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EFFECT OF NON-STANDARD CURING METHODS ON THE COMPRESSIVE STRENGTH OF LATERIZED CONCRETE

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ABSTRACT

Thirty concrete mixes of differing water-binder ratio containing 0, 10, 20, 30, 40 and 50 % laterite as a partial replacement for sand were used to prepare laterized concrete specimens for the study of the effect of nonstandard curing methods on the strength of specimen. The effectiveness of a curing method was measured quantitatively as the ratio of the compressive strength of specimen cured using the non-standard method to those cursed using the standard water-curing method specified in the BS1881: Part 3:1970 (control). The results of the investigation show that with continuous wetting of the nonstandard curing media by sprinkling with water, the strength of the concrete obtained could be comparable to those cured using the control method. Of the four nonstandard curing methods considered in the study it was observed that the strength of sand- and sawdust-cured specimen were in some instances the same as or higher than those of the standard cured specimens at early age (7 days). Although at later age (28 days) there were significant differences between the strength of specimens cured using the nonstandard methods and those of corresponding laterite content and water-binder ratio cured using the control method as established by t-test, the designed strength of 20 MPa was attained by all specimens cured using the nonstandard methods, which is indicative that these nonstandard methods could be used as alternative to the standard water curing, especially in situations where much water may not be available for curing specimens.

Keywords: non-standard curing methods, laterized concrete, compressive strength.

INTRODUCTION

Excessive early loss of water due to inadequate curing of concrete could lead to undesirable effects such as reduced strength, increased porosity, increased shrinkage and internal cracking of the matrix [9]. Proper curing decreases, among other things, permeability, surface dusting, thermal shock effects, and scaling tendency. On the other hand, it increases strength development, abrasion resistance, durability property, pozzolanic activity and weatherability [3]. Proper curing maintains relative humidity above eighty percent, thereby advancing hydration to the maximum attainable limit [10]. For proper curing ACI Committee 318, "Building Code Requirements for Reinforced Concrete," specifies that concrete be maintained in a moist condition for at least seven days after placement. It was based on these afore-stated facts that an experimental programme was designed to study the effectiveness of non-standard methods of curing laterized concrete measured in terms of the compressive strength of non-standard cured specimens relative to the strength of those cured using the BS1881: Part 3:1970 standard curing method. It is believed that the findings of this work will provide practicing engineers and other construction professionals the information necessary for improving the nonstandard methods of curing prevalently used on the field in some regions where laterized concrete holds much promise as a new material for construction. Laterized concrete is a concrete containing laterite as a full or partial replacement for sand.

MATERIALS AND METHODS

Materials

A type I Ordinary Portland Cement (OPC) was used as the binder throughout this experimental programme. The cement, which was imported and packaged in 50 kg bags by Eastern Bulkcem Company Limited, Port Harcourt, Nigeria, had a specific gravity, soundness, initial and final setting times of 3.15, 0.51mm, 53 and 92 minutes, respectively. The sharp river sand used had a specific gravity of 2.59; its grading conformed to zone 2 of BS 882. The coarse aggregate was a crushed rock of maximum size 37mm obtained from Crushed Rock Industries, Akamkpa, Cross River State of Nigeria. The coarse aggregate had a specific gravity of 2.66, and an average impact and crushing values of 15.26 and 21.02 percent, respectively. The laterite used as a partial replacement of sharp sand in the concrete mix was taken from a borrow pit in Otamiri village near Federal University of Technology, Owerri, where this research work was conducted. The laterite had a specific gravity of 2.5 and conforms to BS zone 3 grading. The grain size distribution of the fine and coarse aggregate used are presented in Table-1.

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Table-1. Particle size distribution and properties of aggregates.

Grain size distribution of aggregates				**Physical properties of aggregates**			
Sieve size (mm)	**Laterite** (%)	**Sand** (%)	**Coarse** (%)	**Type**	**Specific gravity**	**Impact value**	**Crushing value**
50.000	100.0	100.0	100.0	Laterite	2.50		
37.500	100.0	100.0	94.0	Sand	2.59		
19.000	100.0	100.0	49.0	Coarse	2.66	15.26	21.02
14.000	100.0	100.0	39.0				
10.000	100.0	100.0	18.5				
5.600	100.0	97.5	3.0				
3.350	100.0	95.9	0.5				
2.000	100.0	93.3	0.0				
1.180	98.1	83.9					
0.600	70.9	34.9					
0.425	52.9	26.8					
0.300	27.6	19.9					
0.212	15.9	9.1					
0.150	3.5	1.7					
0.075	0.0	0.0					

The bulk chemical composition of the laterite analyzed by EMSL Analytical Inc., Westmont, NJ, USA is presented in Table-2.

Table-2. Percentage chemical composition of laterite.

Compound	Value
Fe_2O_3	2.38
TiO_2	0.82
K_2O	0.13
SiO_2	77.80
MgO	0.13
Al_2O_3	18.40
P_2O_5	0.10
Cr_2O_3	0.09
SO_3	0.09
CaO	0.04
ZrO_2	0.03
MnO	0.01
ZnO	0.01

Specimen preparation and testing methods

Five concrete mixes were prepared with 0, 10, 20, 30, 40, and 50 % replacement levels of sand by laterite. Batched concrete constituents were initially mixed dry until homogeneous mix was obtained. After adding a pre-calculated amount of water, mixing was repeated, and the fresh concrete mix was then placed in concrete mould of size 150 × 150 × 150 mm and rammed with a steel bar having a ramming face of 25 mm^2. All mixing was done by hand. The compositions of the concrete mix design which was according to absolute weight method are shown in Table-3.

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Table-3. Concrete mix composition.

