

Permeation Resistance of Sawdust Ash Blended Cement Laterized Concrete

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Abstract: This paper compared the initial surface absorption of conventional concrete and laterized concrete containing Portland cement (PC) and sawdust ash (SDA). Laterized concrete was produced at laterite contents of 15 and 30% as partial replacement for sand and SDA contents of 10 and 20% as partial replacement for PC. Compressive strengths at 28 days and initial surface absorption after 10 minutes (ISA-10) at 28, 60 and 90 days were determined at the water/cement ratios of 0.35, 0.50 and 0.65 and assessed at equal 28-day strengths of 25-35 N/mm². At equal water/cement ratios, compressive strength reduced and ISA-10 increased with increasing content of laterite and SDA. On the other hand, compressive strength and resistance to surface absorption of the blended cement laterized concretes increased with increasing curing age. At equal strengths, all the blended cement laterized concretes have better resistance to surface absorption than the conventional PC concrete.

Keywords: Absorption; blended cement; laterized concrete; permeation; sawdust ash.

Introduction

Concrete is a widely used construction material. The need to prevent the depletion of non-renewable materials and make concrete construction sustainable led to the replacement of the constituent materials of concrete with alternative ones. For example, the partial replacement of sand with laterite resulted in laterized concrete [1-7]. Hence, the use of laterized concrete will reduce the demand on sand and possibly reduce the cost of concrete where laterite is abundant and cheaper than sand. Concrete is expected to be properly proportioned and placed to ensure it achieves the expected strength and durability performance. Since laterite is characterized by higher content of fine particles than natural sand, laterized concrete would require higher content of water to achieve equal consistence with conventional concrete [2,3,8]. Nevertheless, the study by Falade [3] has shown that laterized concrete could still be designed to have good workability and ensure that it is properly placed. Also, the higher content of fine particles in laterite would result in higher specific surface and higher quantity of cement needed to properly coat the soil particles and ensure adequate hydration reaction within the matrix of the concrete.

Hence, the compressive, tensile and flexural strengths of laterized concrete decreased with increasing content of laterite [4-5]. Nonetheless, if laterite is adequately proportioned and properly cured, laterized concrete would have good strength properties [4-11], good performance in aggressive environment [12-15] and good resistance against sorption [5-11]. However, to ensure good results, laterite content of concrete should be limited to about 20-50% of the total fine aggregate content [2-4,5,8-11,16].

In order to make concrete more sustainable, the use of pozzolans has been supported by cement and concrete standards like BS EN 197-1 [17] and BS EN 206-1 [18]. Hence, attempts have been made to partially replace the Portland cement content of laterized concrete with pozzolanic materials such as fly ash [19,20], cassava peels ash [21] and volcanic ash [22,23], among others. Pozzolans have intrinsic hydraulicity and while they are characterized by low early-age strength development, their continuous pozzolanic reaction with age would result in concrete with high ultimate strength comparable with that of Portland cement concrete at later ages [24]. Hence, pozzolanic cements would be good for mass concrete or concrete works in hot weather, where high rate of strength development could lead to cracking. In addition to the pozzolanic reaction, the pozzolans, by virtue of their sizes and shapes and better packing density, also have the ability to refine the microstructure and improve the durability of concrete [24].

Sawdust is a waste generated in sawmills in large quantity over the world. Hence, the use of Sawdust Ash (SDA) in concrete would provide a means of

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solving the disposal problem of sawdust. As partial replacement for Portland cement, SDA would reduce the performance of concrete at early ages; however, the delayed setting times would lead to improved performance of concrete in hot weather [25]. Also, due to the continuous pozzolanic reaction with increasing age, SDA would contribute to later-age strength development of concrete [26-29] and resistance of concrete to water absorption [30] and sorption [5]. Also, since the manufacture of SDA would require lower calcination temperature than that of Portland cement clinker, SDA blended cement concrete would be cheaper and more environmentally friendly than Portland cement concrete.

From the foregoing, the combination of SDA and laterite as partial replacements for Portland cement and sand contents of concrete respectively would make concrete cheaper, more environmentally compatible and possibly more durable than the conventional concrete where laterite is abundant. Hence, in order to provide more information on the durability of SDA blended cement lateritized concrete, this paper investigated the initial surface absorption after 10 minutes (ISA-10) of this concrete, at different water/cement ratios and 28-day compressive strengths, with a view to providing more information on its permeation resistance and suitability for construction. The initial surface absorption after 10 minutes could be used to sufficiently assess the ability of concrete to provide protection for its embedded reinforcing steel [31] and, possibly, wall finishes.

