Journal of Materials and Engineering Structures

Research Paper

Workability, compressive strength and initial surface absorption of laterized concrete

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ARTICLE INFO

Article history :

Received : 4 December 2018

Revised : 9 March 2019

Accepted : 10 March 2019

Keywords:

Compressive strength

Initial surface absorption

Laterized concrete

Workability

ABSTRACT

This paper investigated the workability, compressive strength and initial surface absorption of plasticised laterized concrete at the water/cement ratios of 0.30, 0.50 and 0.70. Slump, compressive strength at 7, 14, 21 and 28 days and initial surface absorption after 10 minutes (ISA-10) at 28, 60 and 90 days were determined at the laterite contents of 0, 20, 40, 60, 80 and 100%. ISA-10 was also assessed at 28-day strengths of 20, 25 and 30 N/mm^2. Results showed that superplasticiser dosage increased with increasing content of laterite and for economic dosage laterite content should be limited to 40%. At equal water/cement ratios, compressive strength reduced with increasing content of laterite and ISA-10 increased with increasing content of laterite. The results also showed a strong relationship between ISA-10 and compressive strength and that laterized concrete, when specified on the basis of strength, would have resistance to initial surface absorption comparable with that of the conventional concrete if laterite content is limited to 40%. Hence, for good workability, compressive strength and permeation resistance, laterite content of concrete should be limited to 40%.

1 Introduction

Concrete is used for construction due to its versatility in producing functional structures in normal and extreme weather conditions. However, the need to reduce the environmental impact of conventional concrete led to research into alternatives for its constituent materials. The abundance of laterite, the quest to reduce pressure on sand and the possibility of reducing the cost of concrete led to the use laterite as possible alternative for sand as fine aggregates in concrete [1, 2]. Studies have supported the suitability of laterized concrete as an alternative to conventional concrete. If adequately designed, laterized concrete could be made to have good strength properties [1, 3-14]. However, while laterized concrete could be used at elevated temperatures [15] and in aggressive media [16-19], information on its permeation resistance is scanty in literature.

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e-ISSN: 2170-127X,

RESEARCH REVIEW of Sciences and Technologies

The durability of concrete depends on its permeation resistance against the ingress of deleterious fluids [20, 21]. One of the transport mechanisms for assessing the permeation resistance and therefore the quality of the surface zone of concrete is the initial surface absorption [22, 23]. The initial surface absorption measures the water absorption per unit area of the surface zone of concrete, at time intervals, at a head of 200 mm of water which is slightly greater than that which would be caused by driving rain [24]. The initial surface absorption after 10 minutes could be used to assess the ability of concrete to provide protection for its embedded reinforcing steel [24] and wall finishes. Hence, in order to provide more information on the permeation resistance of laterized concrete, this paper investigated its workability, compressive strength and initial surface absorption after 10 minutes at different water/cement ratios and strengths.

2 Experimental Materials and Methods

The materials used in the experiments were ordinary Portland cement (PC, 42.5 strength class) conforming to BS EN 197-1 [25] and fine and coarse aggregates. The fine aggregates were sand and laterite. Laterite was used as fine aggregates at 0, 20, 40, 60, 80 and 100% contents. The coarse aggregates were granite chippings. The properties of the aggregates are presented in Table 1 and the grading curves of the aggregates are illustrated in Figure 1. Concrete design was based on the Building Research Establishment Design Guide [26] using a free water content of 210 kg/m^3 at water/cement ratios of 0.30, 0.50 and 0.70. Potable water, conforming to BS EN 1008 [27], was used for mixing the constituent materials and for curing and testing of the concrete specimens. Mapefluid N200, conforming to EN 934-2 [28], 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 [29].

Laterized concrete was prepared to BS EN 12390-2 [30]. Slump test was carried out on fresh concrete in accordance with BS EN 12350-2 [31]. Concrete specimens were cast, demoulded and cured in water until the test dates. Tests were carried out on hardened concrete specimens to determine the compressive strength and initial surface absorption. Compressive strength was determined in accordance with BS EN 12390-3 [32] using 100 mm cubes at 7, 14, 21 and 28 days. The initial surface absorption after 10 minutes (ISA-10) at the curing ages of 28, 60 and 90 days were obtained in accordance with BS 1881-208 [24] using 150 mm concrete cubes subjected to water absorption. Each specimen was oven dried to constant mass at 105±5ºC, cooled to room temperature in a desiccator, installed as shown in Figure 2 and subjected to a pressure of 200 mm head of water. The tap 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, over three readings, was obtained and multiplied by the calibration factor of the tube. The ISA-10 values for the specimens were obtained using Equation 1.

$$\text{ISA-10} = N_{10} \times C_f \tag{1}$$

where ISA-10 = Initial surface absorption t minutes after water first touched concrete surface.

