American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-9, Issue-7, pp-93-102
www.ajer.org
Research Paper Open Access

Effect of Carbonation on the Permeation Properties of Laterized Concrete

FOLAGBADE Samuel Olufemi
Department of Building, Obafemi Awolowo University, Ile-Ife, Nigeria
Corresponding Author: samuelfolagbade@yahoo.com

ABSTRACT: *The application of the sustainability principle in the construction industry necessitated the use of alternative concrete materials that are more readily available or have lower embodied carbon-dioxide content. Hence, the partial replacement of sand with laterite resulted in laterized concrete. Also, to prevent global warming, actions that would not only reduce carbon-dioxide emissions but capture the emitted carbon-dioxide from the atmosphere become worthwhile. The permeation resistance of laterized concrete reduces with increasing content of laterite and carbonation (a means of removing carbon-dioxide from the atmosphere) has the propensity to augment this. Hence, this paper investigated the effect of carbonation on the void content and initial surface absorption after 10 minutes (ISAT-10) of laterized concrete. Water cured and carbonated specimens containing up to 50% content of laterite prepared at the water/cement ratios of 0.35, 0.50 and 0.65 and curing ages up to 126 days were tested to standards. The results were analysed at the 28-day strengths of 20-50 N/mm^2. At equal water/cement ratios, results showed that ISAT-10 and void content increased with increasing laterite content and reduced with increasing exposure to carbon-dioxide. At equal strengths, all the laterized concretes have lower ISAT-10 values and void contents than the conventional concrete. ISAT-10 reduced, respectively, by 2.7-8.68 and 5.56-14.08% at 8 and 12 weeks of exposure to carbonation while void content reduced by 0.44-2.24 and 1.06-3.19% respectively. Hence, carbonation would increase the resistance of laterized concrete to permeation, encourage the use of higher contents of laterite and contribute to reducing the level of carbon-dioxide in the atmosphere.*

KEYWORDS *absorption, carbonation, laterized concrete, permeation, void content.*

Date of Submission: 23-06-2020 Date of acceptance: 11-07-2020

I. INTRODUCTION

The need to apply the sustainability principle in concrete technology led to the replacement of the conventional materials in concrete. Hence, the partial replacement of sand with laterite resulted in laterized concrete [1, 2]. However, for good strength and durability performance, the laterite content of laterized concrete should be monitored [3, 4]. Also, the use of pozzolanic materials with lower embodied carbon-dioxide contents than Portland cement would reduce the emission of carbon-dioxide into the atmosphere, make concrete construction more environmentally compatible and help in mitigating global warming [5-9]. Since this approach, in the long run, will only prolong and not prevent the world carbon threshold from being exceeded, an approach that will capture carbon-dioxide from the atmosphere becomes worthwhile in order to prevent global warming.

Carbonation, a process through which carbon-dioxide reacts with calcium hydroxide ($Ca(OH)_2$) formed during the hydration reaction of Portland cement, will contribute to reducing the level of carbon-dioxide in the atmosphere. Carbonation will deplete the passivating layer of $Ca(OH)_2$ protecting embedded steel reinforcement against corrosion and causing concrete cracking and reduction in the service life of reinforced concrete [10-13]. On the other hand, carbonation will be beneficial when plain precast concrete kerbs and interlocking blocks used in road construction and masonry units such as blocks and bricks used in wall construction are cured in carbon-dioxide [14, 15]. This is because carbonation would increase the compressive strength of concrete and refine its microstructure to improve its resistance to permeation [13-22]. Although, carbonation has a deteriorating effect; however, this paper attempts to look at the implication of its positive effect on the durability of concrete.

The durability of concrete would be affected if its resistance to permeation is low. Hence, to increase the durability of concrete, the resistance of its surface layer (or concrete cover) against absorption is very important. A means of assessing surface permeation is the initial surface absorption test [20]. According to BS 1881-208 [23], the initial surface absorption after 10 minutes (ISAT-10) is sufficient for assessing the resistance of concrete surface against an absorption pressure equivalent to that of a driving rain. Also, the pore structure (pore size, volume and connectivity) would also influence the resistance of the concrete cover against permeation [3, 20, 24]. Hence, in order to provide more information on the possibility of using carbonation to improve the permeation resistance and encourage the patronage of laterized concrete while at the same time contributing to reducing the carbon-dioxide level in the atmosphere and contribute to the sustainability principle in concrete construction, this paper investigated the effect of carbonation on ISAT-10 and void content of laterized concrete at varying water/cement ratios and 28-day compressive strengths.

II. MATERIALS AND METHODS

The materials used in this study were ordinary Portland cement (42.5 strength class), sand and laterite as fine aggregates and granite chippings as coarse aggregates. Laterite was used at up to 50% content to partially replace sand. The properties of the aggregates are presented in Table 1 and the grading curves of the aggregates are illustrated in Fig. 1.

Table 1: Properties of aggregates

Properties	Fine aggregates		Coarse aggregates
	Laterite	Sand	(Granite)
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	-	-

