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Experimental Study of the Strength Performance of Sawdust Ash Pervious Concrete

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Abstract: Deterioration of highway pavement resulting from flooding is on the increase because of climate change. Previous researches have succeeded in removing the run-off water using pervious concrete but for low traffic density. This research focused on improving the structural performance of pervious concrete for high-density traffic. The 168 test samples of pervious concrete comprising of 54 beams, 54 cubes and 60 cylindrical specimens were cast to undergo slump test, density and void content test, split tensile strength test, flexural strength test, compressive strength test and permeability test. Sawdust ash was added to replace cement with varying percentages of 5, 10, 15 and 20. The result shows that varying percentages of 5, 10, 15 and 20 sawdust ash mix exhibit poor mechanical properties.

Key words: Pervious concrete, sawdust ash, Civil Engineering, strength, construction, mechanical properties

INTRODUCTION

Concrete is a composition material made out of coarse aggregate joined securely in proximity with a fluid bond (cement) which solidifies after some time (Sadiq and Atoyebi, 2015; Zaetang *et al*., 2016; Atoyebi *et al*., 2018a-c). Concrete types vary with respect to the binder used and some other added materials like hydraulic cement such as calcium aluminate cement in limecrete, asphalt as a binder in asphaltic concrete and polymer concretes with the polymer as the cementing material (Harvey *et al*., 1995; Fakhrul *et al*., 2013; Kotwa, 2015; Dutt *et al*., 2016; Modupe *et al*., 2019). Pervious concrete which is also, known as permeable concrete is a composition material comprising of Portland cement, coarse aggregate and water. The major difference to ordinary concrete is the absence of fine aggregate in the primary mixture. The aggregate (coarse), more often than not comprises of a solitary size and is reinforced together at its points of contact by a paste moulded with concrete and water. The outcome is concrete with a high rate of interconnected voids that, when working effectively, allow the fast permeation of water through the concrete (Obla, 2010; Mrakovcic *et al*., 2014; Mahesh and Lavanya, 2016). Pervious concrete has different properties to conventional/normal concrete, normal concrete has a void proportion in the range of 3-5% compared to void proportions of 15-40% in pervious concrete depending upon its application (Sharma *et al*., 2012; Ghosh *et al*., 2015), since, voids are generally, assumed to lessen the strength of concrete, the desired result is to discover a balance between aggregate, water and cement with a specific end goal to increase the permeability and strength, two characteristics which tend to counteract one another.

Likewise, of vital importance is suitable traffic loads and volumes, so that, the porous concrete can keep up its structural integrity. Meanwhile at present pervious concrete is not recommended for high speed, high traffic roads (Ajamu *et al*., 2012; Radlinska *et al*., 2012; Lee *et al*., 2013). Maguesvari and Narasimha (2013) unveils some applications of pervious concrete: parking lots, alleys and driveways, sidewalks/walkways, swimming pool decks, tennis court, streets/road shoulders, patios, other light traffic areas etc. Some properties of pervious concrete are it allows water to seep through and permeate its surface, 40% of evapotranspiration, 10% runoff, 25% shallow infiltration, 25% deep infiltration and it has natural ground cover (Collier, 2016). Typical pervious concrete pavements have a 15-20% void structures. It is consequently lightweight with a density of 1600-1900 kg/m^3 (Ajamu *et al*., 2012). Patil and Murnal (2014) consider concrete to be durable when it responds to environmental conditions

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satisfactorily within its designed service life, its properties can be enhanced with the use of additional compounds like fly ash (Patil and Murnal, 2014). This research provides a way of improving the mechanical properties of pervious concrete through the partial replacement of cement with sawdust ash and addition of fine sand in variable proportions, enhancing the performance of pervious concrete and meets the requirement of ASTM C618, C989 and C1240, respectively (ASTM., 2003; 2015; ASTM., 2018ab).

