and can be classified as self-compacting, and had adequate filling and passing ability as well as a good resistance to segregation. They also affirmed that SCC's capillary as well as its electrical resistivity is strongly conditioned by the capillary pores and by their interrelation.

Kamal *et al*. (2013) investigated the potentials of the SCC mixes incorporating dolomite powder along with either silica fume (SF) or fly ash (FA) to develop bond strength. The variability of bond strength along a flowing path was evaluated. Based on the available test results some of their findings are that the bond strength was reduced due to Portland cement replacement with dolomite, the addition of either SF or FA positively hindered further degradation of bond strength as the dolomite powder content increased; and SCC mixes containing up to 30 % dolomite powder yielded bond strengths that were adequate for design purpose according to the requirements of the ACI 318 R-08 code.

In the present work the mechanical strengths of SDA-SCC are investigated using SDA as powder material to produce concrete samples that are tested for the compressive, splitting tensile and flexural strengths. The test results are used to derive relationships between the strength parameters and to analyze the sensitivity of the test data, using Minitab Software.

2. Materials

The materials used in this study are Portland 'Ashaka' cement which conforms to BS 12 (1996) and sawdust ash (SDA), obtained from thermally activated timber wastes at temperatures of between 400^{o}C and 600^{o}C. The chemical compositions of both the cement and SDA, average particle size (fineness), and binder composites are given in Tables 1 and 2.

The fine aggregate used is river sand with a specific gravity of 2.57, moisture content of 14.4% and a bulk density of 1472 kg/m^3 and falls in zone 2 in the classification table in accordance with BS 882, Part 1201 (1973). The coarse aggregate has a maximum aggregate size of 20 mm, specific gravity of 2.54, bulk density of 1351 kg/m^3 and a crushing value of 10.96. The coarse aggregate falls in zone 2 in the classification chart in accordance with BS 882.

Naphthalene sulphonate was used as the super plasticizer. This will result in a low water-powder ratio for high deformability (Todorova *et al*. 2013) and to equalize the surface charges (zeta potentials) on all solid particles in the dispersion and in this way disagglomerate the particles (Termkhajornkit and Nawa 2004).

Table 1 Chemical Analysis of Raw materials (%) by Weight

Oxides	Ashaka PC	Sawdust ash
SiO_2	20.7	67.2
Al_2O_3	6.1	4.1
Fe_2O_3	2.3	2.3
CaO	62.1	10.0
MgO	1.2	5.8
Na_2O	0.9	0.1
K_2O	1.0	0.1
SO_2	1.6	0.5
P_2O_5	-	0.5
MnO	-	0.01
	Bogue potential compound composition	
	C_3S 46	
	C_2S 24	
	C_3A 12	
	C_4AF 7	

Table 2 Fineness of raw materials

Fineness	PC	SDA
Passing 212μm	94	92
Specific surface Blaine)	355m^2/kg	151m^2/g

3. Experimental set-up

The experiments carried out to study the effects of SDA (powder) and NS on the mechanical strengths of SCC are: the compressive, flexural and splitting tensile strengths. The mix used for the mortar compressive strength tests is shown in Table 3a. This is a mix of 1: 1½ (cement: sand) with a water/cement ratio of 0.42. For the flexural and splitting tensile tests, the mix at 10 % replacement by wt. of cement (Optimum mix) was adopted and this is shown in Table 3b.The dosage of the naphthalene sulphonate was at 2.0 percent (Elinwa 2008).

A cube mould of 50 mm was used for the compressive strength test. For the flexural and splitting tensile tests, beams of dimensions 100 mm × 100mm × 300 mm; and concrete cylinders of 150 mm × 150 mm, were used respectively. SDA was added in proportions of 0, 5, 10, 15 and 20 percent by mass of cement to the mixes and cured for 3, 7, 14, 28, 60 and 90 days respectively.