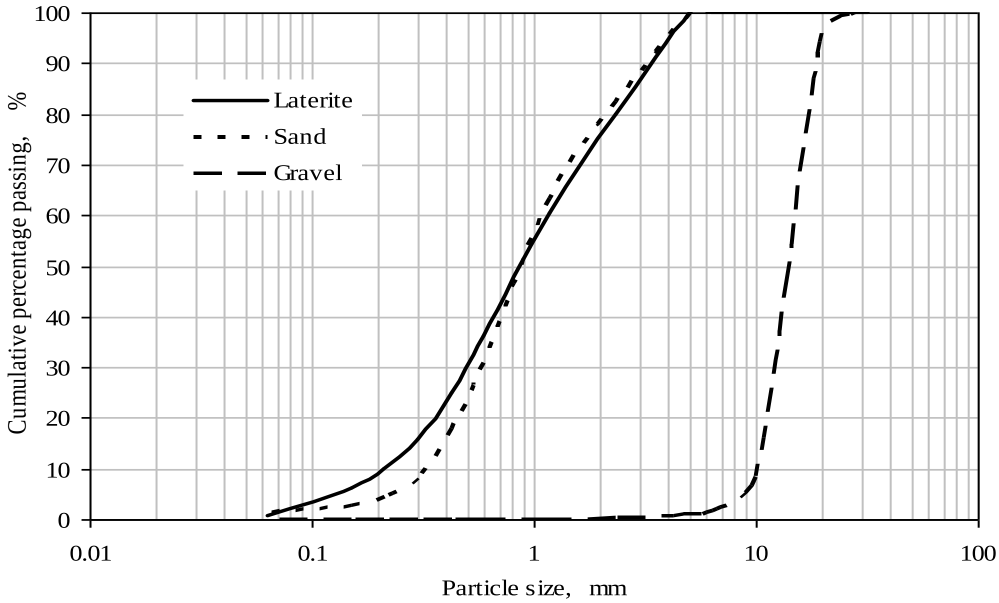

Fig. 1: Grading curves of fine and coarse aggregates

Concrete was designed in accordance with the Building Research Establishment design guide [25] and prepared in accordance with BS EN 12390-2 [26] using potable water conforming to BS EN 1008 [27] at a free water content of 210 kg/m^3 and water/cement ratios of 0.35, 0.50 and 0.65. To obtain a consistence class of S2 (slump of 50-90 mm) in accordance with BS EN 206-1 [28], Mapefluid N200 conforming to BS EN 934-2 [29] was used as superplasticiser during the mixing of concrete.

Compressive strength test was performed in accordance with BS EN 12390-3 [30] using 100 mm cubes at the curing age of 28 days. Using 150 mm water cured and carbonated cubes, ISAT-10 test was conducted in accordance with BS 1881-208 [23] and void content was determined in accordance with ASTM C642 [31] at the curing ages of 42, 70, 98 and 126 days (corresponding respectively to 0, 4, 8 and 12 weeks of accelerated carbonation). The carbonated specimens were prepared in accordance with Dhir et *al*. [32]. After demoulding, the specimens to be carbonated were cured in water for 28 days and air cured for 14 days before being exposed to accelerated carbonation (4% CO_2 at the Relative Humidity of 50±5%).

After oven-drying to constant mass at a temperature of 105±5^{o}C and cooling to room temperature in a desiccator, the specimens for ISAT-10 test were exposed to a pressure of 200 mm head of water (Fig. 2). The tap was turned off after 10 minutes of contact of water with the specimen. This was done to stop the applied water pressure on the specimen. The number of scaled divisions (to the nearest 0.5 division) moved by water in a minute along the capillary tube, after the tap was turned off, was obtained and ISAT-10 was determined as the product of the scaled divisions and the calibration factor of the capillary tube determined in accordance with the test standard. Void content was determined using Equation 1. This involved the mass of specimen oven-dried to constant mass at 105±5^{o}C (A), mass of specimen after immersion to constant mass in water and boiling (B) and apparent mass of specimen after immersion, boiling and suspension in water (C).

$$\text{Void content (\%)} = \frac{B-A}{B-C} * 100 \quad (1)$$

Fig. 2: ISAT installation

III. RESULTS AND DISCUSSION

Effect of carbonation on initial surface absorption and void content of concrete at equal water/cement ratios

Figures 3-8 present the initial surface absorption after 10 minutes (ISAT 10) and void contents of water cured and carbonated laterized concrete specimens at difference contents of laterite, curing ages and water/cement ratios. The Figures show that ISAT 10 and void content decreased with increasing curing age and increased with increasing water/cement ratio and laterite content. Void content and ISAT 10 reduced with increase in curing age due to the formation of more hydration products resulting in improved cement/aggregate matrix, reduced pore size and discontinuous pores [20, 33, 34].

On the other hand, ISAT 10 and void content increased with increasing water/cement ratio due to reduction in cement content and hydration products resulting in porous cement/aggregate matrix. Also, ISAT 10 and void content increased with increase in laterite content because the reduction silica content of the aggregates due to a reduction in the content of sand reduced the hardness and increase the porosity and permeation of the cement/aggregate matrix. Furthermore, the higher content of fine particles due to the clay content of laterite would introduce minute pores into the concrete matrix. The minute pores would lead to higher absorption [35] while the fine particles due to their higher specific surface and the need for more cement to provide adequate coating to the particles would increase the porosity of the concrete matrix. Lack of thorough coating could also be compounded by the stickiness of the clay content of laterite during concrete mixing. These results agree with previous results by Folagbade & Osadola [4] and Folagbade & Aluko [36].