Materials and Methods

The experimental materials were ordinary Portland cement (PC) and calcined sawdust ash (SDA) as cements, sand and laterite as fine aggregates and granite chippings as coarse aggregates. Sawdust was calcined in a furnace maintained at 500°C for about 24 hours. The temperature of the furnace was monitored with the aid of a thermocouple. The oxide compositions of PC and SDA, determined by X-Ray Fluorescence (XRF), are presented in Table 1. The properties of the aggregates are presented in Table 2 and the grading curves of the aggregates are presented in Figure 1. Concrete was produced at 10 and 20% contents of SDA as partial replacement for PC, and 15 and 30% contents of laterite as partial replacement for sand. Concrete design was based on the Building Research Establishment approach [32] at a free water content of 210 kg/m³ and water/cement ratios of 0.35, 0.50 and 0.65. To ensure equal consistence with increasing content of laterite [3], Mapefluid N200 conforming to EN 934-2 [33] was used as superplasticiser to achieve a consistence level of S2 defined by a nominal slump of 50-90 mm [18].

Table 1. Properties of Portland Cement and Sawdust Ash

Elemental Oxide (%)	OPC	SDA
SiO ₂	16.82	62.96
Al ₂ O ₃	4.35	8.29
Fe ₂ O ₃	2.43	3.85
CaO	60.39	9.53
MgO	1.43	5.48
SO ₃	1.64	0.68
K ₂ O	0.16	0.15
Na ₂ O	0.02	0.06
MnO	0.04	0.01
P ₂ O 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 ₂ O ₃ + Fe ₂ O ₃		75.10

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	2.65	2.70
Moisture content, %	7.33	5.17	0.88
Absorption, %	8.15	2.49	1.58
Liquid limit, %	37.0	-	-
Plastic limit, %	17.0	-	-
Plasticity index, %	20.0	-	-

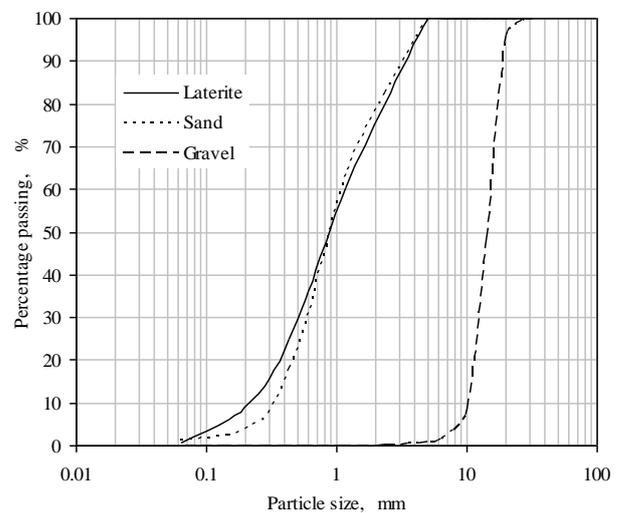


Figure 1. Particle Size Distribution of Aggregates

Concrete was prepared in accordance with BS EN 12390-2 [34] with potable water conforming to BS EN 1008 [35], cast, covered with polythene for about 24 hours, demoulded and cured in water. Compressive strength was determined in accordance with BS EN 12390-3 [36] using 100 mm cubes at 28 days. The initial surface absorption after 10 minutes (ISA-10) at 28, 60 and 90 days were obtained in accordance with BS 1881-208 [31] using 150 mm concrete

cubes oven-dried to constant mass at $105 \pm 5^\circ\text{C}$. The specimens were cooled to room temperature in a desiccator and subjected to a pressure of 200 mm head of water as shown in Figure 2. The tap on the initial surface absorption equipment was turned off after 10 minutes to remove the applied water head, and the average distance moved by water along the capillary tube in a minute was obtained. The ISA-10 values of the specimens were obtained using Equation 1.

$$\text{ISA-10} = N_{10} \times C_f \quad (1)$$

where

ISA-10 = Initial surface absorption 10 minutes after water first touched the surface of concrete.

N_{10} = Number of scale divisions moved, in a minute, 10 minutes after water first touched the surface of concrete.

C_f = Calibration factor of capillary tube determined in accordance with BS 1881- 208 [31].