W/B ratio	Mix	Cement (kg/m³)	Fine aggregate (kg/m³) Sand	Laterite	Coarse aggregate (kg/m³)	Water (kg/m³)
0.40	LAT-0	400	642.16	0.00	1197.84	160.00
	LAT-10	400	577.94	64.22	1197.84	160.00
	LAT-20	400	513.73	128.43	1197.84	160.00
	LAT-30	400	449.51	192.65	1197.84	160.00
	LAT-40	400	385.30	256.86	1197.84	160.00
	LAT-50	400	321.08	321.08	1197.84	160.00
0.45	LAT-0	400	635.18	0.00	1184.82	180.00
	LAT-10	400	571.66	63.52	1184.82	180.00
	LAT-20	400	508.14	127.04	1184.82	180.00
	LAT-30	400	444.63	190.55	1184.82	180.00
	LAT-40	400	381.11	254.07	1184.82	180.00
	LAT-50	400	317.59	317.59	1184.82	180.00
0.50	LAT-0	350	654.38	0.00	1220.63	175.00
	LAT-10	350	588.94	65.44	1220.63	175.00
	LAT-20	350	523.50	130.88	1220.63	175.00
	LAT-30	350	458.07	196.31	1220.63	175.00
	LAT-40	350	392.63	261.75	1220.63	175.00
	LAT-50	350	327.19	327.19	1220.63	175.00
0.55	LAT-0	325	661.79	0.00	1234.45	178.75
	LAT-10	325	595.61	66.18	1234.45	178.75
	LAT-20	325	529.43	132.36	1234.45	178.75
	LAT-30	325	463.25	198.54	1234.45	178.75
	LAT-40	325	397.07	264.72	1234.45	178.75
	LAT-50	325	330.90	330.90	1234.45	178.75
0.60	LAT-0	300	670.08	0.00	1244.92	180.00
	LAT-10	300	603.07	67.01	1244.92	180.00
	LAT-20	300	536.06	134.02	1244.92	180.00
	LAT-30	300	469.06	201.02	1244.92	180.00
	LAT-40	300	402.05	268.03	1244.92	180.00
	LAT-50	300	335.04	335.04	1244.92	180.00

The cast specimens were removed from the mould after 24 hours and cured using the BS1881: Part 3:1970 standard water curing method and the non-standard curing methods described below. The test methods used for testing specimens are presented in Table-4.

Table-4. Test methods used for measuring aggregate and concrete properties.

Properties	Test method
Specific gravity	ASTM C 128-07
Sieve analysis	BS 882:1983
Aggregate crushing and impact value	BS EN 1097-2:1998
Slump	BS 1881:Part 2:1970
Compressive strength	BS 1881: Part 4:1970
Water absorption	BS 1881: Part 122:1983
Water curing	BS 1881: Part 3:1970
Other curing	Non-standard methods

- Water-curing: concrete specimens were cured in water tank according to BS EN 12390-2: 2000 and tested for compression at 7, 14, and 28 days using a standard compression machine.
- Sand-curing: specimens were laid 150 mm apart on alternate 150 mm-thick layers of sand, and covered with a final layer of sand of same thickness. The sand was protected from sliding to its angle of repose by forming a bay of 1800 by 900 mm using two layers of 225 mm unbonded blocks. The experimental set-up was kept wet by sprinkling with water on a continuous basis until specimens were tested.
- Jute bag-curing: a bay of 1800 by 900 mm was formed using two layers of unbonded blocks of 225 mm size. The base of the bay was spread with jute bag before

placing samples at alternate courses, maintaining 75 mm spacing between them. The top of the final course was then covered with jute bag and the set-up was kept moist throughout the curing duration by continuous sprinkling with water.

- Sawdust-curing: The base of an 1800 by 900 mm bay created using 225 mm unbonded block was spread with 150 mm thick wet sawdust before placing cube samples at a distance of 150 mm apart. The space between specimens was filled with moist sawdust before placing other samples on subsequent 150 mm thick layers of moist sawdust. After placing all the samples, the top of the set-up was covered with final 150 mm thick layer of moist sawdust and the whole lot kept wet by sprinkling with water on continuous basis throughout the duration of curing.
- Polythene sheet curing: The base of an 1800 x 900 mm bay created using two courses of unbonded 225 mm blocks was covered with polythene sheet before stacking samples at 150 mm apart. The top of the final course was covered with polythene sheet and the set-up kept continuously moist throughout the duration of curing.

RESULTS AND DISCUSSIONS

Fresh laterized concrete

The results of the workability of laterized concrete measured in terms of the slump of the fresh concrete mix are presented in Figure-1.

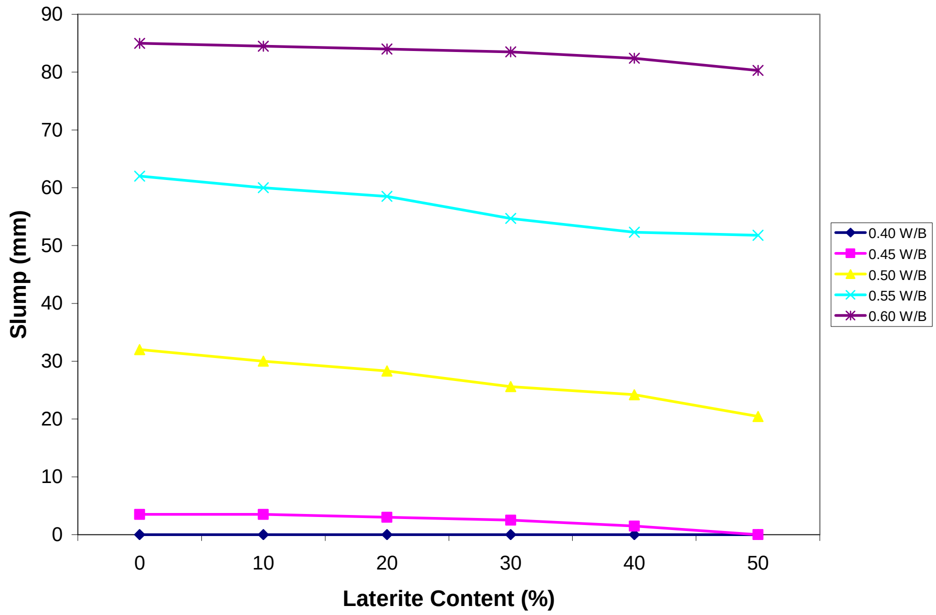

Figure-1. Variation of slump with laterite content of laterized concrete.

The workability increases with increase in water to binder ratio but decreases with increase in laterite content. While the trend of the former was anticipated, since it is a well known fact in practice that increasing the water content of a mix leads to increase in workability, the trend for the later was not predictable. It was anticipated that the trend would show a peak indicating an optimum laterite content that would allow for a workable concrete mix, instead a continuous and steady decrease in workability with increase in laterite content was observed. However, the possible explanation for the trend is that increasing laterite content led to the introduction of more laterite clay fines into the mix, and that caused an increase in the specific surface area of aggregates that subsequently led to a decrease in the workability of the matrix.

Hardened laterized concrete

The results of the influence of curing methods, laterite content, and water-binder ratio on the 7- 14- and 28-day strength of laterized concrete are shown in Tables 5, 6, and 7.

