Journal of Scientific Research & Reports
9(7): 1-7, 2016; Article no.JSRR.22733
ISSN: 2320-0227

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Short Term Study on the Compressive Strength of Microbial Laterized Concrete Cured in Seawater

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Authors' contributions

This work was carried out in collaboration among all the authors. Authors TFA, OOA and OLO designed the study and wrote the protocol. Author TFA conducted and managed the laboratory investigation and wrote the first draft of the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/JSRR/2016/22733
Editor(s):
(1) Prinya Chindaprasirt, Khon Kaen University, Thailand.
Reviewers:
(1) Danupon Tonnayopas, Prince of Songkla University, Thailand.
(2) Suraya Hani Adnan, Universiti Tun Hussein Onn Malaysia, Malaysia.
(3) Ahmed H. Ali, Sherbrooke University, Canada.
Complete Peer review History: http://sciencedomain.org/review-history/12651

Original Research Article

Received 23rd October 2015
Accepted 30th November 2015
Published 11th December 2015

ABSTRACT

The effect of bacteria *(Bacillus subtilis*) on the compressive strength of laterized concrete cured in sea water was investigated. Because of the many variables involved, Taguchi method of experimental design was employed. The variables were water to binder ratio (0.45, 0.50 and 0.55), percentage laterite replacement of fine aggregate (0%, 10% and 20%) and changes in the volume of bacteria culture (0%, 10% and 30%) which depends on the pre-calculated quantity of water required for each test at a cell concentration of 10^5 colony forming unit per ml. Two curing media (water and sea water) were used with constant mix ratio of 1:2:4. Compressive strengths were determined at 7, 14 and 28 days. Results indicated that maximum compressive strengths for microbial laterized concrete were obtained for the following combinations; 0% laterite replacement with volume of bacterial culture at 20%, 20% laterite replacement with volume of bacterial culture at 30% and 40% laterite replacement with volume of bacterial culture at 10%.

Keywords: Compressive strength; water/cement ratio; laterite; sand; granite and bacteria (Bacillus subtilis).

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1. INTRODUCTION

Concrete which has been in existence for several decades, has its demand ever increasing year in year out and this has led to an increase in the cost of the major concrete materials which are cement, aggregate and water. There has been effort by researchers [1-6] in looking for ways in which these concrete constituents can be replaced either fully or partly in order to bring down the cost of producing concrete. Such materials include the use of rice husk ash, saw dust ash, volcanic ash etc as cement replacement and also materials such as erosion sand, filler, laterite etc as sand replacement. Lateritic soil is a residual soil which is found in abundance in the tropical regions, and of all the various soil types in the tropics and sub tropics, laterite is of special interest in concrete production. This is a highly weathered soil which contains large though extremely variable, population of iron and aluminum oxide as well as quartz and other minerals [7]. Laterite is found extensively all over Nigeria and it could be used in producing concrete either in form of full replacement of or in combination with sand. Concrete produced from using laterite as fine aggregate is usually called laterized concrete. The strength of concrete produced among all other factors depends on the mix ratio, water to binder ratio and method of curing. The mix ratio of concrete can be described as the proportioning method used in mixing the concrete ingredients together, which could be either by weight or volume. There are several mix ratios available depending on the grade of concrete to be achieved. Examples include 1:1:2, 1: $1^1/_2$:3, 1:2:4, 1:3:6, 1:4:8 etc. Water cement ratio has been regarded as the primary factor affecting strength of concrete, since cohesion and internal friction developed by concrete depend on it. A low value of water cement ratio is usually recommended for high strength and low permeability. However, water available is usually not enough to fully hydrate all the cement paste leading to unhydrated particles within the concrete. From many years of practice, it has been found that it is almost impossible to reduce the water cement ratio below 0.40 [8]. There are various methods available for curing of concrete which include water curing, membrane curing, application of heat etc. Curing by water in form of immersion is the most commonly used among the several methods available since it promotes hydration, eliminates shrinkage and absorption of the heat of hydration. Curing of concrete in sea water is usually necessitated in concrete production for areas where there is acute shortfall of fresh water. Most sea waters fairly have uniform composition, which is characterized by the presence 3.5 percent of soluble salt by weight. The ionic concentration of Na^+ and Cl^- are usually the highest, typically 11,000 mg/liter and 20,000 mg/liter respectively. And also sufficient amount of Mg^{2+} and SO_4^{2-} are present in 1400 mg/liter and 2700mg/liter respectively. The pH of sea water varies between 7.5-8.4 [8]. Concrete structure exposed to sea water may deteriorate as a result of the combined effect of the chemical actions of sea water constituents on cement hydration products and these lead to increase in permeability thereby making such concrete susceptible to further attack from other destructive agent. A way of reducing the permeability of concrete is by introducing microbes that are able to constantly precipitate calcite. This phenomenon is known as microbiologically induced calcium carbonate precipitation (MICCP). Microbial concrete is concrete made by mixing bacterial culture with concrete ingredient while microbial laterized concrete (MLC) can be defined as laterized concrete containing bacterial culture. This technique has been used by researchers [9-12] in time past and in recent times with far reaching recommendation in favour of it. At present only little information on MLC is available. This paper reports the results of compressive strength test on microbial laterized concrete cured in water and sea water.