A total of 90 mortar cubes were cast for the compressive mortar strength test. For the flexural and splitting tensile tests 18 specimens each were cast. All the tests were carried out in accordance

Table 3a Mix proportions for the mortar compressive strength

Mix No	Type of Plasticizer	Cement (kg/m^3)	SDA (%, kg/m^3)	Sand (kg/m^3)	Coarse Agg	Water (kg/m^3)	SP Dosage (%)	W/C
PC-01-N		479	0 (0)	719	Nil	201	2.0	0.42
PC-02-N		455	5 (24)	719	Nil	201	2.0	0.42
PC-03-N		431	10 (48)	719	Nil	201	2.0	0.42
PC-04-N	NS	407	15 (72)	719	Nil	201	2.0	0.42
PC-05-N		384	20 (96)	719	Nil	201	2.0	0.42

Table 3b Mix proportion for the flexural and splitting tensile test

SP Type	Mix No	Cement (kg/m^3)	SDA (%, kg/m^3)	Sand (kg/m^3)	Coarse Agg	Water (kg/m^3)	SP Dosage (%)	W/C
NS	FC/ST-01-N	479	0	719	719	201	2.0	0.42
	FC/ST-03-N	431	10 (48)	719	719	201	2.0	0.42

with (BS 1881 1983). The mix numbers for the mortar compressive strength tests are labeled PC-01N to PC-05N. PC-01N is the control mix and contains 0 % of SDA. The mixes that are labeled PC-02N to PC-05N are for various percentages of replacement levels.

The Mix numbers for the flexural and splitting tensile strengths are taken from Table 3a and at 10 % replacement, labeled as FC-01/FC-03N and ST-01N/ST- 03N, respectively. FC-01N and ST-01N are the control samples containing 0 % SDA.

At the end of each curing period three specimens were tested to failure and the average recorded. The results of the tests are shown in Tables 4, 5 and 6, for the compressive, flexural and splitting tensile strengths respectively.

4. Discussions of results

Table 4, shows that the process of hydration and the development of C–S-H continued to increase with age, signifying that the excess Ca $(OH)_2$, produced during the process of hydration was totally absorbed by SDA to form C–S–H, making the microstructure denser
(Elinw *et al*. 2008). The mortar cubes compressive strengths recorded its maximum strength at 10 wt % replacement for all ages and decreased after that and the maximum strength of 41.4 kN/mm^2 was achieved at 90 days of curing. This is approximately 30 % of the control, at the same age.

Tables 5 and 6 are plotted as shown in Figures 1 and 2. The figures show that the flexural and splitting tensile strengths increase as the curing progressed. It is interesting to note that the strength gain for the control samples virtually stopped at the end of 28 days of curing, signifying end of hydration, while, the samples containing 10 % wt of SDA continued to gain strength for as long as 90 days of curing. This action further confirms the pozzolanic actions of SDA and therefore, enhancement of strength. The percentage increase in the values of the flexural and splitting strengths at 90 days over that of the control samples are approximately 36 % and 33 %, respectively.

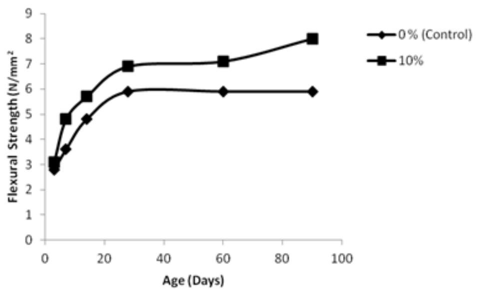

Fig. 1 Flexural strength of SDA-SCC

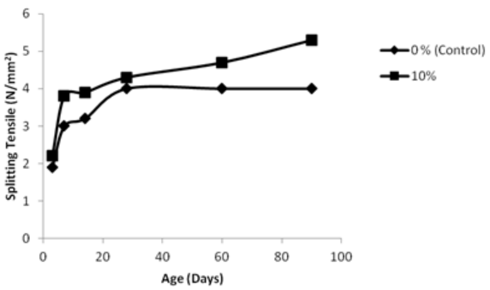

Fig. 2 Splitting tensile strength of SDA-SCC

Table 4 Compressive strength (N/mm^2)

Mix No	3 d	7 d	14 d	28 d	60 d	90 d
PC-01N	9.4	20.8	23.4	30.4	31.7	31.9
PC-02N	10.1	21.0	24.5	32.5	34.4	36.7
PC-03N	11.8	24.1	29.5	36.0	38.6	41.4
PC-04N	6.4	18.5	20.2	26.4	27.9	29.9
PC-05N	3.6	12.7	15.8	19.5	21.3	23.3

Table 5 Flexural strengths at 10% replacements (N/mm^2)