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Table-5. Seven-day compressive strength of laterized concrete cured using standard and non-standard methods of curing and t-test.

W/B ratio	Mix	Laterite (%)	**Compressive strength** (MPa) WC	SC	JBC	SDC	PSC
0.40	LAT-0	0	17.4 ± 0.06^{a}	17.4 ± 0.11^{ns}	$17.2 \pm 0.23^{*}$	17.4 ± 0.29^{ns}	17.3 ± 0.64^{ns}
	LAT-10	10	17.2 ± 0.06	17.3 ± 0.52^{ns}	17.1 ± 0.29^{ns}	17.2 ± 0.23^{ns}	17.2 ± 0.29^{ns}
	LAT-20	20	17.1 ± 0.06	$16.5 \pm 0.91^{**}$	$16.4 \pm 0.24^{**}$	$16.8 \pm 0.12^{**}$	$16.6 \pm 0.42^{**}$
	LAT-30	30	16.9 ± 0.12	$16.4 \pm 0.12^{*}$	$16.4 \pm 0.54^{*}$	$16.5 \pm 0.18^{*}$	$16.5 \pm 0.55^{*}$
	LAT-40	40	16.4 ± 0.06	$16.4 \pm 0.18^{n.s}$	$16.2 \pm 0.06^{*}$	16.4 ± 0.00^{ns}	$16.1 \pm 0.12^{**}$
	LAT-50	50	16.1 ± 0.87	$16.3 \pm 0.24^{*}$	16.0 ± 0.81^{ns}	16.3 ± 0.06^{ns}	16.0 ± 0.25^{ns}
0.45	LAT-0	0	17.3 ± 0.98	17.3 ± 0.12^{ns}	17.1 ± 0.93^{ns}	17.3 ± 0.00^{ns}	17.2 ± 0.23^{ns}
	LAT-10	10	17.2 ± 1.17	17.2 ± 0.41^{ns}	17.0 ± 0.41^{ns}	17.1 ± 0.12^{ns}	17.1 ± 0.18^{ns}
	LAT-20	20	17.1 ± 0.58	16.5 ± 0.24^{ns}	$16.4 \pm 0.12^{**}$	$16.7 \pm 0.06^{**}$	$16.5 \pm 0.12^{**}$
	LAT-30	30	16.8 ± 0.16	$16.4 \pm 0.18^{**}$	$16.3 \pm 0.31^{**}$	$16.4 \pm 0.18^{**}$	$16.4 \pm 1.04^{*}$
	LAT-40	40	16.0 ± 0.61	$16.3 \pm 0.06^{**}$	16.1 ± 0.12^{ns}	$16.3 \pm 0.18^{**}$	16.1 ± 0.19^{ns}
	LAT-50	50	16.0 ± 0.63	$16.2 \pm 0.06^{*}$	15.9 ± 0.31^{ns}	$16.2 \pm 0.06^{*}$	16.0 ± 0.31^{ns}
0.50	LAT-0	0	17.3 ± 0.98	17.2 ± 0.17^{ns}	17.1 ± 0.64^{ns}	17.2 ± 0.17^{ns}	17.2 ± 0.17^{ns}
	LAT-10	10	17.1 ± 0.00	17.1 ± 0.11^{ns}	17.0 ± 0.53^{ns}	17.1 ± 0.12^{ns}	17.1 ± 0.06^{ns}
	LAT-20	20	17.0 ± 0.06	$16.4 \pm 0.00^{**}$	$16.3 \pm 0.12^{**}$	$16.6 \pm 0.06^{**}$	$16.5 \pm 0.06^{**}$
	LAE-30	30	16.6 ± 1.02	$16.3 \pm 0.12^{*}$	$16.2 \pm 0.24^{*}$	$16.3 \pm 0.60^{*}$	$16.3 \pm 0.18^{*}$
	LAT-40	40	16.3 ± 0.61	16.2 ± 0.12^{ns}	$15.9 \pm 0.06^{**}$	16.3 ± 0.12^{ns}	$16.0 \pm 0.25^{**}$
	LAT-50	50	16.0 ± 0.00	$16.2 \pm 0.31^{**}$	$15.9 \pm 0.13^{**}$	$16.2 \pm 0.25^{**}$	$15.9 \pm 0.19^{**}$
0.55	LAT-0	0	17.2 ± 0.58	17.1 ± 0.18^{ns}	17.0 ± 2.40^{ns}	17.1 ± 0.23^{ns}	17.1 ± 0.53^{ns}
	LAT-10	10	17.0 ± 0.09	16.9 ± 0.12^{ns}	16.9 ± 0.41^{ns}	17.0 ± 0.12^{ns}	17.0 ± 0.24^{ns}
	LAT-20	20	16.9 ± 0.09	$16.3 \pm 0.06^{**}$	$16.3 \pm 0.12^{**}$	$16.5 \pm 0.12^{*}$	$16.3 \pm 0.18^{**}$
	LAT-30	30	16.4 ± 0.61	$16.2 \pm 0.00^{*}$	$16.1 \pm 0.19^{**}$	16.3 ± 0.06^{ns}	$16.2 \pm 0.19^{*}$
	LAT-40	40	16.2 ± 0.62	16.1 ± 0.12^{ns}	16.0 ± 1.00^{ns}	16.2 ± 0.12^{ns}	$16.0 \pm 0.38^{*}$
	LAT-50	50	15.9 ± 1.07	16.1 ± 0.00^{ns}	15.8 ± 0.12^{ns}	16.1 ± 0.06^{ns}	15.9 ± 0.31^{ns}
0.60	LAT-0	0	17.2 ± 1.16	17.0 ± 0.35^{ns}	17.0 ± 0.12^{ns}	17.0 ± 0.12^{ns}	17.0 ± 0.12^{ns}
	LAT-10	10	16.9 ± 0.09	16.8 ± 0.17^{ns}	16.9 ± 0.24^{ns}	16.9 ± 0.06^{ns}	17.0 ± 0.29^{ns}
	LAT-20	20	16.8 ± 0.05	$16.2 \pm 0.12^{**}$	$16.2 \pm 0.12^{**}$	$16.4 \pm 0.12^{**}$	$16.2 \pm 0.12^{**}$
	LAT-30	30	16.3 ± 0.06	$16.1 \pm 0.19^{**}$	16.1 ± 0.56^{ns}	$16.2 \pm 0.00^{**}$	$16.1 \pm 0.06^{**}$
	LAT-40	40	16.2 ± 0.31	$16.0 \pm 0.06^{**}$	$15.9 \pm 0.12^{**}$	$16.1 \pm 0.06^{*}$	$15.9 \pm 0.13^{*}$
	LAT-40	50	15.8 ± 0.38	$16.0 \pm 0.00^{**}$	15.8 ± 0.12^{ns}	$16.0 \pm 0.18^{**}$	15.8 ± 0.13^{ns}

* = $p < 0.05$; ** = $p < 0.005$; ns = not significant; a = coefficient of variation (%);
WC = water curing; SC = sand curing; JBC = jute bag curing; SDC = sawdust curing; PSC = polythene sheet curing

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Table-6. Fourteen-day compressive strength of laterized concrete cured using standard and non-standard methods of curing and t-test.