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

C_f = Calibration factor of capillary tube determined in accordance with BS 1881- 208 [24].

Table 1: 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	-	-

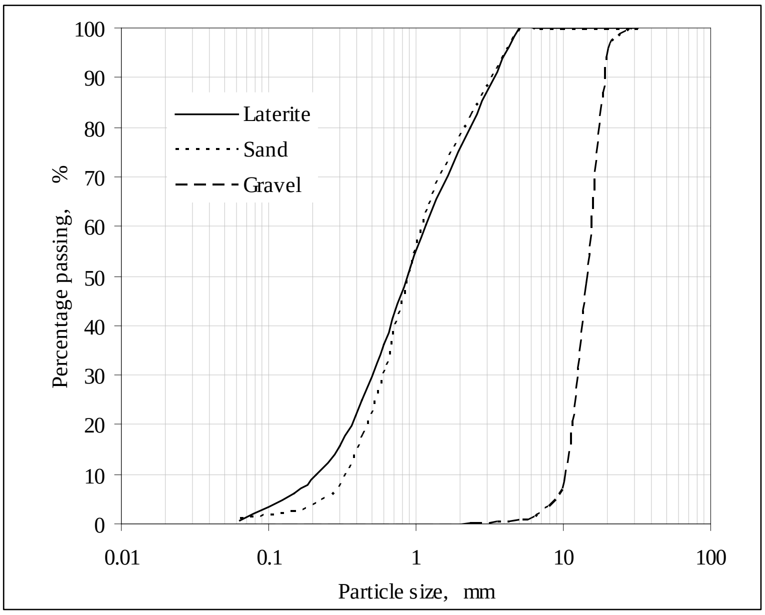

Fig. 1: Particle size distribution of aggregates

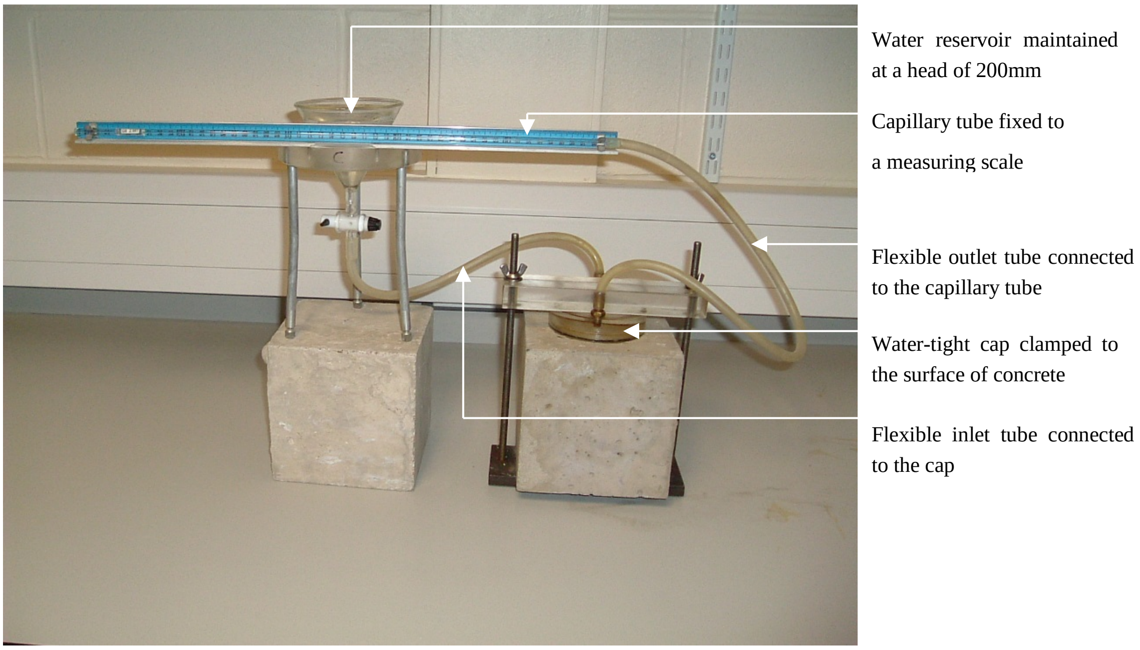

Fig. 2: Initial surface absorption test installation

3 Results and Discussion

3.1 Superplasticiser dosage of laterized concrete

Table 2 presents the superplasticiser dosage of concretes at the free water contents of 210 kg/m^3 and water/cement ratios of 0.30, 0.50 and 0.70. As expected, Table 2 shows that superplasticiser dosage reduced with increasing water/cement ratio. Also, at equal water/cement ratios, the superplasticiser dosages increased with increasing content of laterite. This might not be unconnected with the fact that due to its higher clay content, laterite has higher finer particles than sand (Figure 1) and therefore higher specific surface that would require higher content of water to achieve the same level of workability with sand. Furthermore, while the superplasticiser dosage factors increased with increasing water/cement ratio (Figure 3a), the dosage factor (Table 2) shows an average increase of 53%, 97%, 310%, 513% and 607% in superplasticiser dosage at 20%, 40%, 60%, 80% and 100% contents of laterite respectively. Furthermore, the line of best fit in Figure 3b shows that an exponential relationship exists between superplasticiser dosage and laterite content. Hence, laterized concrete would become stiffer and less workable as laterite content increases.

Table 2: Slump and superplasticizer dosages of concrete

% Laterite content	w/c	Slump (mm)	Superplasticiser dosage (kg/m^3)	Dosage [1] Factor (%)	Average Dosage Factor (%)
0	0.30	60	1.51	100	100
	0.50	80	0.99	100	
	0.70	80	0.73	100	
20	0.30	75	1.98	130	153
	0.50	75	1.51	150	
	0.70	70	1.31	180	
40	0.30	55	2.24	150	197
	0.50	65	1.98	200	
	0.70	60	1.72	240	
60	0.30	55	4.95	330	410
	0.50	60	3.96	400	
	0.70	60	3.70	500	
80	0.30	60	6.93	460	613
	0.50	70	5.94	600	
	0.70	60	5.68	780	
100	0.30	60	7.92	530	707
	0.50	60	6.93	700	
	0.70	60	6.46	890	

[1] Dosage factor measures superplasticiser dosage with respect to the mixes with 0% Laterite

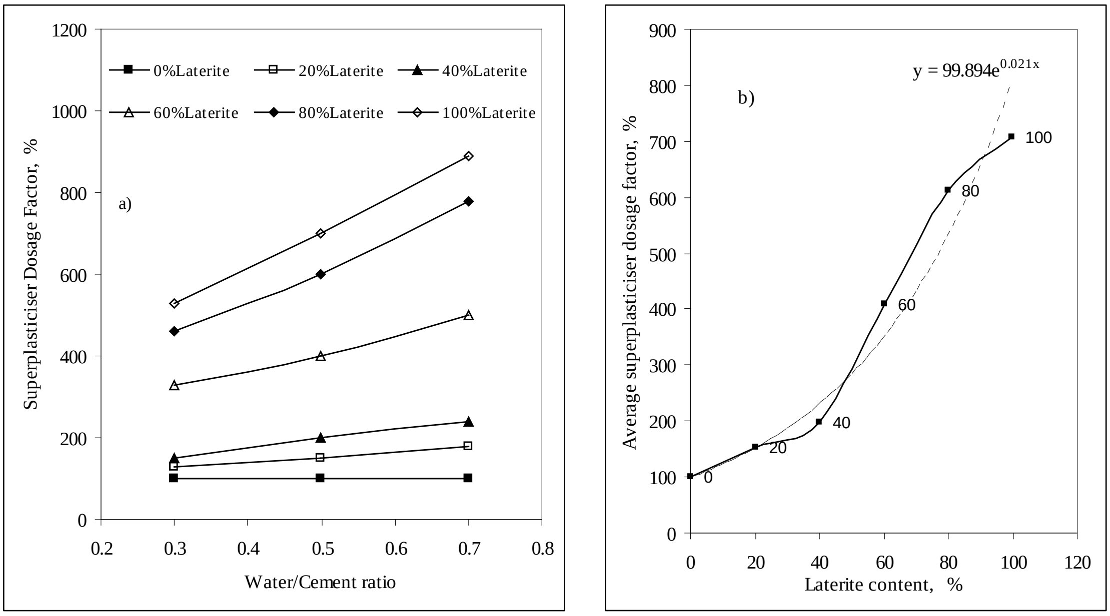

Fig. 3: Superplasticiser dosage factors at different laterite contents and water/cement ratios