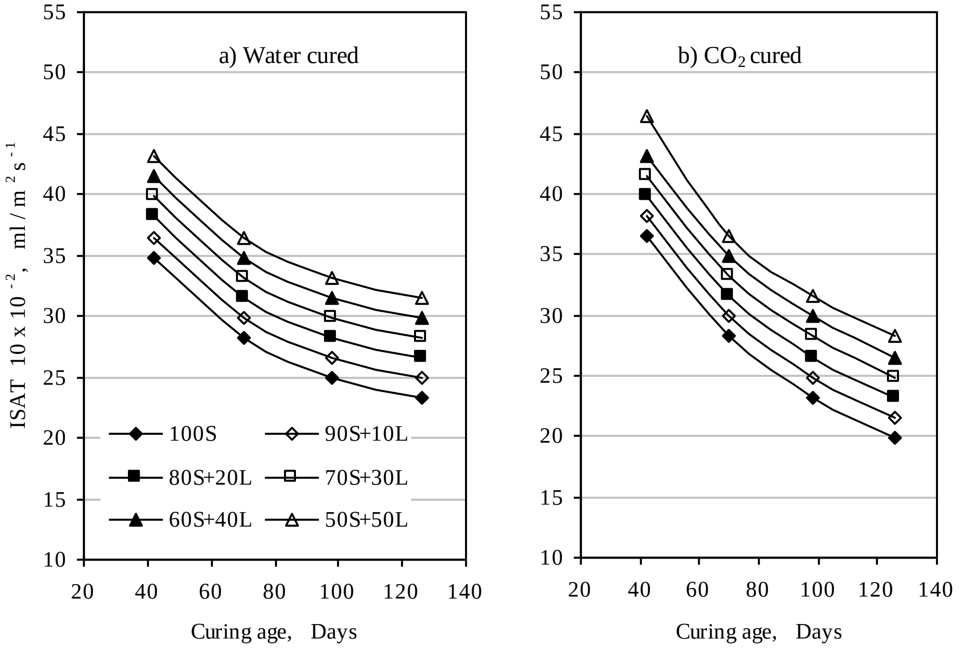

Fig. 3: ISAT- 10 of concrete at the water/cement ratio of 0.35

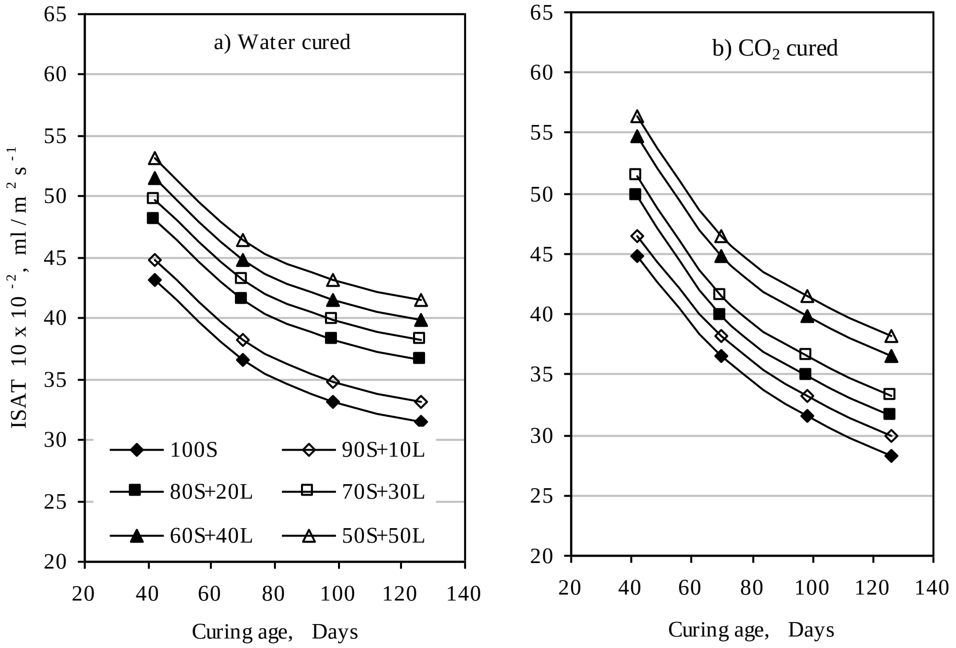

Fig. 4: ISAT- 10 of concrete at the water/cement ratio of 0.50

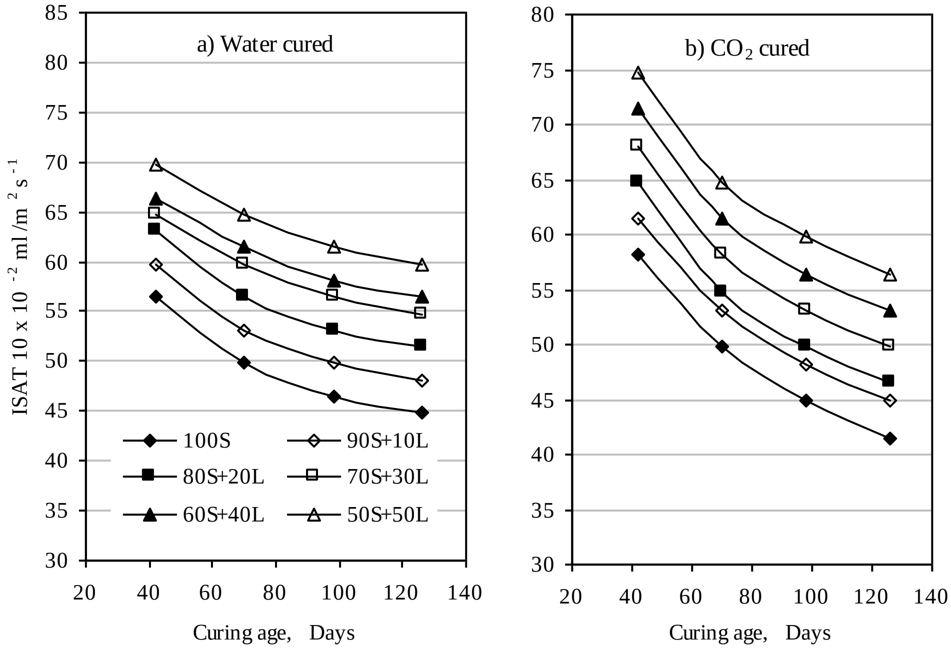

Fig. 5: ISAT- 10 of concrete at the water/cement ratio of 0.65

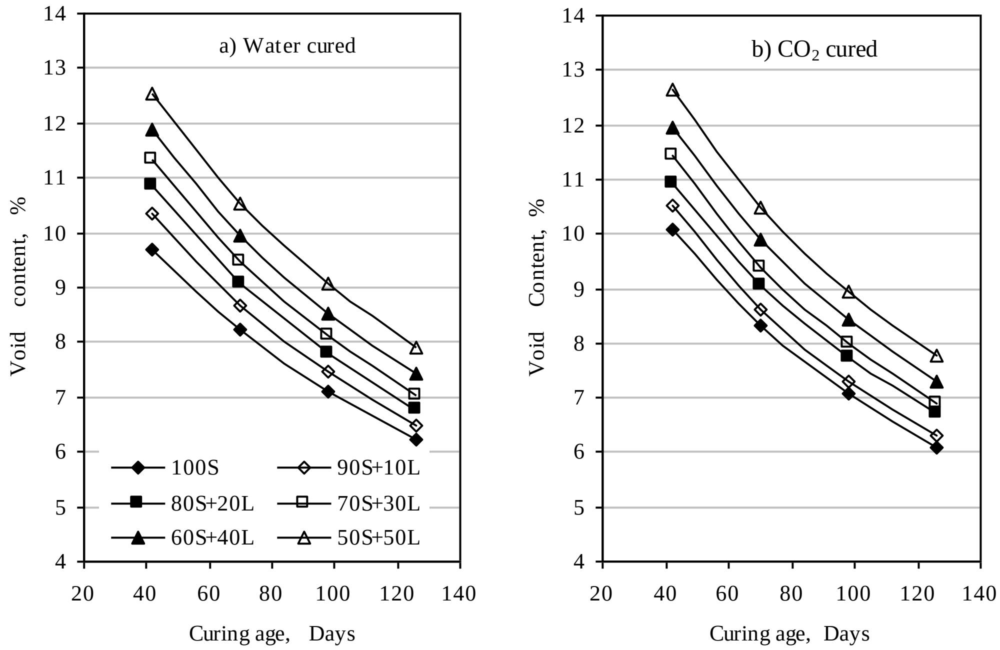

Fig. 6: Void content of concrete at the water/cement ratio of 0.35

At the curing age of 42 days, Figures 3-8 also show that ISAT-10 and void contents of the carbonated concrete specimens were higher than that of the water cured specimens. The higher values obtained for the carbonated specimens at this age would be due to the fact that between the ages of 28 and 42 days, the carbonated specimens were undergoing air drying (air curing). Compared with water curing, air curing is generally noted to be associated with reduced hydration reaction. Hence, the air drying must have accounted for the lower resistance of the carbonated specimens to permeation at 42 days. However, with increasing curing, the situation reverted such that the carbonated specimens have lower ISAT-10 values than the water cured specimens at the curing age of 126 days (or 12 weeks of accelerated carbonation). This observation shows that beyond 42 days, carbonation increased the resistance of concrete to permeation than water curing resulting in lower ISAT-10 values and void contents for the carbonated concrete specimens at the curing age of 126 days.

