Effect of Sawdust Ash on the Compressive Strength and Sorptivity of Laterised Concrete

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Abstract

This paper investigated the effect of sawdust ash (SDA) on the compressive strength and sorptivity of laterised concrete. Compressive strength up to 28 days and sorptivity at 28, 90 and 180 days were obtained at the laterite contents of 20 and 40% as partial replacement for sand and SDA contents of 10, 20, 30 and 40% as partial replacement for Portland cement (PC). Fifteen concrete mixes were investigated at the water/cement ratios of 0.30, 0.50 and 0.70 and assessed at equal 28-day strengths of 20-40 N/mm^2. At equal water/cement ratios, while compressive strength reduced by 0.76-0.79% for a percentage replacement of sand with laterite and by 1.26-1.63% for a percentage replacement of PC with SDA, sorptivity increased by 0.82-0.90% for a percentage replacement of sand with laterite and by 0.52-1.16% for a percentage replacement of PC with SDA. However, at equal strengths, laterised and SDA-laterised concretes, at up to 40% laterite and SDA contents, have higher resistance to sorption than the conventional PC concrete.

Keywords: absorption, compressive strength, laterised concrete, permeation resistance, sawdust ash.

1. Introduction

Concrete is a construction material amenable to various weather conditions. However, the need to make concrete construction cheaper and environmentally compatible has led to research into alternatives for its constituent materials- cement, aggregates and admixtures. For example, the abundance of laterite, the quest to reduce pressure on sand and the possibility of reducing the cost of concrete led to the use of laterized concrete- a concrete containing laterite as partial replacement for sand (Adepegba, 1975; Osunade, 2002; Olawuyi & Olusola, 2010). Laterite, due to the higher content of fine particles, is characterized by higher water demand (Falade, 1994). Nonetheless, if appropriately proportioned, laterized concrete would have good workability (Falade, 1994), good strength properties (Lasisi & Osunade, 1985; Salau & Balogun, 1990; Osunade, 2002; Udoeyo, Iron & Odim, 2006; Kamaruzaman & Muthusamy, 2013), resistance against shrinkage and long-term deformation (Salau & Balogun, 1999; Salau, 2003) and good performance in aggressive media (Lanre & Asce, 2007; Apeh & Ogunbode, 2012; Olusola & Opeyemi, 2012; Ige, 2013; Olusola & Ata, 2014). However, for good results, laterite content should be maintained at less than 50% of the total fine aggregate content of the concrete (Balogun and Adepegba, 1982; Salau & Balogun, 1999; Apeh & Ogunbodede, 2012).

In order to reduce the environmental impact (embodied energy and carbon footprint) of Portland cement, various byproducts of industrial wastes (fly ash, GGBS, silica fume and metakaolin) and byproducts of agricultural wastes (corncob ash, rice husk ash and sawdust ash), among others, have been discovered as good pozzolans that could be used as partial replacement for Portland cement in concrete. Due to their continuous pozzolanic reactivity with increasing curing age, the use of pozzolans in the right proportion will contribute to the strength development of laterized concrete (Olawuyi and Olusola, 2010; Ogunbode and Akanmu, 2012; Olawuyi, Olusola and Babafemi, 2012; Ogunbode, Ibrahim, Kure and Saka, 2013).

Sawdust is a common waste in sawmills over the world and the use of sawdust ash in concrete would be a means of solving the disposal problem. As a pozzolan, sawdust ash would delay the setting times and reduce the performance of concrete at early ages. However, the delayed setting times would lead to improved workability of concrete in hot weather (Falade, 1990). Also, due to the continuous pozzolanic reaction with increasing age, sawdust ash would contribute to later-age strength development of concrete (Udoeyo and Dashibil, 2002; Elinwa and Mahmood, 2002; Elinwa and Ejeh, 2004; Raheem, Adedokun, Ajayi, Adedoyin and Adegboyega, 2017) and resistance to water absorption of concrete (Udoeyo, Inyang, Young and Oparadu, 2006). However, information on the durability performance and especially the permeation resistance of sawdust ash laterized concrete is scanty in literature. The durability of concrete depends on its resistance to permeation (McCarter, Ezirim and Emerson, 1992). One of the transport mechanisms for assessing permeation resistance of concrete is sorptivity which measures the rate of absorption of water by hydraulic cement concretes (Neville, 2012; ASTM C1585, 2013). Hence, to assess the resistance of sawdust ash laterized concrete to sorption, and therefore provide more information on its suitability for construction, this paper investigated its sorptivity at different water/cement ratios and strengths.