Analysis and Discussion of Results

Initial Surface Absorption of Concrete at Equal Water/Cement Ratios

Figures 3-5 present the ISA-10 of concretes at different water/cement ratios, curing ages and contents of SDA and laterite. The Figures show that

ISA-10 of concrete reduced with increasing curing age and increased with increasing water/cement ratio. The reduction in ISA-10 of concrete with increasing age must be due to refinement of pore structure by hydration products. This is because as hydration progresses, the pores would gradually be filled with hydration products and become reduced in size or discontinuous to reduce permeability [24 37 38]. On the other hand, the increase in ISA-10 with increasing water/cement ratio must be due to reduction in the content of the cementitious materials with increasing water/cement ratio.

The comparison of the Figures also shows that ISA-10 increased with increasing content of laterite. The increase in ISA-10 with increase in laterite content would be due to the clay content of laterite resulting in higher content of fine particles and minute pores and higher absorption values [39]. It is also worth mentioning that the stickiness of clay content of laterite could also impair the thorough coating of the fine aggregates with cement and prevent the concretes from developing dense microstructure. The Figures also show that ISA-10 of concrete increased with increase in the content of SDA. The increase in ISA-10 with increase in the content of SDA would be due to the reduction in the content of Portland cement and therefore $\text{Ca}(\text{OH})_2$ required for the pozzolanic reaction of SDA; thus resulting in the production of insufficient hydration products and development of less dense microstructure.