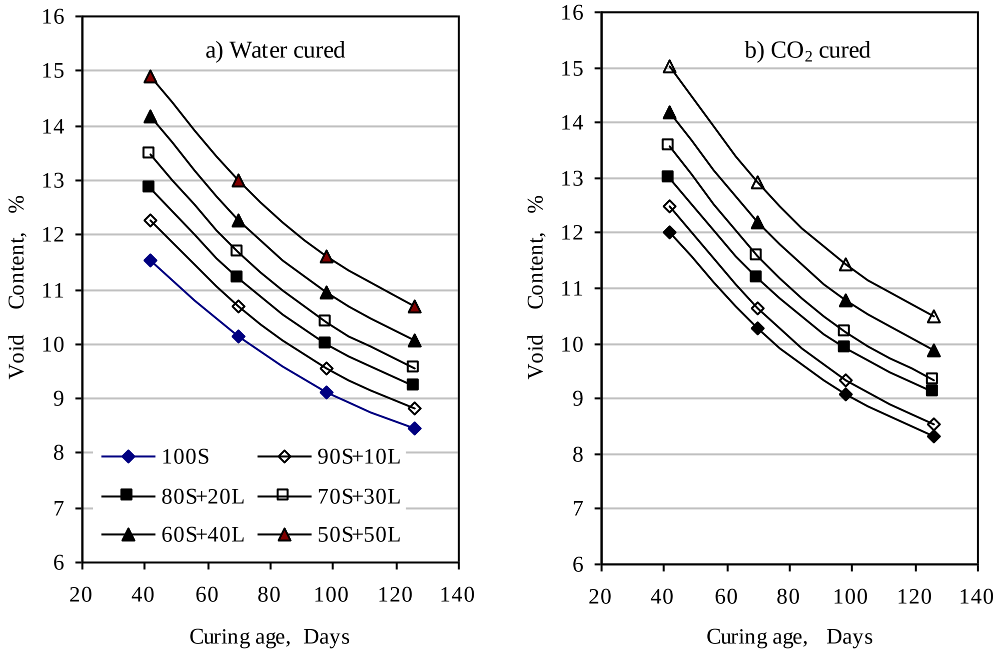

Fig. 7: Void content of concrete at the water/cement ratio of 0.50

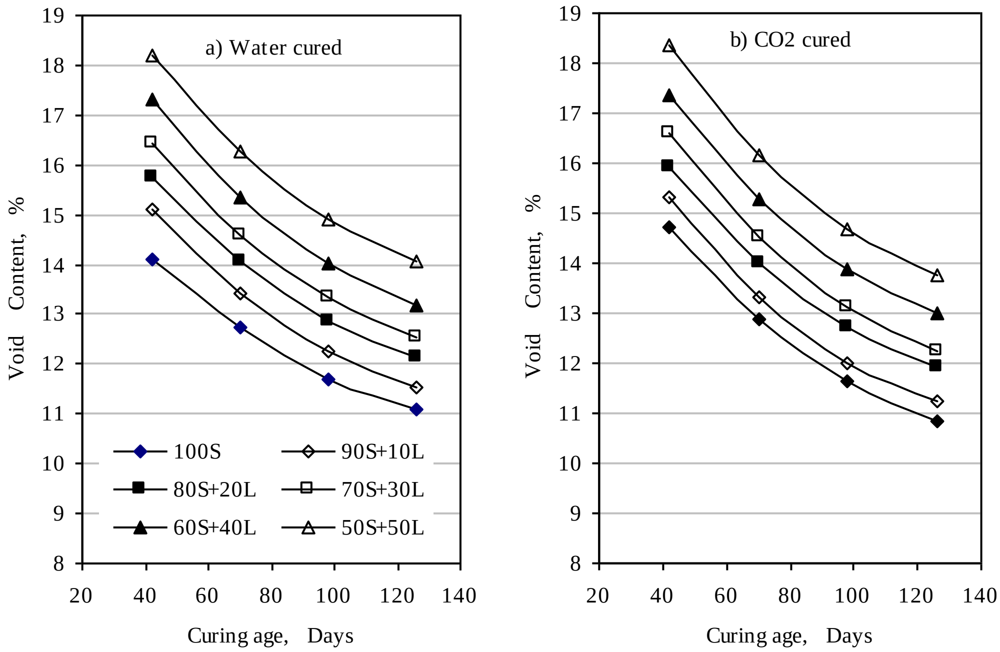

Fig. 8: Void content of concrete at the water/cement ratio of 0.65

Hence, since at equal contents of laterite, carbonation increased the resistance of concrete to permeation than water curing, it therefore follows that carbonation would permit the use of higher content of laterite than water curing to achieve equal level of permeation resistance. This result also agrees with results from previous studies by Chi et *al*. [13] Zhan et *al*. [14], El-Hassan & Shao [15], Parrott [16], Dias [17], Neville [18] You et *al*. [19] and Li et *al*. [21] which submitted that carbonation would refine the microstructure and improve the performance of concrete.

Using the ISAT-10 ratios (ratios of ISAT 10 of carbonated concretes with respect to ISAT 10 of water cured conventional concretes) at different water/cement ratios and curing ages, Table 2 shows the average

ISAT-10 ratios and the disparities between the ISAT-10 ratios of the carbonated concrete specimens and that of the water cured concrete specimens. Table 2 shows that the percentage disparity reduced with increasing curing age and increased with increasing content of laterite (L) at equal curing ages and water/cement ratios. Compared with the water cured, Table 2 shows that the resistance of the carbonated conventional concrete with 100% Sand (100S) against surface absorption was higher than that of the water cured 100S concrete by an average of 5.08 and 10.74% at the curing ages of 98 and 126 days (corresponding to 8 and 12 weeks of accelerated carbonation) respectively. This result also confirms the earlier submission that carbonation would improve the permeation resistance of concrete.

Table 2: Initial surface absorption ratios of concrete

Mix	Curing Medium	w/c	ISAT-10 Ratio, %				Disparity, %	
			d42	d70	d98	d126	d98	d126
100S	Water	0.35	100	100	100	100	-	-
		0.50	100	100	100	100		
		0.65	100	100	100	100		
	CO_2	0.35	104.76	100.00	93.33	85.71	-5.08	-10.74
		0.50	103.85	100.00	95.00	89.47		
		0.65	102.94	100.00	96.43	92.59		
90S + 10L	CO_2	0.35	109.52	105.88	100.00	92.86	1.19	-4.13
		0.50	107.69	104.55	100.00	94.74		
		0.65	108.82	106.67	103.57	100.00		
80S + 20L	CO_2	0.35	114.29	111.76	106.67	100.00	6.27	1.23
		0.50	115.38	109.10	105.00	100.00		
		0.65	114.71	110.00	107.14	103.70		
70S + 30L	CO_2	0.35	119.05	117.65	113.33	107.14	12.54	7.84
		0.50	119.23	118.18	110.00	105.26		
		0.65	120.58	116.67	114.29	111.11		
60S + 40L	CO_2	0.35	123.81	123.53	120.00	114.29	20.48	16.20
		0.50	126.92	122.73	120.00	115.79		
		0.65	126.47	123.33	121.43	118.52		
50S + 50L	CO_2	0.35	133.33	129.41	126.67	121.43	26.75	22.80
		0.50	130.77	127.27	125.00	121.05		
		0.65	132.35	130.00	128.57	125.93		

Compared with water cured 100S concrete, the resistance to surface absorption of laterized concrete reduced with increasing content of laterite and increased with increasing exposure to carbonation such that laterized concrete with 10% laterite (90S+10L) have comparable resistance with water cured 100S concrete at 8 weeks of carbonation (curing age of 98 days) and better resistance than 100S concrete at 12 weeks of carbonation (curing age of 126 days) and laterized concretes with 20% laterite (80S+20L) have comparable resistance with the water cured 100S concrete at 12 weeks of carbonation (curing age of 126 days). Hence, further increase in the duration of exposure to carbonation would permit the use of higher quantities of laterite to achieve equal level of resistance to absorption with the water-cured 100S concrete.

Using the void content ratios (ratios of void content of carbonated concretes with respect to void content of water cured conventional concretes) at different water/cement ratios and curing ages, Table 3 shows the average void content ratios and the disparities between the void content ratios of the carbonated concrete specimens and that of the water cured concrete specimens. Table 3 shows that the percentage disparity reduced with increasing curing age and increased with increasing content of laterite (L) at equal curing ages and water/cement ratios. Also, compared with the water cured 100S concrete, Table 3 shows that the void content of the carbonated 100S concrete was lower than that of the water cured 100S concrete by an average of 1.17 and 1.86% at the curing ages of 98 and 126 days (corresponding to 8 and 12 weeks of accelerated carbonation) respectively. Compared with water cured 100S concrete, the void content of laterized concrete increased with increasing content of laterite and reduced with increasing exposure to carbonation such that with further exposure to carbonation laterized concrete with higher contents of would achieve equal level of porosity with the water-cured 100S concrete.