2. Experimental Materials and Methods

The materials used in the study consisted of ordinary Portland cement (PC, 42.5), sawdust ash (SDA) and fine and coarse aggregates. Sawdust ash was calcined at 500^{o}C. The oxide compositions of PC and SDA are presented in Table 1. The fine aggregates were sand and laterite. Since laterite content has been recommended to be below 50% (Balogun and Adepegba, 1982; Salau & Balogun, 1999; Apeh and Ogunbodede, 2012), laterite was used to replace sand at 20 and 40% levels. The coarse aggregates were granite chippings angular in shape. The properties of the aggregates are presented in Table 2.

Table 1: Properties of Portland Cement and Sawdust Ash

Elemental Oxide (%)	PC	SDA
SiO_2	16.82	62.96
Al_2O_3	4.35	8.29
Fe_2O_3	2.43	3.85
CaO	60.39	9.53
MgO	1.43	5.48
SO_3	1.64	0.68
K_2O	0.16	0.15
Na_2O	0.02	0.06
MnO	0.04	0.01
P_2O_5	0.21	0.48
TiO_2	0.24	0.00
LOI	9.84	4.85
AR	1.67	14.20
Free Lime	0.36	0.00
$SiO_2 + Al_2O_3 + Fe_2O_3$		75.10

Concrete was designed in accordance with the Building Research Establishment Design Guide (Teychenne, Franklin & Erntroy, 1997) at a free water content of 210 kg/m^3 and water/cement ratios of 0.30, 0.50 and 0.70. Since the water requirement of concrete will increase with increasing content of laterite (Falade, 1994), Mapefluid N200, conforming to EN 934-2, was used as superplasticiser during mixing to achieve a consistence level of S2 defined by a nominal slump of 50-90 mm in BS EN 206-1. Concrete was prepared to BS EN 12390-2 with potable water conforming to BS EN 1008, cast, covered with polythene for about 24 hours, demoulded and cured in water until the tests' dates. Tests were carried out on hardened concrete specimens to determine the cube compressive strength and sorptivity. Cube compressive strength was determined in accordance with BS EN 12390-3 using 100 mm cubes at the curing ages of 7, 14, 21 and 28 days.

Table 2: Properties of Aggregates

Properties	Fine Aggregates		Coarse Aggregates (Granite)
	Laterite	Sand	
Fineness modulus	3.03	3.12	6.95
Coefficient of uniformity	5.23	3.24	1.55
Coefficient of curvature	0.99	0.96	0.90
Specific gravity	2.53	2.64	2.70
Moisture content, %	7.33	5.17	0.88
Absorption, %	9.15	1.09	1.58
Liquid limit, %	37.0	-	-
Plastic limit, %	17.0	-	-
plasticity index, %	20.0	-	-

Sorptivity at the curing ages of 28, 90 and 180 days were obtained in accordance with ASTM C1585. Concrete specimens 100 mm in diameter and 50 mm thick were oven-dried to constant mass at about 105±5°C, cooled to room temperature in a dessicator containing silica gel and waxed on the side. The upper end of the specimen was covered with a loose plastic sheet attached with masking tape to allow the air entrapped in the pores to escape from the concrete pores while at the same time preventing water loss by evaporation. The initial mass of the specimen was obtained and the other uncovered end was placed on supports in water. The level of water was maintained at 3-5 mm above the top of the support throughout the duration of the test. The test was conducted over 6 hours and the cumulative change in mass at specific intervals was determined. This involved removing the specimen from water, cleaning the test surface with a dampened paper towel to remove water droplets and measuring the weight before placing the sample in water to continue the test. Using Equation 1, the cumulative change in mass at 1 minute, 5 minutes, 10 minutes, 20 minutes, 30 minutes, 1 hour, 2 hours, 3 hours, 4 hours, 5 hours and 6 hours were used to obtain the respective cumulative absorption values.

$$i = \frac{\Delta m}{A * \rho} \quad (1)$$

where i = cumulative water absorption,
Δm = cumulative change in mass due to water absorption,
A = cross-sectional area of test specimen, mm^2 and

ρ = density of water.