The percentage increase in the average superplasticiser dosage factor was gradual up to 40% content of laterite after which the gradient become more considerable (Figure 3b). Hence, it becomes imperative to limit laterite content to not more than 40% in order not to make laterized concrete uneconomical due to the high dosage and high cost of superplasticiser at higher contents of laterite. This is also in consonance with Balogun and Adepegba [33], Salau and Balogun [6] and Udoeyo *et al*. [8] which limit laterite content to not more than 50% on the basis of strength consideration.

3.2 Compressive strength of concrete at equal water/cement ratios

The cube compressive strengths of concretes at different water/cement ratios and curing ages are presented in Table 3 with their respective strength factors (i.e., strength ratios with respect to the control sample with 0% laterite content).

In line with previous studies, cube compressive strength increased with increasing curing age due to the formation of hydration products and reduced with increasing water/cement ratio due to reduction in cement content.

In line with Ata [9], Olusola and Opeyemi [17] and Ettu, Ibearugbulem, Ezeh & Anya [34], compressive strength reduced with increasing content of laterite. This is because the reduction in the sand content would result in lower silica content and reduced hardness of the cement/laterite matrix and hence lower compressive strength with increasing content of laterite. Also, the reduction in strength might not be unconnected with the fact that laterite has higher finer particles (due to the higher content of clay) and therefore higher specific surface that would require higher content of cement to achieve the same level of strength development with sand. With respect to the strength ratios, Table 3 shows that compressive strength reduced at an average of 11.2%, 21.0%, 28.9%, 35.2% and 42.9% at 20%, 40%, 60%, 80% and 100% content of laterite respectively. Hence, the decrease in compressive strength of laterized concrete with increasing laterite content must be due to the lower silica content and higher clay content of laterite.

Table 3: Cube compressive strength and strength factors of laterized concretes

Laterite content, %	W/C	Compressive strength, N/mm^2				Strength factor [a], %						
		7d	14d	21d	28d	7d	14d	21d	28d	Mean[b]	OMean [c]	% Red [d]
0	0.30	26.0	34.0	38.0	41.0	100	100	100	100	100	100	-
	0.50	20.0	26.0	29.0	32.0	100	100	100	100	100		
	0.70	15.5	20.0	23.0	25.0	100	100	100	100	100		
20	0.30	23.0	31.0	34.5	37.5	88.5	91.2	90.8	91.5	90.5	88.8	11.2
	0.50	17.0	23.0	26.0	29.0	85.0	88.5	89.7	90.6	88.5		
	0.70	13.5	17.5	20.0	22.0	87.1	87.5	87.0	88.0	87.4		
40	0.30	21.0	27.5	31.0	34.0	80.8	80.9	81.6	82.9	81.6	79.0	21.0
	0.50	15.0	20.0	23.0	26.0	75.0	76.9	79.3	81.3	78.1		
	0.70	12.0	15.5	17.5	19.5	77.4	77.5	76.1	78.0	77.3		
60	0.30	17.0	24.0	27.5	30.5	65.4	70.6	72.4	74.4	70.7	71.1	28.9
	0.50	13.0	18.0	21.0	24.0	65.0	69.2	72.4	75.0	70.4		
	0.70	11.0	14.5	16.5	18.5	71.0	72.5	71.7	74.0	72.3		
80	0.30	15.5	21.5	25.0	27.5	59.6	63.2	65.8	67.1	63.9	64.8	35.2
	0.50	12.0	16.0	19.0	21.0	60.0	61.5	65.5	65.6	63.2		
	0.70	10.0	13.5	15.5	17.5	64.5	67.5	67.4	70.0	67.4		
100	0.30	13.0	18.0	21.0	23.5	50.0	52.9	55.3	57.3	53.9	57.1	42.9
	0.50	10.5	14.5	17.0	19.0	52.5	55.8	58.6	59.4	56.6		
	0.70	9.0	12.0	14.0	16.0	58.1	60.0	60.9	64.0	60.8		

a) Strength ratio with respect to the control sample (0% laterite)
b) Mean strength factor over the curing ages
c) Overall mean of strength factors over the water/cement ratio
d) % Reduction of strength factor with respect to the control sample