Table 3: Void content ratios of concrete

Mix	Curing Medium	w/c	Void Content Ratio, %				Disparity, %	
			d42	d70	d98	d126	d98	d126
100S	Water	0.35	100	100	100	100	-	-
		0.50	100	100	100	100		
		0.65	100	100	100	100		
	CO_2	0.35	101.96	100.12	98.88	98.07	-1.17	-1.86
		0.50	102.17	100.20	98.90	98.34		
		0.65	102.34	100.47	98.72	98.01		
90S + 10L	CO_2	0.35	106.69	104.01	102.39	101.29	2.33	1.21
		0.50	106.50	103.94	102.30	101.07		
		0.65	106.52	104.09	102.31	101.26		
80S + 20L	CO_2	0.35	110.71	109.23	108.29	107.72	8.14	7.69
		0.50	110.67	109.16	108.11	107.69		
		0.65	110.69	109.12	108.03	107.67		
70S + 30L	CO_2	0.35	116.58	114.09	112.64	111.74	12.61	11.58
		0.50	116.65	114.29	112.39	111.36		
		0.65	116.64	113.92	112.81	111.64		
60S + 40L	CO_2	0.35	121.22	119.20	117.98	117.20	18.07	17.16
		0.50	120.99	119.21	118.20	117.04		
		0.65	121.10	119.03	118.02	117.24		
50S + 50L	CO_2	0.35	129.04	126.97	125.84	124.92	25.97	24.89
		0.50	129.31	127.00	126.10	124.85		
		0.65	128.97	126.89	125.96	124.91		

Effect of carbonation on the permeation properties of concrete at different 28-day compressive strengths

Using the 28-day strength values of water cured concrete specimens in Table 4 in conjunction with the ISAT-10 and void content values in Figures 3-8, Table 5 presents the void contents and ISAT-10 values of 19 concrete options at the 28-day strengths of 20-50 N/mm^2 that are possible within the limit of this study. These consist of one option at 20 N/mm^2, two options at 25 N/mm^2, three options each at 30, 35, 45 and 50 N/mm^2 and four options at 40 N/mm^2. The Table shows that equal strengths were achieved by the concrete options at different water/cement ratios and that the water/cement ratios required by each concrete mix to achieve equal strengths decrease with increase in the content of laterite. In other words, higher contents of cement would be required with increasing content of laterite.

Table 4: 28-day compressive strengths of water cured concretes

	28-day compressive strength, N/mm^2		
Mix	0.35	0.50	0.65
100S	58.0	45.0	39.5
90S+10L	54.0	42.0	36.5
80S+20L	48.5	37.5	33.0
70S+30L	39.0	30.5	26.5
60S+40L	34.0	26.0	23.0
50S+50L	29.0	23.0	20.0

At equal strengths, all the carbonated concretes have lower ISAT-10 values and void contents than the water cured concretes. For ISAT-10, the percentage reduction ranges between 2.70 and 8.68% after 8 weeks of carbonation and between 5.56 and 14.08% after 12 weeks of carbonation. For void content, the percentage reduction ranges between 0.44 and 2.24% after 8 weeks of carbonation and between 1.06 and 3.19% after 12 weeks of carbonation. Observation also shows that the resistance of these concrete options also increased with increasing content of laterite. These results also confirmed that carbonation would improve the resistance of laterized concrete in permeation with increasing exposure to carbon-dioxide medium and increasing content of laterite at equal exposure age. In addition, deductions from results obtained across the range of strength investigated show that all the water cured and carbonated laterized concretes have lower void contents and ISAT-10 values than the conventional (100S) concrete. Hence, at equal strengths, while the water cured and carbonated laterized concretes have higher resistance to permeation than the water cured and carbonated 100S concretes, the carbonated laterized concretes performed better than the 100S concrete.