Using Darcy's Law expressed in Equation 2 (Hall, 1989), the cumulative absorption values were plotted against the square root of test times and sorptivity (the initial rate of water absorption) was obtained as the slope of the line that best fits the plot.

$$i = S * t^{0.5} \qquad (2)$$

where S = sorptivity
t = test time in seconds

3. Results and Discussion

3.1 Compressive strength and sorptivity of concrete at equal water/cement ratios

Table 3 presents the cube compressive strengths of concretes at different water/cement ratios, curing ages and laterite contents (Lat) with their strength factors obtained, over the curing ages, with respect to the compressive strengths of the conventional (or control) concrete. As expected, the compressive strength increased with curing age due to the hydration reaction of Portland cement and reduced with increasing water/cement ratio due to the decreasing content of the cement. In line with Olawuyi & Olusola (2010), Olusola & Opeyemi (2012) and Ettu, Ibearugbulem, Ezeh & Anya (2013), compressive strength reduced with increasing content of laterite. This reduction in strength might not be unconnected with the fact that laterite has higher finer particles (due to the clay content) that would necessitate the need for higher content of cement to achieve the same level of strength development with sand. Also, since laterite is not a cement replacing material that would undergo hydration or pozzolanic reaction over the curing ages, the strength factors remain also constant and do not show a particular trend at each level of laterite content. Table 3 further shows that the partial replacement of sand with 20% and 40% laterite resulted in a strength reduction of 15.28% and 31.44% respectively. Hence, a percentage replacement of sand with laterite resulted in a strength reduction of 0.76-0.79%.

Table 3: Cube compressive strengths and strength factors of concretes at different contents of laterite

Mix combination	W/C	Compressive strength, N/mm^2				Strength factor [a], (%)					Over-all Mean	% [b] Red.
		7d	14d	21d	28d	7d	14d	21d	28d	Mean		
100PC+0SDA+0Lat	0.30	54.0	65.0	69.0	72.5	100	100	100	100	100	100	-
	0.50	31.0	40.5	44.5	48.0	100	100	100	100	100		
	0.70	22.0	29.0	32.0	34.0	100	100	100	100	100		
100PC+0SDA+20Lat	0.30	45.5	55.0	58.5	61.5	84.26	84.62	84.78	84.83	84.62	84.72	15.28
	0.50	26.0	34.5	38.0	40.5	83.87	85.19	85.39	85.42	84.97		
	0.70	18.5	24.5	27.0	29.0	84.09	84.48	84.38	85.29	84.56		
100PC+0SDA+40Lat	0.30	37.0	44.5	48.0	50.0	68.52	68.46	68.84	68.96	68.70	68.56	31.44
	0.50	21.0	27.5	30.5	33.0	67.74	67.90	68.54	68.75	68.23		
	0.70	15.0	20.0	22.0	23.5	68.18	68.97	68.75	69.12	68.76		

[a] Strength ratio with respect to the control sample (0% laterite)

[b] % Reduction in strength with respect to the control sample (0% laterite)

Table 4 presents the cube compressive strengths of concretes at different water/cement ratios, curing ages and contents of laterite and SDA with their strength factors. The strength factors are percentages comparing the strengths of concretes containing SDA with the strengths of the conventional and laterised concretes at each level of laterite content. Also, compressive strength increased with curing age due to the hydration reaction of Portland cement and the pozzolanic reaction of SDA and reduced with increasing water/cement ratio due to the decreasing content of the binder (Portland cement and SDA). Table 4 shows that, compared with Portland cement, compressive strength reduced with increasing content of SDA. However, the strength factors show that the differences in compressive strengths between the 100%PC concretes and the SDA concretes reduced with increasing curing age. This is probably due to the continuous pozzolanic activity of SDA with increasing curing age (Udoeyo & Dashibil, 2002; Elinwa & Mahmood, 2002; Elinwa & Ejeh, 2004; Udoeyo *et al.*, 2006). Compared with the conventional concretes (i.e., concretes containing 100%PC and 0%laterite), Table 4 shows that the partial replacement of PC with SDA resulted in a strength reduction of 16.27, 25.81, 39.96 and 57.44% at the partial replacement levels of 10, 20, 30 and 40% SDA respectively. This corresponds to a strength reduction of 1.63, 1.29, 1.33 and 1.44% for a percentage replacement of PC with SDA. Compared with laterised concretes with 100%PC and 20%laterite, the percentage strength reductions were 15.76, 25.21, 39.93 and 57.51 at the partial replacement levels of PC with 10, 20, 30 and 40% SDA respectively; thus resulting in a strength reduction of 1.58, 1.26, 1.33 and 1.44% respectively for a percentage replacement of PC with SDA. Similarly, at 40%laterite content, compressive strength reduced by 16.12, 26.39, 40.19 and 57.05% at the partial replacement levels of 10, 20, 30 and 40% SDA respectively. This also resulted in a strength reduction of 1.61, 1.32, 1.34 and 1.43% respectively for a percentage replacement of PC with SDA. Hence, overall, a percentage replacement of PC with SDA resulted in a strength reduction of 1.26-1.63%.