2. EXPERIMENTAL

The cement used was Ordinary Portland Cement (OPC) and the fine aggregates were sharp sand and laterite which complied with BS 882: 1992 [13]. The percentage of laterite replacement with sand was varied at 0%, 20% and 40%. The coarse aggregate was 20 mm nominal size granite. The particle size distribution of sharp sand and laterite are as shown in Fig. 1. A laboratory cultured bacterium known as *Bacillus subtilis* was used at varied percentage (0%, 10% and 30%) which depends on the pre-calculated quantity of water required for each mix at a cell concentration of 10^5 colony forming unit per ml. Potable water suitable for domestic consumption was used for curing as well as sea water obtained from the Atlantic Ocean in Lagos, Nigeria.

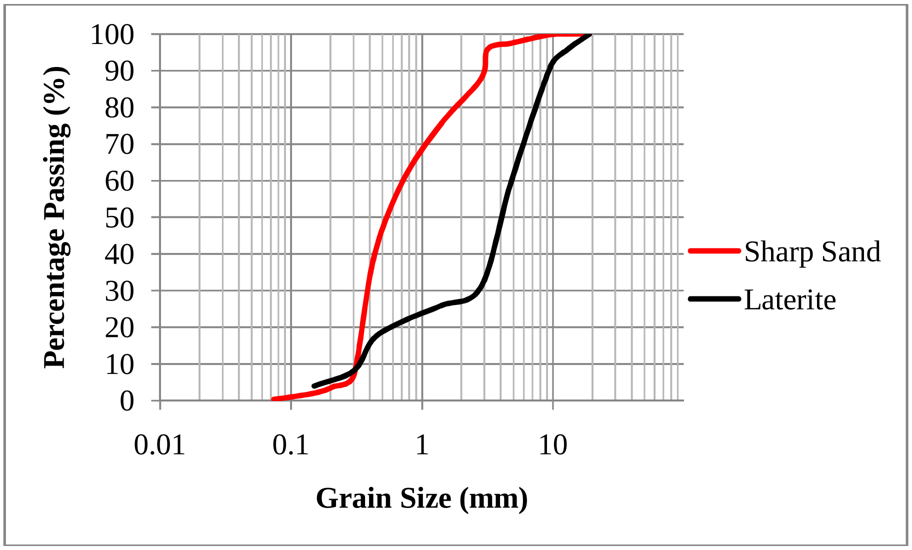

Fig. 1. Particle size distribution of sharp sand and laterite

Table 1. Details of mixtures

Mixture no.	W/B ratio	Laterite content %	Bacterial culture %	Vol. of water required (litre)	Vol. of water used (litre)	Vol. of bacteria culture used (litre)	Cement used (Kg)	Sand required (Kg)	Sand used (Kg)	Laterite used (Kg)	Granite used (kg)
M1	0.45	0	0	4.68	4.68	0	10.41	20.83	20.83	0	41.66
M2	0.50	0	0	5.21	5.21	0	10.41	20.83	20.83	0	41.66
M3	0.55	0	0	5.76	5.76	0	10.41	20.83	20.83	0	41.66
M4	0.45	0	10	4.68	12.64	1.40	10.41	20.83	20.83	0	41.66
M5	0.45	20	20	4.68	11.23	2.81	10.41	20.83	16.88	4.17	41.66
M6	0.45	40	30	4.68	9.83	4.21	10.41	20.83	12.50	8.33	41.66
M7	0.50	0	20	5.21	12.48	3.12	10.41	20.83	20.83	0	41.66
M8	0.50	20	30	5.21	10.92	4.68	10.41	20.83	16.88	4.17	41.66
M9	0.50	40	10	5.21	14.04	1.56	10.41	20.83	12.50	8.33	41.66
M10	0.55	0	30	5.76	12.04	5.16	10.41	20.83	20.83	0	41.66
M11	0.55	20	10	5.76	15.48	1.72	10.41	20.83	16.88	4.17	41.66
M12	0.55	40	20	5.76	13.76	3.44	10.41	20.83	12.50	8.33	41.66