Table 5: ISAT-10 and void contents of concretes at equal 28-day strengths

28-day [a] f_c, N/mm^2	Mix	w/c	Curing medium	Day 98 (8-week carbonation) ISAT-10 [b] x 10^{-2}, ml/m^{2}s^{-1}	Disp.[c], %	VC [d], %	Disp.[e], %	Day 126 (12-week carbonation) ISAT-10 [b] x 10^{-2}, ml/m^{2}s^{-1}	Disp.[c], %	VC [d], %	Disp.[e], %
20	50S+	0.65	Water	61.42	-2.70	14.90	-1.34	59.76	-5.56	14.05	-1.92
	50L		CO_2	59.76		14.70		56.44		13.78	
25	60S +	0.53	Water	44.29	-3.75	11.49	-1.31	42.63	-7.79	10.65	-1.78
	40L		CO_2	42.63		11.34		39.31		10.46	
	50S +	0.44	Water	38.18	-4.35	10.49	-1.24	36.52	-9.09	9.51	-1.68
	50L		CO_2	36.52		10.36		33.20		9.35	
30	70S +	0.51	Water	40.74	-8.27	10.57	-1.89	39.08	-12.87	9.75	-2.46
	30L		CO_2	37.37		10.37		34.05		9.51	
	60S +	0.41	Water	34.73	-4.78	9.41	-1.38	33.07	-10.04	8.42	-1.90
	40L		CO_2	33.07		9.28		29.75		8.26	
	50S +	0.33	Water	32.50	-5.11	8.79	-1.48	30.84	-10.77	7.56	-1.59
	50L		CO_2	30.84		8.66		27.52		7.44	
35	80S +	0.55	Water	43.56	-8.08	11.08	-1.08	41.90	-12.36	10.34	-1.55
	20L		CO_2	40.04		10.96		36.72		10.18	
	70S +	0.41	Water	33.07	-7.62	8.94	-1.79	31.41	-13.31	8.00	-2.38
	30L		CO_2	30.55		8.78		27.23		7.81	
	60S +	0.33	Water	31.11	-5.35	8.41	-1.31	29.45	-11.27	7.26	-1.65
	40L		CO_2	29.45		8.30		26.13		7.14	
40	100S	0.62	Water	43.43	-3.82	11.14	-0.54	41.77	-7.95	10.52	-1.90
			CO_2	41.77		11.08		38.45		10.32	
	90S +	0.53	Water	38.20	-4.35	10.22	-2.15	36.54	-9.09	9.51	-3.15
	10L		CO_2	36.54		10.00		33.22		9.21	
	80S +	0.45	Water	35.04	-8.68	9.36	-0.96	33.38	-14.08	8.54	-1.41
	20L		CO_2	32.00		9.27		28.68		8.42	
	70S +	0.33	Water	29.45	-5.06	7.98	-1.50	27.79	-11.34	6.89	-2.18
	30L		CO_2	27.96		7.86		24.64		6.74	
45	100S	0.50	Water	33.20	-5.00	9.12	-0.44	31.54	-10.53	8.45	-1.66
			CO_2	31.54		9.08		28.22		8.31	
	90S +	0.45	Water	32.00	-5.19	8.94	-2.24	30.34	-10.94	8.16	-3.19
	10L		CO_2	30.34		8.74		27.02		7.90	
	80S +	0.38	Water	30.39	-7.44	8.33	-0.84	28.73	-13.64	7.39	-1.22
	20L		CO_2	28.13		8.26		24.81		7.30	
50	100S	0.43	Water	29.28	-5.67	8.25	-0.48	27.62	-12.02	7.51	-1.60
			CO_2	27.62		8.21		24.30		7.39	
	90S +	0.39	Water	28.59	-5.81	8.09	-2.22	26.93	-12.33	7.22	-3.05
	10L		CO_2	26.93		7.91		23.61		7.00	
	80S +	0.33	Water	27.73	-5.37	7.68	-0.78	26.07	-12.08	6.63	-1.06
	20L		CO_2	26.24		7.62		22.92		6.56	

[a] 28-day compressive strength (f_c, N/mm^2)
[b] Initial surface absorption after 10 minutes (ISAT-10 x 10^{-2}, ml/m^{2}s^{-1})
[c] Disparity in ISAT-10 of carbonated with respect to water cured specimens
[d] Void content of concrete
[e] Disparity in void content of carbonated with respect to water cured specimens

Table 5 also shows that for a particular concrete mix (or at equal contents of laterite), water/cement ratio, ISAT-10 and void content reduced with increasing compressive strength. The reduction in ISAT-10 and void content would be due to the fact that decreasing water/cement ratio at equal water contents implies increasing cement content which is associated with increasing hydration products and therefore increased strength, improved microstructure, reduced ISAT-10 and void content and improved permeation resistance.

Also, according to Concrete Society [37], ISAT-10 greater than 0.50 ml/m^{2}s^{-1} would be considered high while ISAT-10 lower than 0.25 ml/m^{2}s^{-1} would be considered low. Table 5 therefore shows that 50S+50L concrete (either water cured or carbonated) could be classified as having 'high ISAT-10 values' and therefore low resistance to permeation at the curing ages of 98 and 126 days. On the other hand, while none of the water cured options has ISAT-10 values that could be classified as low at both ages, some carbonated options like 70S+30L at 40 N/mm^2, 80S+20L at 45 N/mm^2 and 100S, 90S+10L and 80S+20L options at 50 N/mm^2 at the curing age of 126 days could be classified as having 'low ISAT-10 values' and therefore would have high resistance against permeation.

IV. CONCLUSION

This study investigated the effect of carbonation on the permeation resistance of laterized concrete and the following conclusions have been drawn.

- At equal water/cement ratios, ISAT-10 and void content of concrete increased with increase in the content of laterite. Compared with water curing, carbonation resulted in specimens with lower ISAT-10 values and void contents at equal contents of laterite resulting in laterized concrete with higher resistance to permeation with increasing curing age.
- At equal 28-day compressive strengths, all carbonated laterized concrete specimens have lower void contents and ISAT-10 values than the water cured laterized and conventional concretes. The void contents and ISAT-10 values also reduced with increasing content of laterite at equal strengths.
- To achieve equal permeation resistance, lower water/cement ratio and therefore higher content of cement is required with increasing content of laterite.
- Increasing compressive strength is associated with reduced water/cement ratio and consequent reduction in ISAT-10 and void content of concrete.

Hence, carbonation while ensuring reduction in the level of carbon dioxide in the atmosphere would result in laterized concrete with better resistance against permeation than when water-cured. Carbonation would also permit the use of higher content of laterite and reduce the pressure on river sand.

REFERENCES

[1]. Falade, F.: Influence of water/cement ratios and mix proportions on workability and characteristic strength of concrete containing laterite fine aggregate. Building and Environment, 29 (2), 237-240 (1994).

[2]. Udoeyo, F. F., Iron, U. H. and Odim, O. O.: Strength performance of laterized concrete. Construction and Building Materials, 20 (10), 1057-1062 (2006).

[3]. Onipe, M. O. and Folagbade, S. O.: Void content and sorptivity of laterized concrete, in Aluko B. T., Odeyinka H. A., Amole O. O., Babasehinde A. A. and Daramola O. P. (Eds.), Proceedings of the Environmental Design and Management International Conference on Advances in Built Environment Research- Recent Advances and Future Directions, Faculty of Environmental Design and Management, Obafemi Awolowo University, Ile-Ife, Nigeria, 159-168 (2017).

[4]. Folagbade, S. O. and Osadola, O. A.: Workability, compressive strength and initial surface absorption of laterized concrete. Journal of Materials and Engineering Structures, 6(3), 455-463 (2019).

[5]. Folagbade, S. O.: Influence of fly ash and silica fume on the compressive strength development of Portland cement concrete. Journal of Environmental Design and Management, 6(1 & 2), 36-50 (2014).