Table 4: Compressive strengths and strength factors of concretes at different contents of laterite and SDA

Mix combination	W/C	Compressive strength, N/mm^2				gtrength factor [a], (%)					Over-all Mean	% [b] Red.
		7d	14d	21d	28d	7d	14d	21d	28d	Mean		
100PC+0SDA+0Lat	0.30	54.0	65.0	69.0	72.5	100	100	100	100	100	100	-
	0.50	31.0	40.5	44.5	48.0	100	100	100	100	100		
	0.70	22.0	29.0	32.0	34.0	100	100	100	100	100		
90PC+10SDA+0Lat	0.30	43.0	54.0	59.0	63.0	79.63	83.08	85.51	86.90	83.78	83.73	16.27
	0.50	24.5	33.5	38.0	42.0	79.03	82.72	85.39	87.50	83.66		
	0.70	17.5	24.0	27.5	29.5	79.55	82.76	85.94	86.76	83.75		
80PC+20SDA+0Lat	0.30	37.0	47.5	52.5	57.0	68.52	73.08	76.09	78.62	74.08	74.19	25.81
	0.50	21.5	29.5	34.5	38.0	69.35	72.84	77.53	79.17	74.72		
	0.70	15.0	21.0	24.5	26.5	68.18	72.41	76.56	77.94	73.77		
70PC+30SDA+0Lat	0.30	29.5	38.5	42.5	46.5	54.63	59.23	61.59	64.14	59.90	60.04	39.96
	0.50	17.0	24.0	27.5	31.0	54.84	59.26	61.80	64.58	60.12		
	0.70	12.0	17.0	20.0	22.0	54.55	58.62	62.50	64.71	60.10		
60PC+40SDA+0Lat	0.30	20.0	27.0	31.0	33.5	37.04	41.54	44.93	46.21	42.43	42.56	57.44
	0.50	11.5	17.0	20.0	22.5	37.10	41.98	44.94	46.88	42.73		
	0.70	8.0	12.0	14.5	16.0	36.36	41.38	45.31	47.06	42.53		
100PC+0SDA+20Lat	0.30	45.5	55.0	58.5	61.5	100	100	100	100	100	100	-
	0.50	26.0	34.5	38.0	40.5	100	100	100	100	100		
	0.70	18.5	24.5	27.0	29.0	100	100	100	100	100		
90PC+10SDA+20Lat	0.30	36.5	45.5	50.0	53.5	80.22	82.73	85.47	86.99	83.85	84.24	15.76
	0.50	21.0	29.0	33.0	35.5	80.77	84.06	86.84	87.65	84.83		
	0.70	15.0	20.5	23.0	25.0	81.08	83.67	85.19	86.21	84.04		
80PC+20SDA+20Lat	0.30	31.5	40.0	44.5	48.5	69.23	72.73	76.07	78.86	74.22	74.79	25.21
	0.50	18.0	25.5	29.5	32.0	69.23	73.91	77.63	79.01	74.95		
	0.70	13.0	18.0	21.0	23.0	70.27	73.47	77.78	79.31	75.21		

[a] Strength ratio of SDA laterised concrete to the respective laterised concrete

[b] % Reduction of SDA laterised concrete to the respective laterised concrete

Table 4: Compressive strengths and strength factors of concretes at different contents of laterite and SDA (contd.)