MATERIALS AND METHODS

The materials used in this research are cement, granite as coarse aggregate, fine aggregate, Sawdust Ash (SDA) and water. Type I Portland cement conforming to ASTM. (2018) was used in all mixes a total of 168 test samples comprising of 54 nos 100×100×400 mm rectangular beams, 54 nos 150×150×150 mm cubes and 60 nos 100×140 mm cylindrical specimens were cast. Sawdust ash was used as a mineral additive to partially replace cement with variable proportions (5, 10, 15 and 20%) in enhancing the performance of pervious concrete and meets the requirement of ASTM C618, C989 and C1240, respectively (ASTM., 2003, 2015; ASTM., 2018a). The physical and chemical properties of the SDA were determined through different tests at the Chemistry Laboratory, Landmark University, Omu-Aran, Kwara State, Nigeria using Atomic absorption spectrophotometer (Model Analyst 800). The particle size of the SDA in this research passes through a sieve of opening 300 μm.

Compressive strength test: Three cubes from each pervious concrete batch mix were tested after 7, 14 and 28 days of curing. The compressive strength (f_c) is given by Eq. 1 (BSI., 2003a):

$$f_{CK} = \frac{F}{A_C} \tag{1}$$

Where:

f_{CK} = Compressive strength (N/mm^2)
F = Maximum failure load (N)
A_C = Specimen cross-sectional area (BSI., 2003a)

Flexural strength test: Flexural strength test was carried out using the centre-point loading method. Three beams from each pervious concrete batch mix were tested after 7, 14 and 28 days of curing. The flexural strength is expressed as the modulus of rupture (f_{cf}) which is given by Eq. 2 (BSI., 2009).

$$f_{cf} = \frac{3Fa}{2bd^2} \tag{2}$$

Where:

f_{cf} = Flexural strength in MPa (N/mm^2)
F = Maximum load at failure (N)
a = Distance between the supporting rollers (mm)
L = Length of beam (400 mm)
b = Width of beam (100 mm)
d = Depth of beam (100 mm)

Permeability/hydraulic conductivity test (infiltration rate method): The permeability of pervious concrete is measured at the end of the 28 days. A total of 6 cylindrical specimens were tested for the six pervious concrete batch mix. The permeability of pervious concrete is calculated using the Infiltration rate (I) as given in Eq. 3 (ASTM., 2009):

$$I = \frac{KM}{D^2 xt}(h) \tag{3}$$

Where:

K = 126,870 (inches)
M = Mass of water (Ib)
D = Diameter of cylinder (inches)
t = Time to infiltrate (sec)

Splitting tensile strength test: Three cylinders from each pervious concrete batch mix were tested after 7, 14 and 28 days of curing. The tensile splitting strength (f_{ct}) is given by Eq. 4 (BSI., 2003b; Atoyebi *et al*., 2018a):

$$f_{ct} = \frac{2F}{\pi Ld} \tag{4}$$

Where:

f_{ct} = Tensile splitting strength (N/mm^2)
F = Failure maximum load (N)
L = Length of the line of contact of the specimen (mm)
d = Designated cross-sectional dimension (mm)
π = Greek letter Pi constant value (3.142)

RESULTS AND DISCUSSION

Characterization of the mineral additives: The result in Table 1 reveals the elemental oxide in the SDA sample having combined percentages of (SiO+AlO+FeO) of 73.0%, this indicates that it is a good pozzolanic material in accordance with the requirements by ASTM (2003). The silica content in the SDA (65.65%) is low as compared to reports on Sawdust Waste Incineration Fly Ash (SWIFA) which is 67.20% (Elinwa *et al*., 2008) and corn cob ash with a value of 66.38% (Adesanya and Raheem, 2009) (Table 1).