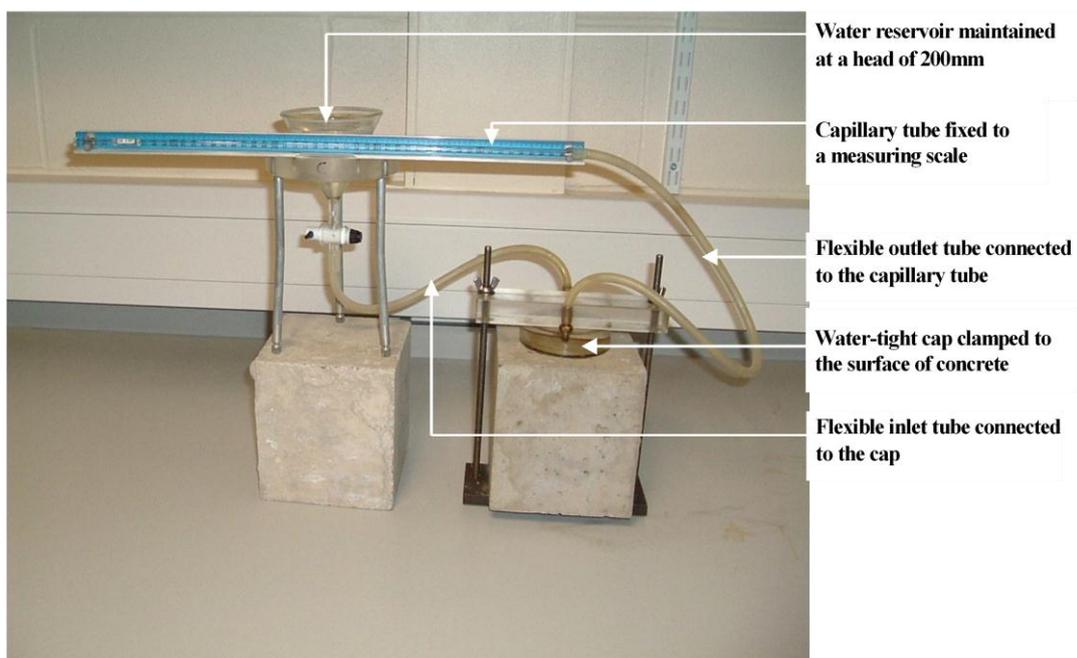


Figure 2. ISAT installation

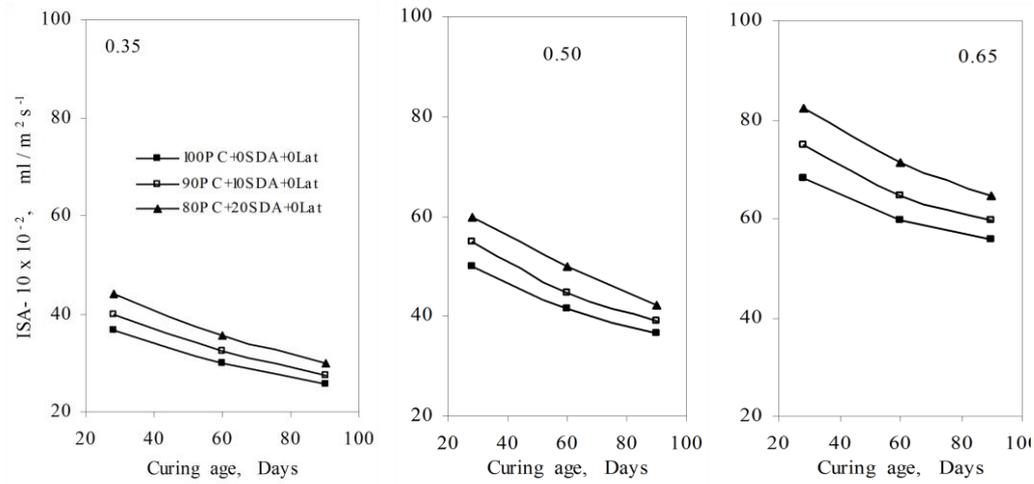


Figure 3. ISA-10 of Concretes at 0% Content of Laterite

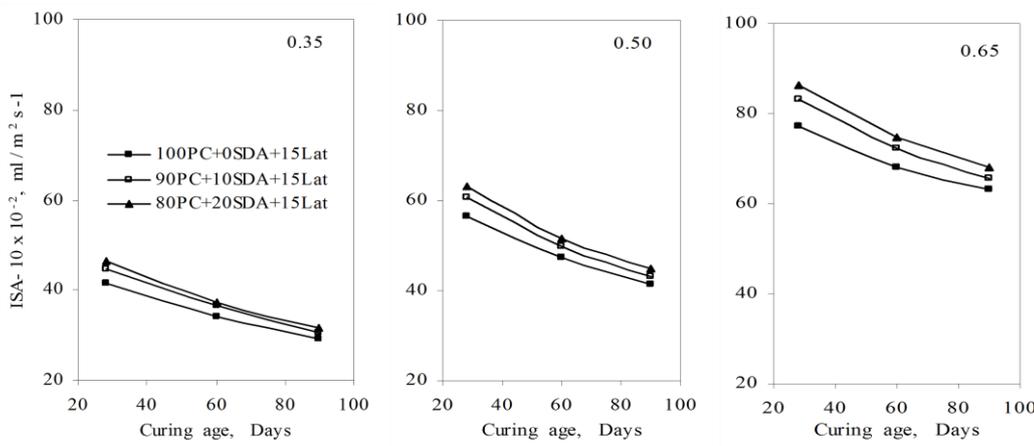


Figure 4. ISA-10 of Concretes at 15% Content of Laterite

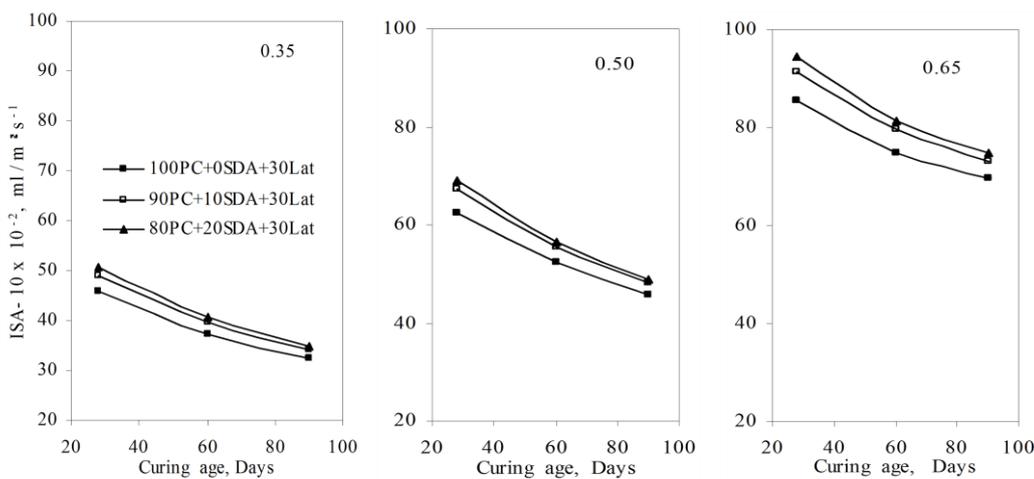


Figure 5. ISA-10 of Concretes at 30% Content of Laterite

The ISA-10 factors (Table 3) measure the differences between the ISA-10 of the 100%PC concretes and the laterized concretes at different ages and water/