3.3 Initial surface absorption of concrete at equal water/cement ratios

The Initial Surface Absorption after 10 minutes (ISA-10) of concretes at the curing ages of 28, 60 and 90 days and water/cement ratios of 0.30, 0.50 and 0.70 are presented in Table 4. The Table shows that ISA-10 reduced with increasing curing age and increased with increasing water/cement ratio and increasing laterite content. The reduction in ISA-10 with curing must be due to pore refinement arising from the filling up of the voids in concrete by the hydration products formed from the hydration reaction of cement. Hence, the increase in ISA-10 with increasing water/cement ratio must be due to reduction in the content of cement as water/cement ratio increases. The increase in ISA-10 with increasing laterite content must be due to the increasing content of clay resulting in stickiness and difficulty in the thorough mixing of cement and aggregates. Also, in line with Kelham [35], the likelihood of increasing volume of fine pores with increasing laterite content would lead to increase in ISA-10 of laterized concrete. Furthermore, the reduction in the sand content with increasing content of laterite would result in cement/laterite matrix characterised by lower silica content, lower hardness and higher porosity and hence higher ISA-10 than the cement/sand matrix being replaced. The disparities between the ISA-10 of the laterized concretes and the conventional concrete (Table 4) show that ISA-10 increased at an average of 18.1%, 61.1%, 109.9%, 154.7% and 216.8% at 20%, 40%, 60%, 80% and 100% contents of laterite respectively. This result shows that, the resistance against surface absorption of laterized concrete becomes unreliable at laterite contents greater than 20%.

Table 4: Initial surface absorption of concretes at different water/cement ratios and curing ages

Laterite content, %	**W/C**	**ISA-10 x 10^{-2}, ml/m^{2}S^{-1}**			**ISA-10 Ratio, % [a)]**					
		28d	**60d**	**90d**	**28d**	**60d**	**90d**	**Mean[b]**	**O/Mean [c]**	**% Inc [d]**
0	0.30	43.2	28.2	24.9	100	100	100	100	100	-
	0.50	54.9	38.2	34.9	100	100	100	100		
	0.70	89.6	69.7	59.8	100	100	100	100		
20	0.30	48.1	34.9	31.5	111.3	123.8	126.5	120.5	118.1	18.1
	0.50	59.8	48.1	43.2	108.9	125.9	123.8	119.5		
	0.70	102.9	79.7	68.1	114.8	114.3	113.9	114.3		
40	0.30	63.1	51.5	48.1	146.1	182.6	193.2	174.0	161.1	61.1
	0.50	79.7	68.1	61.4	145.2	178.3	175.9	166.5		
	0.70	126.2	99.6	86.3	140.9	142.9	144.3	142.7		
60	0.30	83.0	69.7	66.4	192.1	247.2	266.7	235.3	209.9	109.9
	0.50	101.3	88.0	81.3	184.5	230.4	233.0	216.0		
	0.70	152.7	124.5	111.2	170.4	178.6	186.0	178.3		
80	0.30	101.3	88.0	84.7	234.5	312.1	340.2	295.6	254.7	154.7
	0.50	119.5	106.2	99.6	217.7	278.0	285.4	260.4		
	0.70	172.6	146.1	132.8	192.6	209.6	222.1	208.1		
100	0.30	126.2	112.9	107.9	292.1	400.4	433.3	375.3	316.8	216.8
	0.50	149.4	132.8	126.2	272.1	347.6	361.6	327.1		
	0.70	199.2	176.0	161.0	222.3	252.5	269.2	248.0		

[a)] Ratios of ISA-10 of concrete with respect to the control mix (0% Laterite content).

[b)] Mean ISA-10 ratio of concrete over the curing ages.

[c)] Overall mean of ISA-10 ratios of concrete over the water/cement ratios.

[d)] % Increase of ISA-10 ratio of concrete with respect to the control sample.