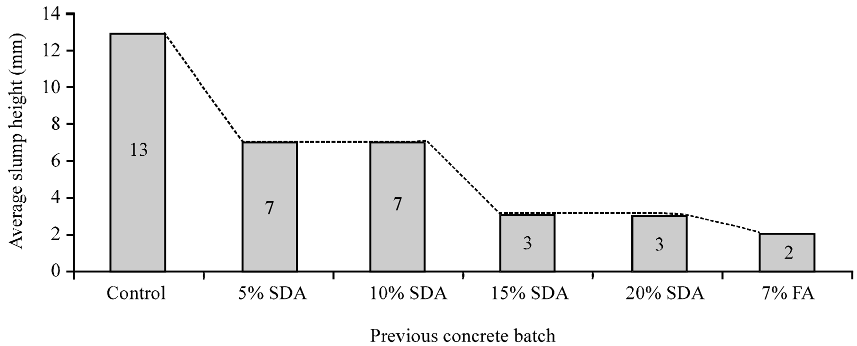

Fig. 1: Slump height vs. pervious concrete batch

Table 1: Chemical composition of SDA

Chemical constituents	Composition (%)
SiO_2	65.65
Al_2O_3	5.22
Fe_2O_3	2.13
CaO	9.62
MgO	4.51
SO_3	1.09
Na_2O	0.07
C_aCO_3	7.92
LOI	4.30
Total SiO_2+Al_2O_3	70.87
Total SiO_2+Al_2O_3+Fe_2O_3	73.00

Table 2: Physical properties of Sawdust Ash (SDA)

Physical properties	Values
Specific Gravity (G)	2.17
Loose bulk density (kg/m^3)	1040
Loss in ignition (%)	4.30
Yield (%)	3.00
Moisture content (%)	0.30
Particle passing (μm)	300

The loose bulk density, specific gravity and other physical properties of SDA are presented in Table 2. It shows that SDA has a specific gravity lesser than that of cement with a specific gravity of 3.15.

Slump test: Figure 1 shows that freshly mixed pervious concrete is typically stiff, within a slump range of 0-25 as specified by ASTM (2015) making it a true slump and low workability compared to conventional concrete. Increase in the SDA content causes increase in amount of silica in the concrete and its reaction with lime during cement hydration requires more water, hence, causing a stiff slump (Al-Chaar *et al.*, 2011).

Density and void content of hardened mixed pervious concrete: The density of pervious concrete as shown in Fig. 2 ranges from 1998.51-2380.49 kg/m^3 for the different mix. Densities within the upper range of normal-weight concrete on the order of 2000-2600 as specified by BSI. (2003c) were achieved for all except for 20% SDA which falls a little below it with a value of 1998.51 kg/m^3 (Fig. 2).

The percentage replacement of cement with SDA is inversely proportional to the density giving a 2% decrease in the pervious concrete density at every 5% SDA replacement. Moreover, 7% fine aggregate pervious concrete produced the highest density 2380.49 kg/m^3.

The influence of the SDA on the pervious concrete void content is shown in Fig. 3. As the SDA percentage replacement increases, there is an increase in the pervious concrete void content but a great decrease was recorded at the addition of 7% fine aggregate to the pervious concrete mix. According to, sika guide to pervious concrete, pervious concrete air void content varies between 15 and 30%. Maximum void content of 16.14% was achieved and a minimum of 12.08% for the SDA pervious concrete.

Compressive strength: The maximum compressive strength 24.329 N/mm^2 of at 28 days was obtained from 7% FA batch, it is observed that increase in the SDA content is inversely proportional to the pervious concrete compressive strength. Table 3, 20% SDA batch gave the least strength of 9.267 N/mm^2, attaining a strength above the minimum strength of 6 N/mm^2 after 28 days of curing recommended by BSI. (1976) for masonry cement. Likewise, based on ACI-318-08 (ACI., 2008) acceptance criteria for standard-cured specimens for strength test, the compressive strength result of all pervious concrete batch mix were analyzed, the analysis outcome revealed that the control mix and 7% fines addition mix is considered satisfactory, since, the two conditions for acceptance criteria as stated in the methodology are satisfied.