Mix No	3 d	7 d	14 d	28 d	60 d	90 d
FC-01N	2.8	3.6	4.8	5.9	5.9	5.9
FC-03N	3.1	4.8	5.7	6.9	7.1	8.0

Table 6 Splitting tensile test at 10 % replacements (N/mm^2)

Mix No	3 d	7 d	14 d	28 d	60 d	90 d
ST-01N	1.9	3.0	3.2	4.0	4.0	4.0
ST-03N	2.2	3.8	3.9	4.3	4.7	5.3

Table 7 is the optimum strengths achieved at 10 wt. % SDA for the compressive, flexural and splitting tensile strengths respectively. When the ratios of the compressive strength to the flexural and splitting tensile strengths are computed for the various curing ages (3, 7, 14, 28, 60 and 90 days) and averaged, it is seen that the magnitude of the ratios are approximately 5 and 7 times respectively. In the same vein, the splitting tensile to flexural is approximately 1.5.

5. Statistical analysis

The statistical analysis for the mortar compressive strength was carried out using the Minitab Statistical Software and shown in Tables 8 and 9. Regression equation was generated for **the model and presented as:**$F_c = 14.5 + 4.47\,x_2 - 2.06\,x_1$**, with a correlation factor** (R^2) **of** 76.1 %. Fc, is the mortar compressive strength, x_1 *and* x_2, are percentage replacements of cement by SDA and age respectively. The model chosen is significant with a P < 0.01. The variation in the mortar compressive strength as a result of the interaction between the SDA and age of curing is 76 %.

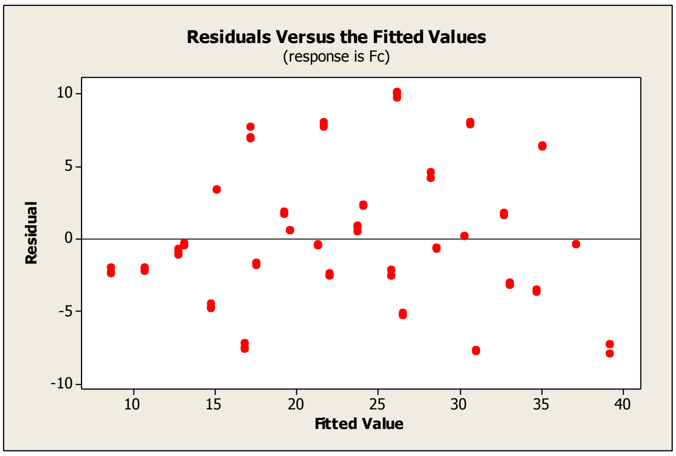

Fig. 3 Residual plot for compressive strength

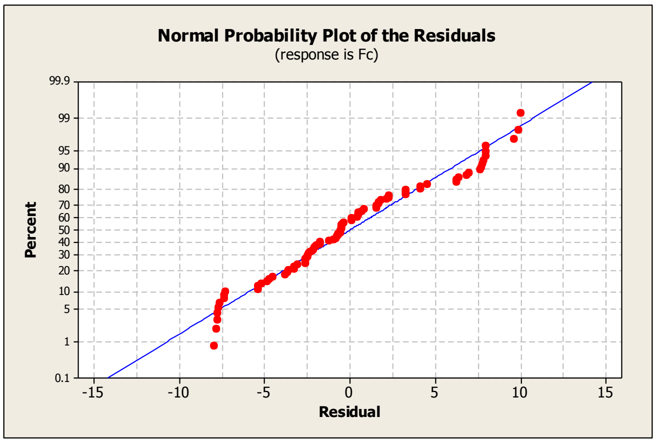

Fig. 4 Normality plot

The residual and normality plots for the linear model of the compressive strengths of the mortar cubes are shown in Figures 3 and 4. These show few large residuals (Field 2002) and hence, limited apparent outliers (Razak and Wong 2004) and confirm that there are no trends to show that the models are inappropriate.

Table 10 also shows the linear regression analyses for the strength development relations between the mortar compressive strength and flexural strength; compressive strength and splitting tensile, and the flexural and splitting tensile. The analyses show that there are strong linear relationships between the test parameters and thus, the models chosen are perfectly describing the interactions taken place in the systems.