Mix combination	W/C	Compressive strength, N/mm^2				Strength factor [a], (%)					Over-all Mean	% [b] Red.
		7d	14d	21d	28d	7d	14d	21d	28d	Mean		
70PC+30SDA+20Lat	0.30	25.0	32.5	36.0	39.5	54.95	59.09	61.54	64.23	59.95	60.07	39.93
	0.50	14.0	20.5	23.5	26.0	53.85	59.42	61.84	64.20	59.83		
	0.70	10.0	14.5	17.0	19.0	54.05	59.18	62.96	65.52	60.43		
60PC+40SDA+20Lat	0.30	17.0	23.0	26.0	28.5	37.36	41.82	44.44	46.34	42.49	42.49	57.51
	0.50	9.5	14.5	17.0	19.0	36.54	42.03	44.74	46.91	42.56		
	0.70	7.0	10.0	12.0	13.5	37.84	40.82	44.44	46.55	42.41		
100PC+0SDA+40Lat	0.30	37.0	44.5	48.0	50.0	100	100	100	100	100	100	-
	0.50	21.0	27.5	30.5	33.0	100	100	100	100	100		
	0.70	15.0	20.0	22.0	23.5	100	100	100	100	100		
90PC+10SDA+40Lat	0.30	29.5	37.0	40.5	43.0	79.73	83.15	85.26	86.00	83.54	83.88	16.12
	0.50	16.5	23.0	26.0	28.5	78.57	83.64	85.25	86.36	83.46		
	0.70	12.0	17.0	19.0	20.5	80.00	85.00	86.36	87.23	84.65		
80PC+20SDA+40Lat	0.30	25.5	32.5	36.0	38.5	68.92	73.03	75.79	77.00	73.69	73.61	26.39
	0.50	14.5	20.0	23.0	25.5	69.05	72.73	75.41	77.27	73.62		
	0.70	10.5	14.5	16.5	18.0	70.00	72.50	75.00	76.60	73.53		
70PC+30SDA+40Lat	0.30	20.5	26.5	29.0	31.0	55.41	59.55	61.05	62.00	59.50	59.81	40.19
	0.50	11.5	16.0	19.0	21.0	54.76	58.18	62.30	63.64	59.72		
	0.70	8.0	12.0	14.0	15.0	53.33	60.00	63.64	63.83	60.20		
60PC+40SDA+40Lat	0.30	13.5	18.5	21.5	23.0	36.49	41.57	45.26	46.00	42.33	42.95	57.05
	0.50	8.0	12.0	14.0	15.5	38.10	43.64	45.90	46.97	43.65		
	0.70	5.5	8.5	10.0	11.0	36.67	42.50	45.45	46.81	42.86		

[a] Strength ratio of SDA laterised concrete to the respective laterised concrete

[b] % Reduction of SDA laterised concrete to the respective laterised concrete

Table 5 presents the sorptivity of concretes at different water/cement ratios, curing ages and laterite contents with their respective sorptivity factors (i.e., percentages comparing the sorptivity of concretes at different contents of laterite with the sorptivity of the conventional concrete). Table 5 shows that sorptivity increased with increasing content of laterite. The increase in sorptivity might not be unconnected with the fact that laterite has higher finer particles, than sand, that would result in higher content of minute pores (Kelham, 1988; Kerr, 2008). Also, the clay content of laterite could result in stickiness and difficulty in the thorough mixing of cement and aggregates which could affect the development of dense microstructure for the resulting concrete. With respect to the sorptivity factors, Table 5 shows that the partial replacement of sand with 20% and 40% laterite resulted in a sorptivity increase of 13.62% and 35.78% respectively thus amounting to a sorptivity increase of 0.68-0.89% with a percentage replacement of sand with laterite.

Table 5: Sorptivity and sorptivity factors of concretes at different contents of laterite

Mix combination	W/C	Sorptivity x 10^{-3}, mm/√s			Sorptivity factor [a], (%)				Over-all Mean	% [b] Inc.
		28d	90d	180d	28d	90d	180d	Mean		
100PC+0SDA+0Lat	0.30	22.0	18.0	15.5	100	100	100	100	100	-
	0.50	27.5	24.0	21.5	100	100	100	100		
	0.70	39.0	34.0	30.0	100	100	100	100		
100PC+0SDA+20Lat	0.30	25.5	21.0	18.0	115.91	116.67	116.13	116.24	116.32	16.32
	0.50	32.0	28.0	25.0	116.36	116.67	116.28	116.44		
	0.70	45.5	39.5	34.8	116.67	116.18	116.00	116.28		
100PC+0SDA+40Lat	0.30	30.0	24.5	21.1	136.36	136.11	136.13	136.20	135.78	35.78
	0.50	37.4	32.6	29.1	136.00	135.83	135.35	135.73		
	0.70	53.0	46.0	40.5	135.90	135.29	135.00	135.40		

[a] Sorptivity ratio with respect to the control sample (0% laterite)

[b] % Increase in sorptivity with respect to the control sample (0% laterite)