Flexural strength: Experimental results of the fleexural strenth tests after 7, 14 and 28 days. The optimum average

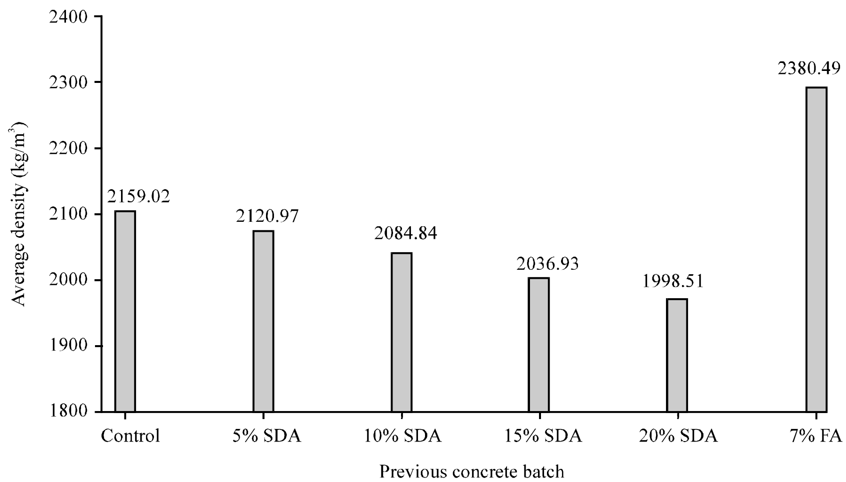

Fig. 2: Pervious concrete average density chart

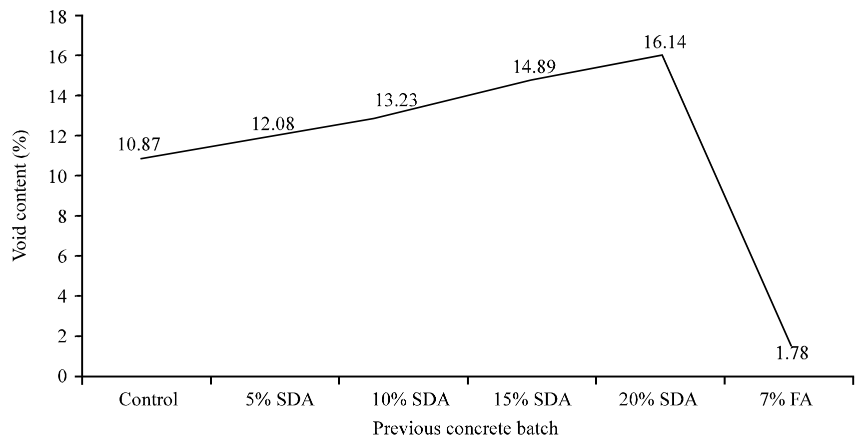

Fig. 3: Average void content (%) of pervious concrete batch

Table 3: Experimental results of the compressive strength tests after 7, 14 and 28 days

	Average load (kN)			Average compressive strength (N/mm^2)		
Pervious concrete batch	7 days	14 days	28 days	7 days	14 days	28 days
Control	384.119	453.466	505.033	17.072	20.15	22.445
5% SDA	182.246	233.570	251.753	8.099	10.38	11.189
10% SDA	172.026	214.990	235.534	7.646	9.55	10.468
15% SDA	170.269	204.145	214.140	7.568	9.07	9.517
20% SDA	162.574	202.500	208.517	7.225	9.00	9.267
7% FA	427.243	496.280	547.422	18.988	22.05	24.329

flexural strength for pervious concrete is 7.14 which is higher than the mean target flexural strength and falls above the pervious concrete flexural strength of approximately 2-5 N/mm^2 Table 4. Nevertheless, all the pervious concrete mix are suitable to enjoy the maximum benefit of flexural strength gain as seen from the test result of the MOR range of approximately 3-7 N/mm^2. Correspondingly, based on ACI 318-08 (ACI., 2008) acceptance criteria for standard-cured specimens for strength test, the flexural strength result of all pervious concrete batch mix were examined, the analysis outcome revealed that the control mix and 7% fines addition mix is considered satisfactory, since, the two conditions for acceptance criteria as stated in the methodology are satisfied (Fig. 4).