6. Conclusion

Some of the conclusions reached on the work are that using SDA as a supplementary material in the production of SCC is highly beneficial. The mortar compressive strength of SCC at 90 days was approximately 30 % above the value of the control, at 10 wt% replacement.

SDA can defer the reaction of cement hydration and prolong the setting time of cement paste (9). This was very much pronounced from the strength development of the flexural and splitting tensile strengths as shown by Ft: 28/90 and St: 28/90 values recorded as 36 % and 33 % respectively.

From the study, the mortar compressive strength for SDA-SCC is approximately 5 times that of the flexural strength and 7 times that of the splitting tensile strength. The flexural is 1.5 times that of the splitting tensile, for SCC with SDA as replacement material.

The developed linear models for the mortar compressive strength, compressive to flexural/splitting tensile strengths and splitting to flexural strength are adequate because it shows that the data from the experiments are relevant and that the correlation factors are 76 %, 98.5 %, 95.2 %, and 94.5 %, respectively with p-values less than 0.050.

References

EFNARC (2002), “Specification and guidelines for self-compacting concrete, London. EFNARC Publication, 1 – 32.

Elinwa, A.U., Ejeh, S.P. and Mamuda, A.M. (2008), “Assessing of the fresh concrete properties of self-compacting concrete containing sawdust ash”, *Construct. Build. Mater.*, **22**(6), 1178-1182.

Elinwa, A.U. and Mahmood, Y.A. (2001), “Ash from timber waste as cement replacement material”, *Cement Concrete Compos.*, **24**, 219- 222.

Elinwa, A.U. and Mamuda, A.M. (2014), “Sawdust ash as powder material for self-compacting concrete containing naphthalene sulfonate”, Advances in Civil Engineering, vol. 2014, Article ID 129276, P8, http://dx.doi.org/10.1155/2014/129276.

Ahmad, F, Nasir, S, Muhd, F.N. and Ali, E. (2013), “Assessment of fresh and hardened properties of self-compacting concrete made with fly ash as mineral admixture”, *Int. J. Current Eng. Technol.*, **3**(1), 158 – 163.

Johnsirani, K.S., Jagannathan, A. and Kumar, D.R. (2013), “Experimental investigation on self compacting concrete using quarry dust”, *Int. J. Sci. Res. Public.*, **3**(6), 1 – 5.

Kumar, D.S. and Rajeev, C. (2012), “Development of self compacting concrete by use of Portland pozzolana cement, hydrated lime and silica fume”, *ISCA J. Eng. Sci.*, **1**(1), 35 -39.

Shazim, A.M., Muhammad, A.S. and Hassan, A. (2008), "Production of low cost self-compacting concrete using rice husk ash". 1st International Conference on Construction in Developing Countries (ICCIDC -1); Advancing and Integrating Construction Education Research and Practice, August, 4 – 5, Karachi, Pakistan.

Pedro Silva and Jorge de Binto (2013), "Electrical resistivity and capillary of self compacting concrete with incorporation of fly ash and limestone filler", *Adv. Concrete Constr.*, **1**(1), 65-84.

Kamal, M.M., Safan, M.A. and Al-Gazzer, M.A. (2013), "Steel-concrete bond potentials in self compacting concrete mixes incorporating dolomite powder", *Adv. Concrete Constr.*, **1** (4), 273-288.

BS 12 (1996), "Specification for Portland cement", British Institution.

BS 882, Part 1201 (1973), "Aggregates from natural sources for concrete (including granolithic), British Standard Code of Practice.

Todorova, E., Chernev, G. and Markov, P. (2013), "Influence of metakaolinite and stone flour on the properties of self-compacting concrete", *J. Chem. Technol. Metall.*, **48**(2) 196-201.

Termkhajornkit, P. and Nawa, T. (2004), "The fluidity of fly ash cement paste containing naphthalene sulfonate superplasticizer", *Cement Concrete Res.*, **34**, 1017-1024.

BS 1881 (1983), "Testing concrete: Method for the determination of compressive strength of concrete cubes", British Standard Code of Practice.

Field A (2002), "Discovering statistics using SPSS for windows", Sage Publications, London, 492pp.

Razak, H.A. and Wong, H.S. (2004),"Strength estimation model for high-strength concrete incorporating metakaolin and silica fume, *Cement Concrete Res.*, **35**, 688 -695.

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