W/B ratio	Mix	Laterite (%)	Compressive strength (MPa) WC	SC	JBC	SDC	PSC
0.40	LAT-0	0	20.9 ± 1.38^{a}	20.6 ± 0.15^{ns}	$20.5 \pm 0.29^{*}$	20.7 ± 0.09^{ns}	$20.5 \pm 0.10^{*}$
	LAT-10	10	20.5 ± 0.05	20.5 ± 0.20^{ns}	$20.3 \pm 0.10^{**}$	$20.4 \pm 0.05^{**}$	20.5 ± 0.15^{ns}
	LAT-20	20	20.5 ± 0.10	$20.1 \pm 0.15^{**}$	$20.1 \pm 0.55^{**}$	$20.3 \pm 0.15^{**}$	$20.2 \pm 0.20^{**}$
	LAT-30	30	20.4 ± 0.14	$20.1 \pm 0.10^{**}$	$20.1 \pm 0.80^{*}$	$20.2 \pm 0.05^{**}$	$20.0 \pm 0.25^{**}$
	LAT-40	40	20.3 ± 0.09	$19.9 \pm 0.05^{**}$	20.1 ± 1.34^{ns}	$20.1 \pm 0.30^{**}$	$20.0 \pm 0.25^{**}$
	LAT-50	50	20.2 ± 0.05	$19.8 \pm 0.20^{**}$	$19.7 \pm 0.55^{**}$	$19.9 \pm 0.10^{**}$	$19.8 \pm 0.05^{**}$
0.45	LAT-0	0	20.8 ± 0.10	$20.5 \pm 0.10^{**}$	$20.4 \pm 0.20^{**}$	$20.6 \pm 0.05^{**}$	$20.4 \pm 0.20^{**}$
	LAT-10	10	20.3 ± 0.05	$20.4 \pm 0.15^{**}$	20.2 ± 1.04^{ns}	20.3 ± 0.00^{ns}	$20.4 \pm 0.15^{**}$
	LAT-20	20	20.1 ± 0.10	20.1 ± 0.25^{ns}	20.0 ± 1.05^{ns}	$20.2 \pm 0.05^{**}$	20.1 ± 0.39^{ns}
	LAT-30	30	20.0 ± 0.10	20.0 ± 0.30^{ns}	20.0 ± 1.15^{ns}	$20.2 \pm 0.09^{**}$	20.0 ± 0.10^{ns}
	LAT-40	40	19.9 ± 0.19	19.9 ± 0.35^{ns}	$20.0 \pm 0.20^{*}$	$20.1 \pm 0.10^{**}$	19.9 ± 0.20^{ns}
	LAT-50	50	19.8 ± 0.20	$19.7 \pm 0.10^{*}$	$19.6 \pm 0.05^{**}$	19.8 ± 0.05^{ns}	$19.7 \pm 0.10^{*}$
0.50	LAT-0	0	20.7 ± 0.05	$20.4 \pm 0.20^{**}$	$20.0 \pm 0.93^{*}$	$20.5 \pm 0.10^{**}$	$20.4 \pm 0.05^{**}$
	LAT-10	10	20.1 ± 0.15	$20.4 \pm 0.15^{**}$	20.2 ± 1.39^{ns}	$20.2 \pm 0.15^{*}$	$20.3 \pm 0.15^{**}$
	LAT-20	20	20.0 ± 0.15	$20.1 \pm 0.05^{**}$	20.0 ± 0.00^{ns}	$20.1 \pm 0.20^{*}$	20.0 ± 0.25^{ns}
	LAT-30	30	19.9 ± 0.10	$20.0 \pm 0.25^{*}$	$19.8 \pm 0.10^{**}$	$20.1 \pm 0.10^{**}$	19.9 ± 0.05^{ns}
	LAT-40	40	19.8 ± 0.20	$19.9 \pm 0.30^{*}$	19.8 ± 1.01^{ns}	$20.0 \pm 0.05^{**}$	$19.9 \pm 0.30^{*}$
	LAT-50	50	19.7 ± 0.15	19.7 ± 0.10^{ns}	$19.5 \pm 0.36^{*}$	$19.8 \pm 0.00^{**}$	$19.6 \pm 0.15^{*}$
0.55	LAT-0	0	20.6 ± 0.20	$20.4 \pm 0.20^{**}$	$20.3 \pm 0.25^{**}$	$20.5 \pm 0.10^{*}$	$20.4 \pm 0.14^{**}$
	LAT-10	10	20.0 ± 0.10	$20.3 \pm 0.15^{**}$	20.1 ± 0.55^{ns}	$20.1 \pm 0.05^{**}$	20.2 ± 0.89^{ns}
	LAT-20	20	19.9 ± 0.15	$20.0 \pm 0.05^{**}$	19.9 ± 0.10^{ns}	$20.0 \pm 0.10^{**}$	$20.0 \pm 0.20^{*}$
	LAT-30	30	19.8 ± 0.10	$19.9 \pm 0.10^{**}$	$19.7 \pm 0.35^{*}$	$20.0 \pm 0.15^{**}$	19.8 ± 0.05^{ns}
	LAT-40	40	19.7 ± 0.00	$19.8 \pm 0.25^{*}$	$19.6 \pm 0.46^{**}$	$19.9 \pm 0.00^{**}$	19.7 ± 0.10^{ns}
	LAT-50	50	19.6 ± 0.10	19.6 ± 0.15^{ns}	$19.4 \pm 3.66^{**}$	$19.7 \pm 0.20^{*}$	$19.5 \pm 0.21^{*}$
0.60	LAT-0	0	20.5 ± 0.15	$20.3 \pm 0.25^{**}$	20.3 ± 1.82^{ns}	$20.4 \pm 0.10^{**}$	$20.3 \pm 0.29^{**}$
	LAT-10	10	20.0 ± 0.05	$20.2 \pm 0.20^{**}$	20.0 ± 0.35^{ns}	$20.1 \pm 0.10^{**}$	20.0 ± 0.20^{ns}
	LAT-20	20	19.8 ± 0.74	$20.0 \pm 0.10^{*}$	19.8 ± 0.76^{ns}	19.9 ± 0.10^{ns}	19.9 ± 0.15^{ns}
	LAT-30	30	19.7 ± 0.20	$19.9 \pm 0.05^{**}$	$19.6 \pm 0.20^{*}$	$19.8 \pm 0.00^{*}$	$19.6 \pm 0.10^{*}$
	LAT-40	40	19.6 ± 0.15	$19.7 \pm 0.05^{**}$	$19.4 \pm 0.10^{**}$	$19.7 \pm 0.50^{**}$	$19.5 \pm 0.20^{*}$
	LAT-50	50	19.4 ± 0.15	$19.5 \pm 0.15^{*}$	$19.3 \pm 0.31^{*}$	$19.6 \pm 0.15^{**}$	19.4 ± 0.05^{ns}