Permeability/hydraulicconductivitytest(infiltrationrate method) Experimental results of permeability (Infiltration

Table 4: Experimental results of the flexural strength tests after 7, 14 and 28 days

	Average load (kN)			Average Modulus of Rupture (MOR) (N/mm^2)		
Pervious concrete batch	7 days	14 days	28 days	7 days	14 days	28 days
Control	10.17	15.41	20.3	3.05	4.62	6.09
5% SDA	11.16	11.28	11.48	3.34	3.38	3.44
10% SDA	10.82	11.01	11.11	3.24	3.3	3.33
15% SDA	10.43	10.68	10.94	3.13	3.2	3.28
20% SDA	10.06	10.52	10.73	3.02	3.15	3.22
7% FA	12.14	18.41	23.81	3.64	5.52	7.14

Table 5: Experimental results for permeability (Infiltration rate test) at 28 days

Pervious concrete batch	Diameter of cylindrical mould (cm)	Mass of water (kg)	Constant, k (h)	Time (sec)	Infiltration rate (cm/sec)	Void content (%)
Control	10	18.15	126,870	77	3.00	18.2
5% SDA	10	18.15	126,870	65	3.06	19.1
10% SDA	10	18.15	126,870	63.7	3.63	20.4
15% SDA	10	18.15	126,870	61	3.78	22.0
20% SDA	10	18.15	126,870	60	3.85	22.5
7% FA	10	18.15	126,870	1100	0.21	5.20

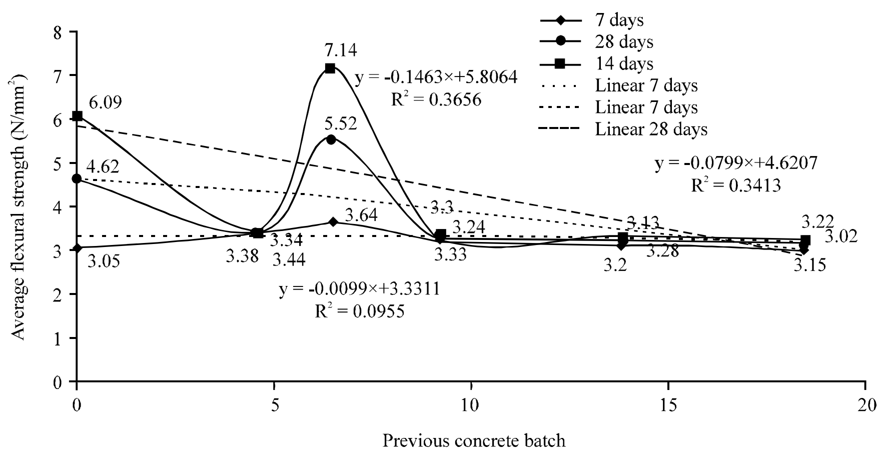

Fig. 4: Comparison of 7, 14 and 28 day's pervious concrete flexural strength

rate test) 28 days. Figure 5 shows that the infiltration rate is higher with an increase in SDA percentage replacement for pervious concrete due to the percentage of pores present in the PC specimens Table 5. It has been observed that 12.5 mm aggregate size gives higher values of permeability ranging from of 2.1-38.5 mm/sec which is in conformity with sika pervious concrete guidebook. Figure 5 shows the relationship between void content and permeability as well as pervious concrete mix, respectively.

Clogged and unclogged pervious concrete pavement system: From the field testing method for permeability of pervious concrete, two water samples were utilized to determine the infiltration rate of water through the concrete, sample (A) having a mass of 3.62 kg of potable water and sample (B) containing a water mass of 3.62 kg of polluted water. However, both samples were used for the permeability test, sample (A) was able to allow the flow of 3.62 kg mass of potable water within a time frame of 26 sec which is directly proportional to 3.0 cm/sec of infiltration rate, in contrast with sample (B) having the same mass of contaminated water but was able to allow flow of water in 2000 sec which is directly proportional to 0.12 cm/sec of infiltration rate.