cement ratios. The comparison of mixes 1, 4 and 7 shows that the partial replacement of sand with 15% and 30% laterite respectively increased ISA-10 of

laterized concrete by 13.59% and 25.39%. Hence, ISA-10 increased by 0.85-0.91% (with an average of 0.88%) with a percentage replacement of sand with laterite. Hence, the increase in ISA-10 and therefore reduction in resistance to permeation would become significant with increasing content of laterite at equal water/cement ratios. The differences between the ISA-10 values of the conventional concretes (mix 1) and the SDA blended cement laterized concretes (mixes 2, 3, 5, 6, 8, and 9) reduced with increasing curing age. This reduction would be attributed to the pozzolanic reaction of SDA which improves with increasing curing age. This result is in line with previous study by Khan and Lynsdale [40] which shows that the incorporation of supplementary cementitious materials is capable of increasing the resistance of concrete at later ages against permeation.

Compared with the conventional concretes (0% laterite), Table 3 shows that the partial replacement of PC with 10 and 20% SDA resulted in ISA-10 increases of 8.25 and 18.75%, respectively. This corresponds, respectively, to an ISA-10 increase of 0.83 and 0.94% (with an average of 0.89%) for a

percentage replacement of PC with SDA. Compared with concretes with 100%PC and 15%laterite, the ISA-10 increases were 6.96 and 11.16 at the partial replacement levels of 10 and 20% respectively; thus resulting in ISA-10 increases of 0.70 and 0.56% respectively (with an average of 0.63%) for a percentage replacement of PC with SDA. Similarly, at 30%laterite content, ISA-10 increased by 7.81 and 11.08% at the partial replacement levels of 10 and 20% SDA respectively. This also resulted in ISA-10 increase of 0.78 and 0.55% respectively (with an average of 0.67%) for a percentage replacement of PC with SDA. Based on the foregoing, a percentage replacement of PC with SDA resulted in an ISA-10 increase of 0.89% for conventional concrete and 0.63-0.67% (with an average of 0.65%) for laterized concrete. These results show that the inclusion of laterite resulted in improved resistance of concrete to surface permeation. Hence, the synergy between laterite and SDA must have improved the resistance of concrete to permeation. Hence, the higher fineness and packing ability of laterite and pozzolanic reaction of SDA must have resulted in the improved resistance of the concrete to surface absorption.

Table 3. ISA-10 factors of concretes

Mix	Mix combination	W/C	ISA-10 factor ^{a)} , (%)				Over-all Mean	% Increase in ISA-10 factor ^{b)}
			28d	60d	90d	Mean		
1.	100PC+0SDA+0Lat	0.35	100	100	100	100	100.00	-
		0.50	100	100	100	100		
		0.65	100	100	100	100		
2.	90PC+10SDA+0Lat	0.35	109.04	108.36	106.62	108.01	108.26	8.26
		0.50	110.04	107.95	106.85	108.28		
		0.65	109.69	108.19	107.55	108.48		
3.	80PC+20SDA+0Lat	0.35	120.55	119.36	116.39	118.77	118.75	18.75
		0.50	120.08	120.00	115.89	118.66		
		0.65	120.71	119.40	116.37	118.83		
4.	100PC+0SDA+15Lat	0.35	113.70	113.71	113.23	113.55	113.59	13.59
		0.50	113.25	113.98	113.70	113.64		
		0.65	113.36	113.88	113.49	113.58		
5.	90PC+10SDA+15Lat	0.35	122.74	122.07	119.46	121.42	120.55	20.55
		0.50	121.69	120.00	118.36	120.02		
		0.65	121.88	120.74	117.99	120.20		
6.	80PC+20SDA+15Lat	0.35	127.40	125.08	122.57	125.02	124.75	24.75
		0.50	126.71	124.10	122.74	124.52		
		0.65	126.73	124.92	122.48	124.71		
7.	100PC+0SDA+30Lat	0.35	125.21	125.08	126.07	125.45	125.39	25.39
		0.50	125.10	126.02	125.21	125.44		
		0.65	125.55	124.92	125.36	125.28		
8.	90PC+10SDA+30Lat	0.35	134.25	133.11	132.30	133.22	133.20	33.20
		0.50	134.94	133.98	131.78	133.57		
		0.65	134.07	133.28	131.06	132.80		
9.	80PC+20SDA+30Lat	0.35	138.63	136.12	135.80	136.85	136.47	36.47
		0.50	138.35	135.90	134.25	136.17		
		0.65	138.91	135.95	134.35	136.40		