* = $p < 0.05$; ** = $p < 0.005$; a = coefficient of variation (%); WC = water curing; SC = sand curing; JBC = jute bag curing; SDC = sawdust curing; PSC = polythene sheet curing

Table-7. Twenty eight-day compressive strength of laterized concrete cured using standard and non-standard methods of curing and t-test.

W/B ratio	Laterite (%)	Compressive strength (MPa)				
		WC	SC	JBC	SDC	PSC
0.40	0	22.2 ± 0.09[a]	22.0 ± 0.14[ns]	21.8 ± 0.18[*]	22.1 ± 0.27[ns]	21.8 ± 0.18[*]
	10	21.9 ± 0.14	21.6 ± 0.05[**]	21.6 ± 0.01[**]	21.7 ± 0.09[**]	21.8 ± 0.14[*]
	20	21.7 ± 0.14	21.3 ± 0.19[**]	21.4 ± 0.19[**]	21.4 ± 0.14[**]	21.5 ± 0.09[**]
	30	21.6 ± 0.00	21.2 ± 0.09[**]	21.2 ± 0.00[**]	21.3 ± 0.05[**]	21.2 ± 0.18[**]
	40	21.6 ± 0.00	21.2 ± 0.05[**]	21.1 ± 0.09[**]	21.3 ± 0.14[**]	21.1 ± 0.23[**]
	50	21.4 ± 0.14	21.0 ± 0.23[**]	20.9 ± 0.14[**]	21.1 ± 0.19[**]	20.9 ± 0.19[**]
0.45	0	21.1 ± 0.00	21.9 ± 0.09[**]	21.7 ± 0.23[**]	22.0 ± 0.18[*]	21.8 ± 0.14[**]
	10	21.8 ± 0.09	21.6 ± 0.14[**]	21.5 ± 0.20[**]	21.8 ± 0.14[ns]	21.6 ± 0.09[**]
	20	21.7 ± 0.09	21.3 ± 0.14[**]	21.3 ± 0.09[**]	21.5 ± 0.00[**]	21.4 ± 0.23[**]
	30	21.6 ± 0.09	21.2 ± 0.09[**]	21.1 ± 0.24[**]	21.3 ± 0.09[**]	21.1 ± 0.14[**]
	40	21.5 ± 0.14	21.1 ± 0.05[**]	21.0 ± 0.38[**]	21.2 ± 0.19[**]	20.9 ± 0.00[**]
	50	21.3 ± 0.00	20.9 ± 0.19[**]	20.8 ± 0.19[**]	21.0 ± 0.05[**]	20.8 ± 0.05[**]
0.50	0	22.0 ± 0.23	21.8 ± 0.18[**]	21.6 ± 0.09[**]	21.9 ± 0.14[ns]	21.7 ± 0.00[**]
	10	21.8 ± 0.09	21.6 ± 0.14[**]	21.4 ± 0.23[**]	21.7 ± 0.18[*]	21.5 ± 0.14[**]
	20	21.6 ± 0.09	21.3 ± 0.09[**]	21.2 ± 0.09[**]	21.4 ± 0.23[**]	21.3 ± 0.19[**]
	30	21.5 ± 0.23	21.2 ± 0.05[**]	21.0 ± 0.38[**]	21.3 ± 0.00[**]	21.0 ± 0.10[**]
	40	21.4 ± 0.28	21.1 ± 0.33[**]	20.9 ± 0.14[**]	21.2 ± 0.09[**]	20.8 ± 0.05[**]
	50	21.2 ± 0.19	20.9 ± 0.24[**]	20.7 ± 0.10[**]	21.0 ± 0.14[**]	20.7 ± 0.09[**]
0.55	0	22.0 ± 0.41	21.7 ± 0.46[*]	21.6 ± 0.18[**]	21.9 ± 0.04[ns]	21.6 ± 0.18[**]
	10	21.7 ± 0.23	21.5 ± 0.42[*]	21.2 ± 0.22[**]	21.6 ± 0.23[*]	21.4 ± 0.09[**]
	20	21.6 ± 0.18	21.3 ± 0.14[**]	21.1 ± 0.19[**]	21.4 ± 0.09[**]	21.2 ± 0.14[**]
	30	21.4 ± 0.14	21.1 ± 0.05[**]	20.9 ± 0.24[**]	21.2 ± 0.18[**]	21.0 ± 0.23[**]
	40	21.3 ± 0.02	20.9 ± 0.10[**]	20.8 ± 0.00[**]	21.0 ± 0.09[**]	20.7 ± 0.04[**]
	50	21.0 ± 0.10	20.8 ± 0.24[**]	20.5 ± 0.10[**]	20.9 ± 0.14[**]	20.6 ± 0.10[**]
0.60	0	21.9 ± 0.32	21.6 ± 0.32[**]	21.5 ± 0.33[**]	21.8 ± 0.05[*]	21.6 ± 0.10[**]
	10	21.6 ± 0.00	21.4 ± 0.05[**]	21.2 ± 0.14[**]	21.5 ± 0.09[**]	21.2 ± 0.09[**]
	20	21.5 ± 0.60	21.2 ± 0.09[*]	21.0 ± 0.28[**]	21.4 ± 0.19[ns]	21.1 ± 0.05[*]
	30	21.4 ± 0.32	21.1 ± 0.09[**]	20.8 ± 0.10[**]	21.2 ± 0.00[**]	21.0 ± 0.14[**]
	40	21.3 ±1.31	20.9 ± 0.24[*]	20.7 ± 0.10[*]	21.0 ± 0.14[ns]	20.6 ± 0.15[*]
	50	20.9 ± 0.14	20.6 ± 0.19[**]	20.4 ± 0.20[**]	20.8 ± 0.19[*]	20.5 ± 0.00[**]