The first three mixtures considered in this study were the control mix (CM) with proportion of 1(cement):2 (fine aggregate):4 (coarse aggregate) in with neither laterite nor bacterial culture was included. The water to binder ratio was varied at 0.45, 0.50 and 0.55 respectively. In addition nine other mixtures with same mix proportion were considered in accordance with Taguchi method of experimental design which involves the use of orthogonal array with three levels [14]. Details of all mixtures are presented on above Table 1. Considering the number of variables involved in this experiment twenty seven mixtures ought to be produced for each test age and curing medium (excluding the control mix), however, with the use of Taguchi method of experimental design, only nine mixtures were produced and the results of the other eighteen obtained in form of average compressive strength (ACS) when the orthogonal analysis is preformed on results from mixtures number four to twelve (M1-M12). Mixing was done manually and specimen cast in steel moulds. Cubes of 150 mm in size were used for the determination of compressive strength. All specimens were cast in triplicate and left in the laboratory for 24 hours. Thereafter demoulding of cubes was done and specimens were transferred into appropriate curing media: for Mixtures No. 1-3 (control mix) curing was done in water only, while for Mixtures No. 4-12 curing was done in water (W) and replicas of Mixtures No. 4-12 were also cured in sea water (SW). Testing was carried out at 7, 14 and 28 days.

3. RESULTS AND DISCUSSION

Figs. 2 and 3 show the results of the 28-day compressive strength test for the various concrete mixtures. From Fig. 2 the control mixture with water to binder ratio of 0.50 had the highest compressive strength value while for Fig. 3, it was observed that concrete (mixtures 4-12) cured in sea water had slightly higher compressive strength values than those cured in water. Since specimens cured in both media are replicas of one another, it implies that sea water can also be used for curing of concrete.

The better results obtained for concrete cured in sea water could be as a result of the presence of sodium chloride in sea water which is also responsible for the maintenance of osmotic equilibrium of the bacterial growth medium. The major reason for introducing the *Bacillus subtilis* into the concrete mix is to fill the pore structure with the microbiologically induced calcium carbonate precipitated during metabolic activities of these bacteria which reduces permeability and consequently increases compressive strength of the laterized concrete.