Table 6 presents the sorptivity of concretes at different water/cement ratios, curing ages and contents of laterite and SDA with their respective sorptivity factors (i.e., percentages comparing the sorptivity of concretes containing SDA with the sorptivity of the conventional concrete and the laterised concretes at each level of laterite content). Table 6 shows that sorptivity increased with increasing content of SDA. This might not be unconnected with the decreasing content of Portland cement (dilution effect) and the reduction in the $Ca(OH)_2$ content required for the pozzolanic reaction of SDA and the production of sufficient hydration products and dense microstructure to resist permeation into concrete. The sorptivity factors show that the differences in sorptivity values between the 100%PC concretes and the SDA concretes reduced with increasing curing age. This would not be unconnected with improved pozzolanic reaction of SDA with increasing curing age. Compared with the conventional concretes (concretes containing 100%PC and 0%laterite), Table 6 shows that the partial replacement of PC with SDA resulted in a sorptivity increase of 11.63, 19.96, 33.84 and 44.03% at the partial replacement levels of 10, 20, 30 and 40% respectively. This corresponds, respectively, to a sorptivity increase of 1.16, 1.00, 1.13 and 1.10% for a percentage replacement of PC with SDA. Compared with concretes with 100%PC and 20%laterite, the percentages of sorptivity increase were 5.53, 15.47, 26.96 and 34.52 at the partial replacement levels of 10, 20, 30 and 40% SDA respectively; thus resulting in a sorptivity increase of 0.55, 0.77, 0.90 and 0.86% respectively for a percentage replacement of PC with SDA. Similarly, at 40%laterite content, sorptivity increased by 5.24, 13.15, 23.00 and 29.09% at the partial replacement levels of 10, 20, 30 and 40% SDA respectively. This also resulted in a sorptivity increase of 0.52, 0.66, 0.77 and 0.73% respectively for a percentage replacement of PC with SDA. Hence, overall, a percentage replacement of PC with SDA resulted in a sorptivity increase of 0.52-1.16%.

Table 6: Sorptivity and sorptivity factors of concrete at different contents of laterite and SDA

Mix combination	W/C	Sorptivity x 10^{-3}, mm/√s			Sorptivity factor [a], (%)				Over-all Mean	% [b] Inc.
		28d	90d	180d	28d	90d	180d	Mean		
100PC+0SDA+0Lat	0.30	22.0	18.0	15.5	100	100	100	100	100	-
	0.50	27.5	24.0	21.5	100	100	100	100		
	0.70	39.0	34.0	30.0	100	100	100	100		
90PC+10SDA+0Lat	0.30	24.5	20.0	17.1	111.36	111.11	110.32	110.93	111.63	11.63
	0.50	31.0	27.0	24.0	112.73	112.50	111.63	112.29		
	0.70	43.5	38.0	33.5	111.54	111.76	111.67	111.66		
80PC+20SDA+0Lat	0.30	26.9	21.5	18.2	122.27	119.44	117.42	119.71	119.96	19.96
	0.50	33.5	29.0	25.5	121.82	120.83	118.60	120.42		
	0.70	47.4	40.6	35.5	121.54	119.41	118.33	119.76		
70PC+30SDA+0Lat	0.30	29.9	24.1	20.6	135.91	133.89	132.90	134.23	133.84	33.84
	0.50	37.0	32.0	28.5	134.55	133.33	132.56	133.48		
	0.70	53.0	45.3	39.7	135.90	133.24	132.33	133.82		
60PC+40SDA+0Lat	0.30	32.5	26.0	22.1	147.73	144.44	142.58	144.92	144.03	44.03
	0.50	40.0	34.5	30.5	145.45	143.75	141.86	143.69		
	0.70	57.0	48.5	42.5	146.15	142.65	141.67	143.49		
100PC+0SDA+20Lat	0.30	25.5	21.0	18.0	100	100	100	100	100	-
	0.50	32.0	28.0	25.0	100	100	100	100		
	0.70	45.5	39.5	34.8	100	100	100	100		
90PC+10SDA+20Lat	0.30	27.5	22.0	18.7	107.84	104.76	103.89	105.50	105.53	5.53
	0.50	34.5	29.4	26.0	107.81	105.00	104.00	105.60		
	0.70	49.0	41.5	36.1	107.69	105.06	103.74	105.50		
80PC+20SDA+20Lat	0.30	30.1	24.2	20.5	118.04	115.24	113.89	115.72	115.47	15.47
	0.50	37.6	32.1	28.4	117.50	114.64	113.60	115.25		
	0.70	53.4	45.5	39.6	117.36	115.19	113.79	115.45		
70PC+30SDA+20Lat	0.30	33.1	26.5	22.5	129.80	126.19	125.00	127.00	126.96	26.96
	0.50	41.5	35.5	31.2	129.69	126.79	124.80	127.09		
	0.70	58.6	50.0	43.5	128.79	126.58	125.00	126.79		
60PC+40SDA+20Lat	0.30	35.2	28.0	23.8	138.04	133.33	132.22	134.53	134.52	34.52
	0.50	44.1	37.4	33.0	137.81	133.57	132.00	134.46		
	0.70	62.5	53.0	46.0	137.36	134.18	132.18	134.57		