* = p< 0.05; ** = p< 0.005; n.s = not significant; a = coefficient of variation (%);
WC = water curing; SC = sand curing; JBC = jute bag curing; SDC = sawdust curing;
PSC = polythene sheet curing

Each value is the average of the test results of three identical specimens. Altogether 450 cube specimens were tested in compression. Generally, the compressive strength of laterized concrete decreases with increase in laterite content and water-binder ratio as could be observed in the results; and since much research findings have already been reported on the influence of these on laterized concrete [2, 13], the analysis hereafter will be more on the effect of curing methods on the compressive strength of the concrete. A meticulous study of the test results presented will show that curing methods had influence on the compressive strength of laterized concrete. To establish the existence of statistical differences between the strength of specimens cured using the BS1881: Part 3:1970 standard curing method and those cured using the non-standard methods t-tests were conducted with alpha equal 0.05 and 0.005 set as significant and highly significant level, respectively. The computed t were obtained using Equation 1 through Equation 3 and compared with tabulated t. Significant difference was declared when calculated t was greater than tabulated t.

$$t = \frac{\text{Observed difference between group means}}{\text{Standard error of the difference between group means}} \qquad \text{---------- (1)}$$

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The above equation could be expressed in mathematical terms as follows:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\mathrm{SE}(\bar{x}_1 - \bar{x}_2)} \quad \text{-- (2)}$$

$$= \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{S^2_{\bar{x}_1}}{n_1} + \frac{S^2_{\bar{x}_2}}{n_2}}} \quad \text{-- (3)}$$

Where

$S_{\bar{x}_1}, S_{\bar{x}_2}$ = group standard deviation, and

n_1, n_2= group sample size

The degree of freedom for significance testing could be computed as follows:

df = $n_1 + n_2 - 2$ ------------------------------------ (4)

From the results of the t-tests indicated on the generated compressive strength data it would be observed that there was no significant differences between the 7-day strength of many specimens cured using the control method and those cured using the non-standard methods. It was very interesting to note that in some instances, where statistical differences existed, the strength performance of the non-standard cured specimens (see sawdust-cured and sand-cured) were better than those of the standard cured specimens at the early-age strength. But at the later age (28 days) there were highly significant differences between the strength of the standard cured specimens and those of the non-standard cured of corresponding laterite content and water-binder ratio as indicated in the test results. To further establish the possibility of using some of these non-standard methods on the field for curing of Laterized concrete the probability of the strength of the nonstandard-cured specimen being less than 85 % of the strength of the standard-cured specimen was investigated. This was necessary based on the ACI Committee 318 “Building Code Requirement” that specifies that “procedures for protecting and curing concrete shall be improved when the strength of field cured cylinders at test age designated for determination of f'_c is less than 85 percent of that of companion laboratory-cured cylinders.” All the tests showed that the probability of the strength ratio of the nonstandard cured specimens to that of standard cured specimen being less than or equal to 0.85 [Pr (R≤0.85)] was almost zero. The ratio of the 7-, 14-, and the 28-day strength of non-standard cured specimens to those of the standard cured specimens are presented in Tables 8, 9 and 10, respectively.

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Table-8. Seven-day compressive strength of non-standard cured concrete relative to that of standard cured concrete of the same age (R).

W/B ratio	Mix	Laterite (%) (%)	R			
			SC	JBC	SDC	PSC
0.40	LAT-0	0	1.000	0.989	1.000	0.994
	LAT-10	10	1.010	0.994	1.000	1.000
	LAT-20	20	0.965	0.959	0.982	0.982
	LAT-30	30	0.970	0.970	0.976	0.976
	LAT-40	40	1.000	0.988	1.000	0.982
	LAT-50	50	1.010	0.994	1.010	0.994
0.45	LAT-0	0	1.000	0.988	1.000	0.994
	LAT-10	10	1.000	0.988	0.994	0.994
	LAT-20	20	0.965	0.959	0.977	0.965
	LAT-30	30	0.976	0.970	0.976	0.976
	LAT-40	40	1.020	1.010	1.020	1.010
	LAT-50	50	1.010	0.994	1.010	1.000
0.50	LAT-0	0	0.994	0.988	0.994	0.994
	LAT-10	10	1.000	0.994	1.000	1.000
	LAT-20	20	0.965	0.959	0.976	0.971
	LAT-30	30	0.982	0.976	0.982	0.982
	LAT-40	40	0.994	0.975	1.000	0.982
	LAT-50	50	1.010	0.994	1.010	0.994
0.55	LAT-0	0	0.994	0.988	0.994	0.994
	LAT-10	10	0.994	0.994	1.000	1.000
	LAT-20	20	0.964	0.964	0.976	0.964
	LAT-30	30	0.988	0.982	0.994	0.988
	LAT-40	40	0.994	0.988	1.000	0.988
	LAT-50	50	1.010	0.994	1.010	1.000
0.60	LAT-0	0	0.988	0.988	0.988	0.988
	LAT-10	10	0.994	1.000	1.000	0.988
	LAT-20	20	0.964	0.964	0.976	0.964
	LAT-30	30	0.988	0.988	0.976	0.988
	LAT-40	40	0.988	0.981	0.994	0.981
	LAT-50	50	1.010	1.000	1.010	1.000

WC = water curing; SC = sand curing; JBC = jute bag curing; SDC = sawdust curing; PSC = polythene sheet curing

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Table-9. Fourteen-day compressive strength of non-standard cured concrete relative to that of standard cured concrete of the same age (R).