Splitting tensile strength test: Experimental results of the split tensile strenth tests after 7, 14 and 28 days. From Table 6 above, an optimum value of 2.52 N/mm^2 at 28 days was obtained for pervious concrete with 7% fines addition. It was concluded that 7% fines addition is adequate to enjoy the maximum benefit of strength gain. Figure 5 shows the effect of the pervious concrete batch on the split tensile strength of pervious concrete. As could be observed from Fig. 5, there is a general decrease in split tensile strength as the SDA content increases. The

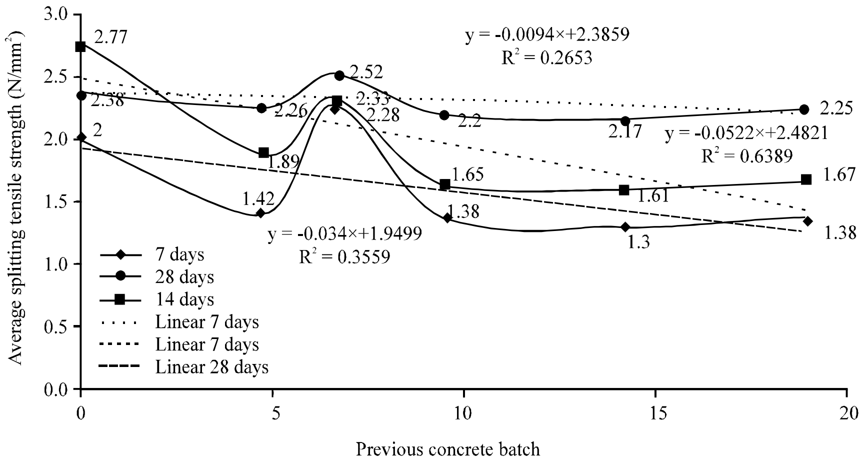

Fig. 5: Comparison of 7 days and 28 day's pervious concrete tensile splitting strength

Table 6: Experimental results of the split tensile strength tests after 7, 14 and 28 days

Pervious concrete batch	Avg. splitting tensile strength @ 7 days (N/mm^2)	Avg. splitting tensile strength @ 14 days (N/mm^2)	Avg. splitting tensile strength @ 28 days (N/mm^2)
Control	2.00	2.77	2.38
5% SDA	1.42	1.89	2.26
10% SDA	1.38	1.67	2.25
15% SDA	1.38	1.65	2.20
20% SDA	1.30	1.61	2.17
7% FA	2.28	2.33	2.52

splitting tensile strength falls within pervious concrete splitting tensile strength of approximately 2-5 N/mm^2 (Shetty, 2004).

Likewise, based on ACI -318-08 (ACI., 2008) acceptance criteria for standard-cured specimens for strength test, for the splitting tensile strength result of all pervious concrete batch mix, it can be seen that the control mix and 7% fines addition mix is considered satisfactory, since, the two conditions for acceptance criteria are satisfied.

CONCLUSION

Based on the results of this study, the conclusions drawn are: SDA is a suitable material as a pozzolan having a combined (SiO_2+Al_2O_3+Fe_2O_3) of more than 70%. Increase in SDA content makes concrete less workable thereby requiring higher water demand. The compressive strength generally increases with curing period and decreases with the increased amount of SDA. Only the control mix and 7% fines addition mix is adequate to enjoy the maximum benefit of strength gained. SDA concrete could be used for general concrete works where strength is of less importance such as in mass concrete, floor screed and mortar. All the pervious concrete mix are satisfactory to enjoy the maximum benefit of flexural strength gained. The splitting tensile strength generally increases with curing period and decreases with an increased percentage of SDA.

Finally, from this research work findings, it unveils that PC would be suitable as rigid pavement for high load road applications for 7% fines addition mix and control mix and for constructing plain concrete structures such as jetty structures, swimming pool decks, load-bearing walls, embankments etc., since, PC meets the minimum design criteria for grade 20 at 28 days thereby PC can be said to be a promising and beneficial in terms of cost.

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