[a] Sorptivity ratio of SDA laterised concrete to the respective laterised concrete

[b] % Increase in sorptivity of SDA laterised concrete to the respective laterised concrete

Table 6: Sorptivity and sorptivity factors of concrete at different contents of laterite and SDA (contd.)

Mix combination	W/C	Sorptivity x 10^{-3}, mm/√s			Sorptivity factor a), (%)				Over-all Mean	% b) Inc.
		28d	90d	180d	28d	90d	180d	Mean		
100PC+0SDA+40Lat	0.30	30.0	24.5	21.1	100	100	100	100	100	-
	0.50	37.4	32.6	29.1	100	100	100	100		
	0.70	53.0	46.0	40.5	100	100	100	100		
90PC+10SDA+40Lat	0.30	32.1	25.7	21.8	107.00	104.90	103.32	105.07	105.24	5.24
	0.50	39.9	34.2	30.3	106.68	104.91	104.12	105.24		
	0.70	56.5	48.5	42.2	106.60	105.43	104.20	105.41		
80PC+20SDA+40Lat	0.30	34.7	27.5	23.5	115.67	112.24	111.37	113.09	113.15	13.15
	0.50	43.0	36.5	32.5	114.97	111.96	111.68	112.87		
	0.70	61.0	52.0	45.5	115.09	113.04	112.35	113.49		
70PC+30SDA+40Lat	0.30	37.2	30.0	25.6	124.00	122.45	121.33	122.59	123.00	23.00
	0.50	46.6	40.0	35.5	124.60	122.70	121.99	123.10		
	0.70	66.2	56.5	49.5	124.91	122.83	122.22	123.32		
60PC+40SDA+40Lat	0.30	39.2	31.6	26.8	130.67	128.98	127.01	128.89	129.09	29.09
	0.50	49.1	42.0	37.0	131.28	128.83	127.15	129.09		
	0.70	69.5	59.5	51.6	131.13	129.35	127.41	129.30		

a) Sorptivity ratio of SDA laterised concrete to the respective laterised concrete
b) % Increase in sorptivity of SDA laterised concrete to the respective laterised concrete

Table 7 compares the percentage reductions in compressive strength and sorptivity of concretes extracted from Tables 4 and 6 respectively. The Table shows that, at each level of SDA content, the differences in the percentage reductions in compressive strengths are very small and less significant with increasing content of laterite. On the other hand, the differences in the percentage reductions in sorptivity are comparatively higher than that of the compressive strengths and they reduced with increasing content of laterite. Hence, it could be deduced that laterite contributed to increasing the resistance of concrete to sorption. This, therefore, shows that the interaction between SDA and laterite produced a reduction in the sorptivity of concrete. This synergy must be due to the fineness and packing ability of laterite and SDA resulting in improved microstructure and increased resistance of concrete to permeation. This is in line with previous studies by Bai, Wild & Sabir (2002) and Folagbade & Newlands (2013) that pozzolanic materials have the ability to improve the microstructure of concrete.

3.2 Sorptivity at equal strengths of concrete

Table 8 presents, within the limits of this study, the interpolated sorptivity values of concretes at equal 28-day strengths ranging between 20 and 40 N/mm^2 and the water/cement ratios at which the strengths were achieved. Since the 28-day strength of concrete is specified by designers, the Table provides various concrete options (incorporating SDA and laterite as partial replacements for PC and sand respectively) that could be used at these strengths. In line with previous studies (Folagbade & Newlands, 2014), the Table shows that equal strengths with the conventional concrete (100PC+0SDA+0Lat) were achieved by the other mixes at lower water/cement ratios and therefore at higher contents of the constituent materials. Also, as shown by Folagbade & Newlands (2014), these constituents could be used to determine the costs and embodied carbon dioxide contents and therefore establish the economic and environmental implications of the laterised concrete mixes. Table 8 shows that sorptivity reduced with increasing compressive strength and all the laterised and SDA laterised concretes, at up to 40% contents of laterite and SDA, have lower sorptivity and therefore higher resistance to sorption than the conventional concrete when concrete is specified on the basis of strength. This must be due to the fineness and packing ability of laterite and SDA resulting in improved microstructure and increased resistance of concrete to permeation.