W/B ratio	Mix	Laterite (%)	R			
			SC	**JBC**	**SDC**	**PSC**
0.41	LAT-0	0	0.986	0.981	0.990	0.981
	LAT-10	10	1.000	0.990	0.995	1.000
	LAT-20	20	0.980	0.980	0.990	0.982
	LAT-30	30	0.985	0.985	0.990	0.980
	LAT-40	40	0.980	0.990	0.990	0.985
	LAT-50	50	0.980	0.975	0.985	0.980
0.45	LAT-0	0	0.986	0.981	0.990	0.981
	LAT-10	10	1.005	0.995	1.000	1.005
	LAT-20	20	1.000	0.995	1.005	1.000
	LAT-30	30	1.000	1.000	1.010	1.000
	LAT-40	40	1.000	1.005	1.010	1.000
	LAT-50	50	0.995	0.990	1.000	0.995
0.50	LAT-0	0	0.986	0.966	0.990	0.986
	LAT-10	10	1.015	1.005	1.006	1.010
	LAT-20	20	1.005	1.000	1.010	1.000
	LAT-30	30	1.005	0.995	1.010	1.000
	LAT-40	40	1.005	1.000	1.005	1.005
	LAT-50	50	1.000	0.990	1.010	0.995
0.55	LAT-0	0	0.990	0.985	0.994	0.990
	LAT-10	10	1.015	1.005	1.005	1.010
	LAT-20	20	1.004	1.000	1.010	1.005
	LAT-30	30	1.005	0.995	1.005	1.000
	LAT-40	40	1.005	0.995	1.010	1.000
	LAT-50	50	1.000	0.990	1.005	0.995
0.60	LAT-0	0	0.990	0.990	0.995	0.990
	LAT-10	10	1.010	1.000	1.005	1.000
	LAT-20	20	1.010	1.000	1.005	1.005
	LAT-30	30	1.010	0.995	1.005	0.995
	LAT-40	40	1.005	0.990	1.005	0.995
	LAT-50	50	1.005	0.995	1.010	1.000

WC = water curing; SC = sand curing; JBC = jute bag curing; SDC = sawdust curing; PSC = polythene sheet curing

Table-10. Twenty eight-day compressive strength of non-standard cured concrete relative to that of standard cured concrete of the same age (R).

W/B ratio	Mix	Laterite (%)	R SC	R JBC	R SDC	R PSC
0.40	LAT-0	0	0.990	0.982	0.995	0.982
	LAT-10	10	0.986	0.986	0.991	0.995
	LAT-20	20	0.982	0.986	0.986	0.990
	LAT-30	30	0.981	0.981	0.986	0.981
	LAT-40	40	0.981	0.977	0.986	0.977
	LAT-50	50	0.981	0.977	0.986	0.977
0.45	LAT-0	0	1.038	1.028	1.043	1.033
	LAT-10	10	0.991	0.986	1.000	0.990
	LAT-20	20	0.982	0.982	0.991	0.986
	LAT-30	30	0.981	0.977	0.986	0.977
	LAT-40	40	0.981	0.977	0.986	0.972
	LAT-50	50	0.981	0.977	0.986	0.977
0.50	LAT-0	0	0.991	0.982	0.995	0.986
	LAT-10	10	0.991	0.982	0.995	0.986
	LAT-20	20	0.986	0.982	0.991	0.986
	LAT-30	30	0.986	0.977	0.991	0.977
	LAT-40	40	0.986	0.977	0.991	0.972
	LAT-50	50	0.986	0.976	0.991	0.976
0.55	LAT-0	0	0.986	0.982	0.995	0.982
	LAT-10	10	0.991	0.977	0.995	0.986
	LAT-20	20	0.986	0.977	0.991	0.981
	LAT-30	30	0.986	0.977	0.991	0.981
	LAT-40	40	0.981	0.977	0.986	0.972
	LAT-50	50	0.990	0.976	0.995	0.981
0.60	LAT-0	0	0.986	0.982	0.995	0.986
	LAT-10	10	0.991	0.981	0.995	0.981
	LAT-20	20	0.986	0.977	0.995	0.981
	LAT-30	30	0.986	0.972	0.991	0.981
	LAT-40	40	0.981	0.972	0.986	0.967
	LAT-50	50	0.986	0.976	0.995	0.981

WC = water curing; SC = sand curing; JBC = jute bag curing; SDC = sawdust curing; PSC = polythene sheet curing.

Information about the early-age development of concrete could be very useful to engineers and construction professionals in determining if there is a problem with a concrete batch, or in predicting if early stripping of forms or removal of form supports would be safe. Presented in Tables, 11 and 12 are the $\frac{7}{28}$ - day and $\frac{14}{28}$ - day strength of laterized concrete cured using the different methods investigated in this work.

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Table-11. $\frac{7}{28}$ -day compressive strength ratio of laterized concrete.

W/B ratio	Mix	Laterite (%)	f_{C7}/f_{C28} WC	SC	JBC	SDC	PSC
0.40	LAT-0	0	0.784	0.791	0.789	0.787	0.794
	LAT-10	10	0.785	0.801	0.792	0.793	0.789
	LAT-20	20	0.788	0.775	0.766	0.785	0.772
	LAT-30	30	0.782	0.774	0.774	0.775	0.778
	LAT-40	40	0.759	0.774	0.768	0.770	0.763
	LAT-50	50	0.752	0.776	0.766	0.773	0.766
0.45	LAT-0	0	0.820	0.790	0.788	0.786	0.789
	LAT-10	10	0.789	0.796	0.791	0.784	0.792
	LAT-20	20	0.788	0.775	0.770	0.777	0.771
	LAT-30	30	0.778	0.774	0.773	0.770	0.777
	LAT-40	40	0.744	0.773	0.767	0.769	0.770
	LAT-50	50	0.751	0.775	0.764	0.769	0.769
0.50	LAT-0	0	0.786	0.789	0.792	0.785	0.793
	LAT-10	10	0.784	0.792	0.794	0.788	0.795
	LAT-20	20	0.787	0.770	0.769	0.776	0.775
	LAT-30	30	0.772	0.769	0.771	0.765	0.776
	LAT-40	40	0.762	0.768	0.761	0.769	0.769
	LAT-50	50	0.755	0.775	0.768	0.771	0.768
0.55	LAT-0	0	0.782	0.788	0.787	0.781	0.792
	LAT-10	10	0.783	0.786	0.797	0.787	0.794
	LAT-20	20	0.782	0.765	0.773	0.771	0.769
	LAT-30	30	0.766	0.768	0.770	0.769	0.771
	LAT-40	40	0.761	0.770	0.769	0.771	0.773
	LAT-50	50	0.757	0.774	0.770	0.770	0.772
0.60	LAT-0	0	0.785	0.787	0.790	0.780	0.787
	LAT-10	10	0.782	0.785	0.797	0.786	0.802
	LAT-20	20	0.781	0.764	0.771	0.766	0.768
	LAT-30	30	0.762	0.763	0.774	0.764	0.767
	LAT-40	40	0.761	0.766	0.768	0.767	0.772
	LAT-50	50	0.756	0.777	0.775	0.769	0.771

WC = water curing; SC = sand curing; JBC = jute bag curing; SDC = sawdust curing;
PSC = polythene sheet curing

Table-12. $\frac{14}{28}$ -day compressive strength ratio of laterized concrete.