[6]. Folagbade, S. O.: Absorption characteristics of cement combination concrete containing Portland cement, fly ash and metakaolin. Civil Engineering Dimension, 18(1), 57-64 (2016).

[7]. Folagbade, S. O.: Early-age performance of cement combination concrete. Civil Engineering Dimension, 19(1), 14-20 (2017).

[8]. Folagbade, S. O. and Newlands, M. D.: Suitability of cement combinations for carbonation resistance of structural concrete. Journal of Engineering, Design and Technology, 12(4), 423-439 (2014).

[9]. Folagbade, S. O. and Newlands M.: Compressive strength development of blended cement concretes containing Portland cement, fly ash and metakaolin. The Indian Concrete Journal, 88(9), 20-29 (2014).

[10]. Parrott, L. J.: A study of carbonation-induced corrosion. Magazine of Concrete Research, 46 (166), 23-28 (1994).

[11]. Parrott, L. J.: Some effects of cement and curing upon carbonation and reinforcement corrosion in concrete. Materials and Structures, 29 (187), 164-173 (1996).

[12]. Jones, M. R., Dhir, R. K., Newlands, M. D. and Abbas, A. M. O.: Study of the CEN Test Method for measurement of the carbonation depth of hardened concrete. Materials and Structures, 33 (226), 135-142 (2000).

[13]. Chi, J. M., Huang, R., and Yang, C. C.: Effects of carbonation on mechanical properties and durability of concrete using accelerated testing methods. Journal of Marine Science and Technology, 10(1), 14-20 (2002).

[14]. Zhan, B., Poon, C. and Shi, C.: CO_2 curing for improving the properties of concrete blocks containing recycled aggregates. Cement and Concrete Composites, 42, 1-8 (2013).

[15]. El-Hassan, H. and Shao, Y.: Early carbonation curing of concrete masonry units with Portland limestone cement. Cement and Concrete Composites, 62, 168-177 (2015).

[16]. Parrott, L. J.: A Review of Carbonation in Reinforced Concrete. Cement and Concrete Association, Wexham Springs, Great Britain (1987).

[17]. Dias, W. P. S.: Reduction of concrete sorptivity with age through carbonation. Cement and Concrete Research, 30, 1255-1261 (2000).

[18]. Neville, A. M.: Properties of Concrete. 5th Edition, London: Prentice-Hall (2012).

[19]. You, K., Jeong, H. and Hyung, W.: Effects of accelerated carbonation on physical properties of mortar. Journal of Asian Architecture and Building Engineering, 13(1), 217-221 (2014).

[20]. Nakarai, K. and Yoshida, T.: Effect of carbonation on strength development of cement-treated toyoura silica sand. Soils and Foundations, 55(4), 857-865 (2015).

[21]. Li, Z., He, Z. and Chen, X.: The performance of carbonation-cured concrete. Materials, 12, 3729, doi:10.3390/ma12223729 (2019).

[22]. Folagbade, S. O.: Effect of carbonation on the compressive strength development of laterised concrete. Civil and Environmental Research, 12(4), 29-35 (2020).

[23]. BS 1881- 208: Testing Concrete- Part 208: Recommendations for the Determination of the Initial Surface Absorption of Concrete, British Standards Institution, London (1996).

[24]. Scrivener, K. L. and Nemati, K. M.: The percolation of pore space in the cement paste/aggregate interfacial zone of concrete. Cement and Concrete Research, 26(1), 35-40 (1996).

[25]. Teychenne, D. C., Franklin, R. E. and Erntroy, H. C.: Design of Normal Concrete Mixes, 2nd Ed., amended by B.K. Marsh, Building Research Establishment, Garston, England (1997).

[26]. BS EN 12390- 2: Testing Hardened Concrete- Part 2: Making and Curing Specimens for Strength Tests, British Standards Institution, London (2000).

[27]. BS EN 1008: Mixing Water for Concrete- Specification for Sampling, Testing and Assessing the Suitability of Water, Including Water Recovered from Processes in the Concrete Industry, as Mixing Water for Concrete, British Standards Institution, London (2002).
[28]. BS EN 206-1: Concrete- Part 1: Specification, Performance, Production and Conformity, British Standards Institution, London (2000).
[29]. BS EN 934-2: Admixtures for Concrete, Mortar and Grout- Part 2: Concrete Admixtures- Definitions, Requirements, Conformity, Marking and Labelling, British Standards Institution, London (2009).
[30]. BS EN 12390- 3: Testing Hardened Concrete- Part 3: Compressive Strength of Test Specimens, British Standards Institution, London (2002).
[31]. ASTM C642: Standard test method for density, absorption, and voids in hardened concrete. American Society for Testing and Materials International, Pennsylvania (2006).
[32]. Dhir, R. K., Hewlett, P. C. and Chan Y. N.: Near surface characteristics of concrete: Intrinsic permeability. Magazine of Concrete Research, 41 (147), 87-97 (1989).
[33]. Mehta, P. K. and Monteiro, P.: Concrete: Microstructure, Properties and Materials, McGraw Hill, New York, NY (1997).
[34]. Korpa, A., Kowald, T. and Trettin, R.: Hydration behaviour, structure and morphology phases in advanced cement-based systems containing micro and nanoscale pozzolanic additives. Cement and Concrete Research, 38 (7), 955-962 (2008).
[35]. Kelham, S. A.: A water absorption test for concrete. Magazine of Concrete Research, 40 (143), 106-110 (1988).
[36]. Folagbade, S. O. and Aluko O.: Permeation resistance of sawdust ash blended cement laterized concrete. Civil Engineering Dimension, 21(2), 76-83 (2019).
[37]. Concrete Society: Permeability Testing of Site Concrete- A Review of Methods and Experience, Technical Report No 31, The Concrete Society, London (1987).