Table 7: Percentage reduction in compressive strength and sorptivity of concrete

SDA content, %	Mix combination	Percentage reduction, %	
		Compressive strength	Sorptivity
10	90PC+10SDA+0Lat	16.27	11.63
	90PC+10SDA+20Lat	15.76	5.53
	90PC+10SDA+40Lat	16.12	5.24
20	80PC+20SDA+0Lat	25.81	19.96
	80PC+20SDA+20Lat	25.21	15.47
	80PC+20SDA+40Lat	26.39	13.15
30	70PC+30SDA+0Lat	39.96	33.84
	70PC+30SDA+20Lat	39.93	26.96
	70PC+30SDA+40Lat	40.19	23.00
40	60PC+40SDA+0Lat	57.44	44.03
	60PC+40SDA+20Lat	57.51	34.52
	60PC+40SDA+40Lat	57.05	29.09

4. Conclusion

This study investigated the compressive strength development and sorptivity of concrete incorporating laterite as partial replacement for sand and SDA as partial replacement for PC and the following conclusions have been drawn:

- Compressive strength increased with increasing curing age due to the hydration reaction of PC and pozzolanic reaction of SDA and reduced with increasing water/cement ratio due to reduction in the content of the binder. In the same vein, sorptivity reduced with increasing curing age and increasing compressive strength and increased with increasing water/cement ratio.
- At equal water/cement ratios, compressive strength reduced and sorptivity increased with increasing laterite and SDA contents. Nonetheless, the synergy between laterite and SDA is capable of contributing to improved microstructure and resistance to permeation.
- At equal strengths, all the laterised and SDA laterised concretes have higher resistance to sorption than the conventional concrete.

Hence, the use of laterite as partial replacement for sand and SDA as partial replacement for PC in the right proportion would result in concrete with better resistance in permeation than the conventional PC concrete.

Table 8: Sorptivity of concrete at different 28-day strengths

Mix combination	Sorptivity (S) of concrete x 10^{-3}, mm/√s									
	20 N/mm^2		25 N/mm^2		30 N/mm^2		35 N/mm^2		40 N/mm^2	
	w/c	S	w/c	S	w/c	S	w/c	S	w/c	S
100PC+0SDA+0Lat	*	*	*	*	*	*	0.67	37.58	0.59	32.50
90PC+10SDA+0Lat	*	*	*	*	0.68	42.73	0.59	36.50	0.52	32.49
80PC+20SDA+0Lat	*	*	*	*	0.62	41.71	0.54	36.29	0.47	32.51
70PC+30SDA+0Lat	*	*	0.61	45.53	0.51	38.20	0.43	33.94	0.37	31.67
60PC+40SDA+0Lat	0.56	44.87	0.44	37.23	0.35	33.75	**	**	**	**
100PC+0SDA+20Lat	*	*	*	*	0.67	43.84	0.57	36.56	0.50	32.51
90PC+10SDA+20Lat	*	*	0.69	49.00	0.58	40.10	0.50	35.05	0.44	32.05
80PC+20SDA+20Lat	*	*	0.63	47.79	0.53	40.10	0.45	35.44	0.39	32.81
70PC+30SDA+20Lat	0.65	54.48	0.51	42.82	0.42	37.57	0.35	34.71	**	**
60PC+40SDA+20Lat	0.47	42.78	0.36	37.23	**	**	**	**	**	**
100PC+0SDA+40Lat	*	*	0.65	49.22	0.54	40.53	0.47	36.21	0.40	33.06
90PC+10SDA+40Lat	0.69	56.50	0.56	44.71	0.47	38.72	0.39	34.90	0.33	32.96
80PC+20SDA+40Lat	0.62	53.60	0.50	43.67	0.41	38.52	0.34	35.87	**	**
70PC+30SDA+40Lat	0.52	48.89	0.40	41.11	0.31	37.68	**	**	**	**
60PC+40SDA+40Lat	0.36	41.47	**	**	**	**	**	**	**	**

* Water/Cement ratio higher than the range investigated
** Water/Cement ratio lower than the range investigated

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