3.4 Relationship between initial surface absorption and compressive strength of concrete

Figure 4 illustrates the relationship between the 28-day compressive strengths and ISA-10 of concretes at the water/cement ratios of 0.30, 0.50 and 0.70. The coefficient of determination of 92.21% (R^2= 0.9221) shows that a strong relationship exists between compressive strength and initial surface absorption. Hence, using Equation 2, compressive strength which is easier to determine on construction sites could be used to assess the initial surface absorption of concrete.

$$ISA\text{-}10 = 0.0027\times(f_{cu})^2 - 0.2055\times(f_{cu}) + 4.4303 \qquad (2)$$

where f_{cu} = 28-day cube compressive strength of concrete

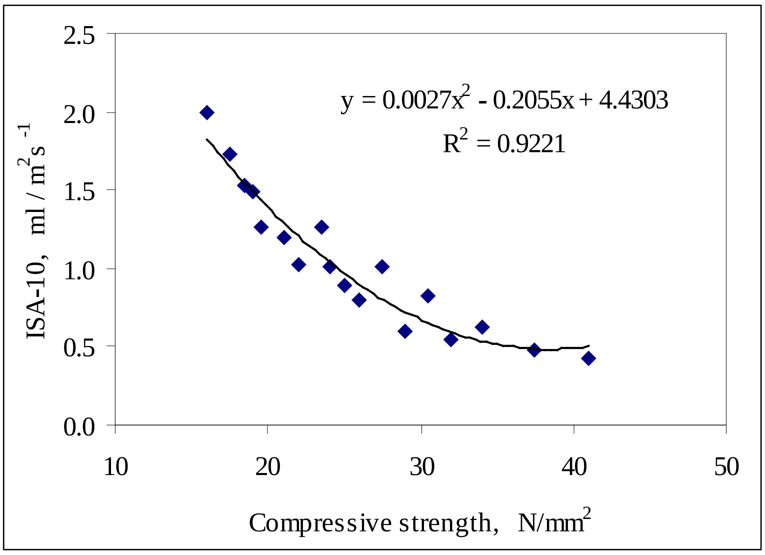

Fig. 4: Relationship between ISA-10 and compressive strength of concrete

3.5 Initial surface absorption of concrete at equal strengths

Since concrete is specified on the basis of the 28-day compressive strength, Table 5 presents the ISA-10 of concretes at the 28-day cube compressive strengths of 20, 25 and 30 N/mm^2. The Table shows that the higher the laterite content, the lower the water/cement ratio required to achieve equal strengths. It could also be deduced from the Table that if laterite content is limited to 40%, it is possible to have laterized concrete with resistance to initial surface absorption comparable with that of the conventional Portland cement concrete when concrete is specified at equal strength between 20 and 30 N/mm^2. The limiting of laterite content of concrete to not more than 40% is also supported by Balogun and Adepegba [33], Salau and Balogun [6] and Udoeyo *et al.* [8].

Table 5: Initial surface absorption of concretes at different cube compressive strengths

Laterite content, %	20 N/mm^2		25 N/mm^2		30 N/mm^2	
	w/c	ISA-10 x 10^{-2}, ml/m^{2}S^{-1}	w/c	ISA-10 x 10^{-2}, ml/m^{2}S^{-1}	w/c	ISA-10 x 10^{-2}, ml/m^{2}S^{-1}
0	**	**	0.70	89.6	0.55	61.42
20	**	**	0.61	79.6	0.47	56.04
40	0.68	120.2	0.52	83.0	0.39	66.87
60	0.64	134.0	0.46	95.0	0.31	83.1
80	0.54	127.3	0.36	103.1	*	*
100	0.45	141.1	*	*	*	*

* Values require lower water/cement ratios than investigated.

** Values require higher water/cement ratios than investigated.

4 Conclusion

This study investigated the workability, compressive strength and initial surface absorption of laterized concrete and the following conclusions have been drawn.

Workability of concrete reduced with increasing content of laterite. This is due to the higher content of fine particles. Hence, superplasticiser dosage increased considerably at laterite contents greater than 40%.

Compressive strength of concrete increased with increasing curing age and reduced with increasing water/cement ratio and laterite content. Compressive strength reduced due to the lower silica content and higher content of fine particles with increasing content of laterite. In the same vein, initial surface absorption reduced with increasing curing age and increased with increasing water/cement ratio and laterite content.

A reliable relationship exists between initial surface absorption and compressive strength of concrete. Hence, it is possible to use the relationship to determine initial surface absorption from the compressive strength of concrete.

Since concrete is specified in practice on the basis of strength, laterized concrete with resistance to surface absorption comparable with that of the conventional Portland cement concrete is possible if laterite content is limited to 40%.

Hence, to ensure reliable workability, compressive strength development and resistance to surface absorption, the laterite content of concrete should be limited to 40%.

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