W/B ratio	Mix	Laterite (%)	f_{C14}/f_{C28} WC	SC	JBC	SDC	PSC
0.40	LAT-0	0	0.941	0.936	0.940	0.937	0.940
	LAT-10	10	0.936	0.949	0.940	0.940	0.940
	LAT-20	20	0.945	0.944	0.939	0.949	0.940
	LAT-30	30	0.944	0.948	0.948	0.948	0.943
	LAT-40	40	0.940	0.939	0.953	0.944	0.948
	LAT-50	50	0.944	0.943	0.943	0.943	0.947
0.45	LAT-0	0	0.941	0.936	0.940	0.936	0.936
	LAT-10	10	0.931	0.944	0.940	0.931	0.944
	LAT-20	20	0.926	0.944	0.940	0.940	0.939
	LAT-30	30	0.926	0.943	0.948	0.948	0.948
	LAT-40	40	0.926	0.943	0.952	0.948	0.952
	LAT-50	50	0.930	0.943	0.942	0.943	0.947
0.50	LAT-0	0	0.941	0.936	0.944	0.936	0.940
	LAT-10	10	0.922	0.944	0.944	0.931	0.944
	LAT-20	20	0.926	0.944	0.943	0.939	0.939
	LAT-30	30	0.926	0.943	0.943	0.944	0.948
	LAT-40	40	0.925	0.943	0.947	0.943	0.957
	LAT-50	50	0.929	0.943	0.942	0.943	0.947
0.55	LAT-0	0	0.936	0.940	0.940	0.936	0.944
	LAT-10	10	0.922	0.944	0.948	0.931	0.944
	LAT-20	20	0.921	0.939	0.943	0.935	0.943
	LAT-30	30	0.925	0.943	0.943	0.943	0.943
	LAT-40	40	0.925	0.947	0.942	0.948	0.952
	LAT-50	50	0.933	0.942	0.946	0.943	0.947
0.60	LAT-0	0	0.936	0.940	0.944	0.936	0.940
	LAT-10	10	0.931	0.944	0.943	0.935	0.943
	LAT-20	20	0.921	0.943	0.943	0.930	0.943
	LAT-30	30	0.921	0.943	0.942	0.934	0.933
	LAT-40	40	0.920	0.943	0.937	0.938	0.947
	LAT-50	50	0.928	0.947	0.946	0.942	0.946

WC = water curing; SC = sand curing; JBC = jute bag curing; SDC = sawdust curing; PSC = polythene sheet curing

From the results it could be observed that the concrete specimens cured using the non-standard curing methods attained between 76 and 80 % of the 28-day strength in 7 days, and between 93 and 96 % of the strength in 14 days, compared with that of the specimen cured using the standard method that was between 75 and 82 %, and 92 and 95 % of the 28-day strength in 7 and 14 days, respectively.

Figure-2 shows the results of the water absorption of laterized concrete tested according to BS 1881:122: 1983.

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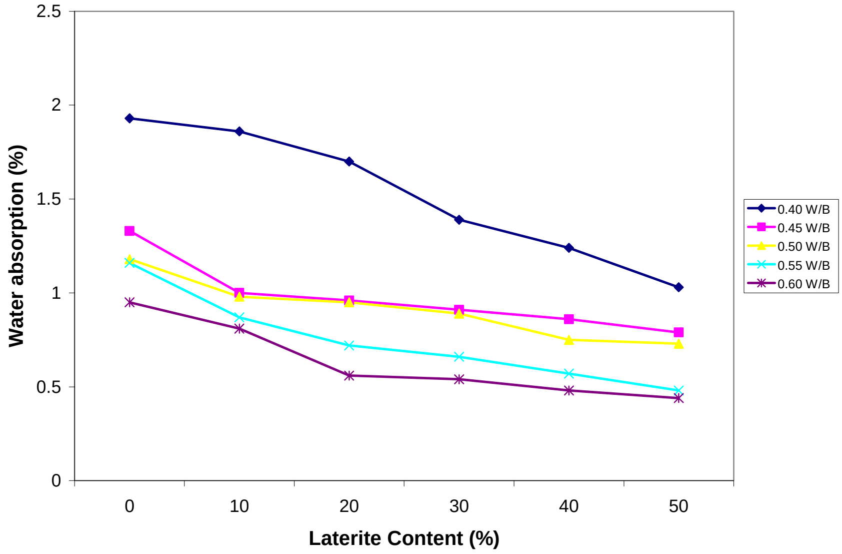

Figure-2. Variation of water absorption and laterite content of laterized concrete.

Each value is the average of three test results. A total of 90 specimens were tested. The trend shows decreasing water absorption with increasing laterite content and water-binder ratio. The possible reasons for the observed trend are twofold. The first reason may be due to the low permeability of laterite compared to that of the sand which is being replaced in the mix. Increasing laterite content introduces more clay fines into the concrete mix and that increases the impermeability of the matrix. The second possible reason may be explained in terms of the interactive effect of the water-binder ratio, laterite content and OPC. Increasing the water-binder ratio in the mix provides adequate water necessary for the secondary reaction between OPC and the lateritic clay fines, resulting in the formation of the secondary cementitious material that further binds the concrete's constituents together, thus making the matrix more impermeable to water.

CONCLUSIONS

Based on the results of this study the following conclusions are drawn:

- The workability of laterized concrete mix increases with increase in water to binder ratio but decreases with increase in laterite content;
- The water absorption of laterized concrete decreases with increase in both water to binder ratio and laterite content;
- Generally, the compressive strength of concrete not containing laterite were higher than those of laterized concrete of corresponding water-binder ratio and curing method, thus indicating the superiority of the former to the later. However, in terms of economic consideration, the readily availability and the inexpensiveness of laterite in tropical and subtropical regions make it a feasible proposition for use for concreting in those regions and
- The results obtained in this study show that nonstandard curing methods such as sawdust-curing and sand-curing could be as effective as standard water-curing method, and therefore could be used as an alternative to the later, especially in situations where these materials are more readily available. The compressive strength of sawdust- and sand-cured laterized concrete specimens was as high as between 98 and 100 % of the strength of specimens cured using the standard water curing method.

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