^{a)} ISA-10 ratio with respect to the conventional concrete (mix 1)

^{b)} % Increase in ISA-10 factors with respect to the conventional concrete

Initial Surface Absorption at Equal Strengths of Concrete

Structural concrete is usually specified on the basis of the 28-day strengths. In line with Folagbade [5], Table 4 shows that compressive strength reduced with increasing content of laterite and SDA. Hence, based on the interpolated values of the 28-day ISA-10 values in Table 3 and the 28-day compressive strengths in Table 4, Table 5 presents the ISA-10 values of the conventional, laterized and SDA blended cement laterized concrete options at equal 28-day strengths, ranging between 20 and 35 N/mm², and the water/cement ratios at which the strengths were achieved. Table 5 shows that the laterized and SDA blended cement laterized concretes achieved equal strengths with conventional concrete at lower water/cement ratios. This would require higher contents of the cementitious materials [41]. Hence, where the cost and the embodied carbon dioxide content of SDA are low such that the cost and embodied carbon dioxide content of Portland cement is offset by the costs and embodied carbon dioxide contents of the cement combinations, cheaper and more environmentally compatible blended cement laterized concretes will result at equal strengths.

Table 5 shows that ISA-10 reduced with increasing strength. The observation of Isa-10 values at the 28-day compressive strength of 30 N/mm² shows a

minimum percentage reduction of 12.56% for mix 2 and a maximum percentage reduction of 24.17% for mix 3. Hence, within the limit of this study, all the laterized and SDA laterized concretes, at up to 30% contents of laterite and 20% contents of SDA, have lower ISA-10 values and therefore higher resistance to surface absorption than the conventional concrete when concrete is specified on the basis of strength.

Conclusion

This study investigated the compressive strength and initial surface absorption of concrete containing laterite as partial replacement for sand and SDA as partial replacement for PC and the following conclusions have been drawn:

- The 28-day compressive strength reduced with increasing water/cement ratio while the initial surface absorption 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 initial surface absorption increased with increasing laterite and SDA contents. However, the synergy between SDA and laterite resulted in improved resistance of concrete to surface absorption especially at later ages.
- With a percentage reduction of 12.56-24.17% in ISA-10 values at equal 28-day compressive

Table 4. 28-Day Compressive Strengths of Concretes

Mix	Mix combination	28-Day Compressive Strength, N/mm ²		
		w/c = 0.35	w/c = 0.50	w/c = 0.65
1.	100PC+0SDA+0Lat	38.0	32.5	29.5
2.	90PC+10SDA+0Lat	35.5	30.0	27.0
3.	80PC+20SDA+0Lat	32.0	26.5	24.0
4.	100PC+0SDA+15Lat	36.5	29.5	26.5
5.	90PC+10SDA+15Lat	32.0	26.0	23.0
6.	80PC+20SDA+15Lat	28.5	23.0	19.5
7.	100PC+0SDA+30Lat	31.0	27.5	25.5
8.	90PC+10SDA+30Lat	27.5	24.0	22.5
9.	80PC+20SDA+30Lat	24.5	21.0	19.5

Table 5. ISA-10 of Concretes at Different 28-Day Compressive Strengths

Mix	Mix combination	ISA-10 of concrete x 10 ⁻² , ml/m ² s ⁻¹					
		25 N/mm ²		30 N/mm ²		35 N/mm ²	
		w/c	ISA	w/c	ISA	w/c	ISA
1.	100PC+0SDA+0Lat	*	*	0.61	62.73	0.42	42.08
2.	90PC+10SDA+0Lat	*	*	0.50	54.80	0.36	40.65
3.	80PC+20SDA+0Lat	0.56	67.97	0.39	47.57	*	*
4.	100PC+0SDA+15Lat	*	*	0.48	54.07	0.37	43.15
5.	90PC+10SDA+15Lat	0.53	64.55	0.39	48.37	*	*
6.	80PC+20SDA+15Lat	0.44	55.67	*	*	*	*
7.	100PC+0SDA+30Lat	*	*	0.38	48.49	*	*
8.	90PC+10SDA+30Lat	0.44	59.21	*	*	*	*
9.	80PC+20SDA+30Lat	*	*	*	*	*	*

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

strength of 30 N/mm², all the laterised and SDA laterised concretes at up to 30% laterite content and 20% SDA content would have higher resistance to surface absorption than the conventional concrete when concrete is specified on the basis of the 28-day compressive strengths.

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

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