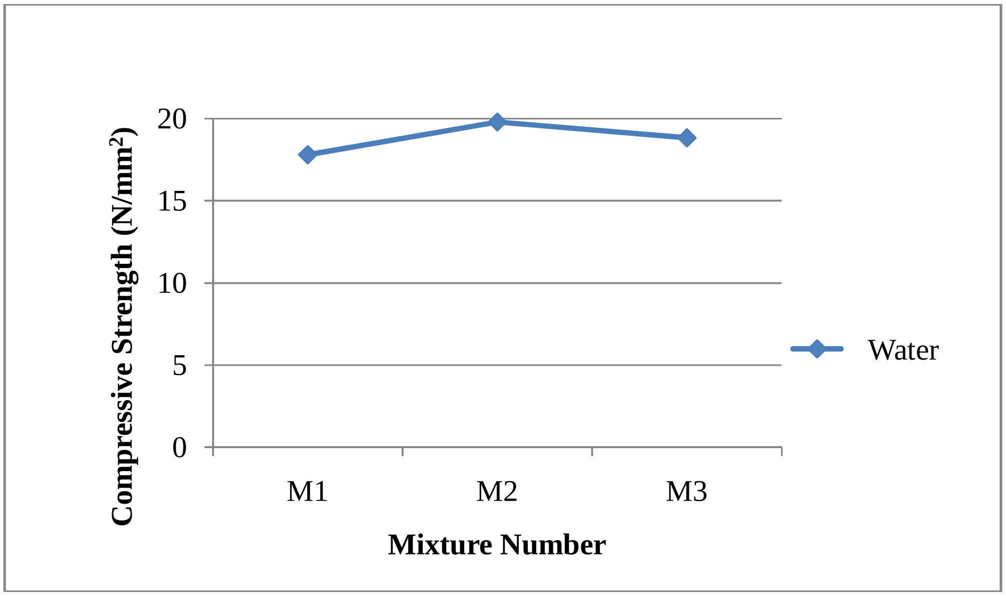

Fig. 2. Compressive strength for control mix at 28-day

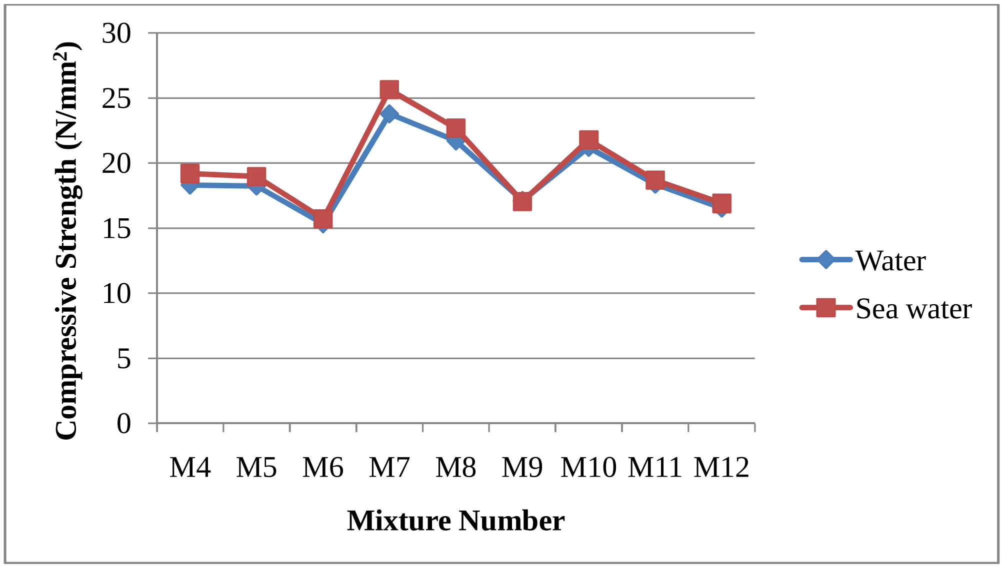

Fig. 3. Compressive strength of concrete mix cured in water and sea water at 28-day

Table 2. Results of orthogonal analysis of concrete cured in water

Mix no.	Age (days)	W/B	LAT	BC	ACS (N/mm^2)	W/B	LAT	BC	ACS (N/mm^2)	W/B	LAT	BC	ACS (N/mm^2)
		Results of all mixture that ought to be considered as obtained from orthogonal analysis performed on mixtures number 4-12											
4		0.45	0	10		0.45	0	20		0.45	0	30	
5	7	0.45	20	20	11.09	0.45	20	30	14.59	0.45	20	10	11.83
6		0.45	40	30		0.45	40	10		0.45	40	20	
7		0.5	0	20		0.5	0	30		0.5	0	10	
8	7	0.5	20	30	14.17	0.5	20	10	12.39	0.5	20	20	12.89
9		0.5	40	10		0.5	40	20		0.5	40	30	
10		0.55	0	30		0.55	0	10		0.55	0	20	
11	7	0.55	20	10	12.26	0.55	20	20	10.57	0.55	20	30	12.84
12		0.55	40	20		0.55	40	30		0.55	40	10	
4		0.45	0	10		0.45	0	20		0.45	0	30	
5	14	0.45	20	20	13.26	0.45	20	30	17.15	0.45	20	10	14.17
6		0.45	40	30		0.45	40	10		0.45	40	20	
7		0.5	0	20		0.5	0	30		0.5	0	10	
8	14	0.5	20	30	16.94	0.5	20	10	15.04	0.5	20	20	15.33
9		0.5	40	10		0.5	40	20		0.5	40	30	
10		0.55	0	30		0.55	0	10	12.73	0.55	0	20	
11	14	0.55	20	10	14.67	0.55	20	20		0.55	20	30	15.41
12		0.55	40	20		0.55	40	30		0.55	40	10	
4	28	0.45	0	10	17.28	0.45	0	20	21.08	0.45	0	30	17.93
5		0.45	20	20		0.45	20	30		0.45	20	10	
6		0.45	40	30		0.45	40	10		0.45	40	20	
7	28	0.5	0	20	20.86	0.5	0	30	19.43	0.5	0	10	19.65
8		0.5	20	30		0.5	20	10		0.5	20	20	
9		O.50	40	10		0.5	40	20		0.5	40	30	
10	28	0.55	0	30	18.69	0.55	0	10	16.47	0.55	0	20	19.41
11		0.55	20	10		0.55	20	20		0.55	20	30	
12		0.55	40	20		0.55	40	30		0.55	40	10	

W/B- Water- binder ratio; BC- Bacterial culture; LAT- Percentage of Laterite replacement for sand; ACS- Average compressive strength

Table 3. Results of orthogonal analysis for concrete cured in sea water

Mix no.	Age (days)	W/B	LAT	BC	ACS (N/mm^2)	W/B	LAT	BC	ACS (N/mm^2)	W/B	LAT	BC	ACS (N/mm^2)
		Results of all mixture that ought to be considered as obtained from orthogonal analysis performed on mixtures number 4-12											
1	7	0.45	0	10	11.92	0.45	0	20	15.31	0.45	0	30	12.52
2		0.45	20	20		0.45	20	30		0.45	20	10	
3		0.45	40	30		0.45	40	10		0.45	40	20	
4	7	0.50	0	20	15.16	0.50	0	30	13.43	0.50	0	10	13.33
5		0.50	20	30		0.50	20	10		0.50	20	20	
6		0.50	40	10		0.50	40	20		0.50	40	30	
7	7	0.55	0	30	12.81	0.55	0	10	11.16	0.55	0	20	14.05
8		0.55	20	10		0.55	20	20		0.55	20	30	
9		0.55	40	20		0.55	40	30		0.55	40	10	
1	14	0.45	0	10	13.63	0.45	0	20	18.96	0.45	0	30	14.45
2		0.45	20	20		0.45	20	30		0.45	20	10	
3		0.45	40	30		0.45	40	10		0.45	40	20	
4	14	0.50	0	20	18.59	0.50	0	30	15.31	0.50	0	10	16.84
5		0.50	20	30		0.50	20	10		0.50	20	20	
6		0.50	40	10		0.50	40	20		0.50	40	30	
7	14	0.55	0	30	15.01	0.55	0	10	13.01	0.55	0	20	16.00
8		0.55	20	10		0.55	20	20		0.55	20	30	
9		0.55	40	20		0.55	40	30		0.55	40	10	
1	28	0.45	0	10	17.95	0.45	0	20	22.2	0.45	0	30	18.30
2		0.45	20	20		0.45	20	30		0.45	20	10	
3		0.45	40	30		0.45	40	10		0.45	40	20	

Mix no.	Age (days)	W/B	LAT	BC	ACS (N/mm²)	W/B	LAT	BC	ACS (N/mm²)	W/B	LAT	BC	ACS (N/mm²)
		Results of all mixture that ought to be considered as obtained from orthogonal analysis performed on mixtures number 4-12											
4	28	0.50	0	20	21.78	0.50	0	30	20.1	0.50	0	10	20.50
5		0.50	20	30		0.50	20	10		0.50	20	20	
6		0.50	40	10		0.50	40	20		0.50	40	30	
7	28	0.55	0	30	19.11	0.55	0	10	16.54	0.55	0	20	20.05
8		0.55	20	10		0.55	20	20		0.55	20	30	
9		0.55	40	20		0.55	40	30		0.55	40	10	

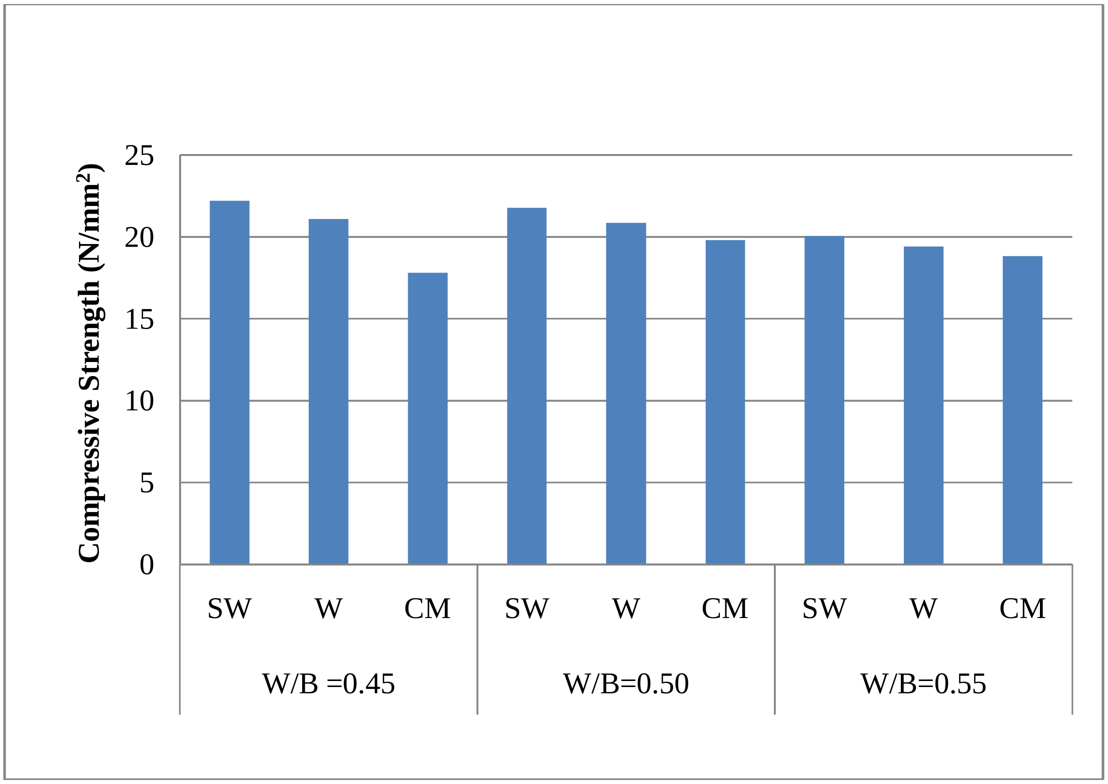

Fig. 4. Comparison of 28-day compressive strength of laterized concrete

The orthogonal analysis performed on mixtures number 4-12 produced the results in Tables 2 and 3 for water and sea water respectively. From the findings of this study, a maximum average compressive strength of 21.08 N/mm^{2}at 28-day for water/ binder ratio of 0.45 was obtained for concrete cured in water and 22.20 N/mm^2 for concrete cured in sea water. For water/cement ratio of 0.50, maximum average compressive strength of 20.87 N/mm^{2}was obtained for water and 21.78 N/mm^2 for sea water. While for water/binder ratio of 0.55, maximum average compressive strength of 19.41N/mm^2 was obtained for water and 20.05 N/mm^2 for sea water. This implies that when mixing of concrete is carried out at: 0% Laterite replacement, the volume of bacterial culture should be 20%, at 20% Laterite replacement the volume of bacterial culture should be 30% and at 40% Laterite replacement the volume of bacterial culture should be 10%. It was observed that there was an improvement in strength as shown on above Fig. 4 when the above results were compared with the 28-day compressive strength of the control mix. This observation agrees with the findings of previous researchers [9-12]. It is believed that this increase in compressive strength of concrete was caused by the treatment with bacterial cell which probably facilitated the deposition of $CaCO_3$ within the pores of concrete. The plugging of the pores enhanced impermeability and consequently the compressive strength of the concrete.

4. CONCLUSIONS

Based on the present experimental investigation, the following conclusions are drawn:

- For a microbial laterized concrete to attain maximum compressive strength, for all the water/cement ratios and curing media used in this study, the following compositions are proposed:
    - For 0% Laterite replacement the volume of bacterial culture should be 20%.
    - For 20% Laterite replacement the volume of bacterial culture should be 30%.
    - For 40% Laterite replacement the volume of bacterial culture should be 10%.
- Microbial Laterized Concrete cured in sea water had higher compressive strength when compared to those cured in water.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/12651