American Journal of Civil Engineering and Architecture, 2016, Vol. 4, No. 4, 117-124
Available online at http://pubs.sciepub.com/ajcea/4/4/2

DOI:10.12691/ajcea-4-4-2

Durability and Fire Resistance of Laterite Rock Concrete

Ephraim M. E.[1], Adoga E.A[2]., Rowland-Lato E. O.[3,*]

[1]Department of Civil Engineering, Rivers State University of Science and Technology, Port-Harcourt, Nigeria
[2]Department of Civil Engineering, Auchi Polythechnic,Auchi,Edo State , Nigeria
[3]Department of Civil Engineering, University of Port Harcourt, Port Harcourt, Nigeria
*Corresponding author: rowlandlato@yahoo.com

Abstract The ability of a structure to retain its structural integrity in adverse conditions of weather and fire out break depends on its durability and fire resistance. This research work investigated these indispensable properties in Laterite Rock Concrete to assess its usability structural concrete. Durability was investigated in terms of water absorption, density, shrinkage and fire resistance. Fire resistance test was carried out using direct fire test. Two mix proportions: 1:2:4 and 1:1½:3 were tested at optimum water/cement ratio of 0.6 and 0.55 for 1:2:4 and 1:1½:3 mixes respectively. From the results, it is concluded that the concrete is durable, environmentally compatible and possesses high fire resistance properties, having satisfied the relevant codes requirements. The 1:2:4 and 1:1½:3 conform to the specifications for grades 15 and 20 correspondingly. Recommendations include specifications for designing structural elements using the Laterite Rock Concrete.

Keywords: *durability, fire resistance, strength, concrete, laterite rock*

Cite This Article: Ephraim M. E., Adoga E.A., and Rowland-Lato E. O., “Durability and Fire Resistance of Laterite Rock Concrete.” *American Journal of Civil Engineering and Architecture*, vol. 4, no. 4 (2016): 117-124. doi: 10.12691/ajcea-4-4-2.

1. Introduction

The structural design process of concrete structures tends to lay great emphasis on the ultimate limit state of strength and buckling as well as serviceability limit states of deflection and cracking. However, economic and sustainability considerations have, in recent times, raised the issues of durability of structures to a level of a limit state in design. Indeed, many investigators hold strongly that acceptable workability, fire resistance, durability and economy are some of the most desirable qualities of a well-proportioned concrete mix [1,11,13,15,17,18,20,26].

Durability and fire resistance are central to both short and long term structural performance of concrete. The durability of concrete a measure of its ability to resist weathering and deteriorating agents; maintain its original form be serviceable and environmentally compatible. The major properties of concrete affecting its dimensional stability with time include shrinkage, characterized by volume changes in concrete due to loss of moisture at different stages and for various reasons. Researchers have shown that the quantum of an aggregate, its size, and its modulus of elasticity influence the magnitude of drying shrinkage. The use of aggregates having higher than normal shrinkage can lead to unacceptable movements in the concrete thereby increasing shrinkage and reducing the durability of the concrete [10].

The ability of the concrete surface to easily get wet and the capacity to absorb and retain water for a long time are two properties that make it vulnerable to chemical attack and environmental deterioration. Surface abrasion by rainwater has been identified as a common deterioration agent associated with water [23,27]. As water permeates the concrete, some of the hydroxides produced by the hydration of cement dissolve and migrate out of the matrix. This is a long term process that can lead to failure of the concrete as well as contamination of the environment. Therefore, the resistance to ingress of external fluids and water absorption are of primary importance for the durability and environmental compatibility of concrete in general and laterite rock concrete in particular. In this regard, Hohberg et al [17] and other authors are in agreement that concrete with dense structure, produced only with standardized and approved raw materials meeting the relevant codes does not pose a danger to the soil, water and air. Thus, the major determinant of environmental compatibility of concrete is its permeability which strongly depends on its density and water absorption. The density of LRC has been studied in the works of a handful of researchers including Akpokojie [1], Madu [22], Raju [24] among others.

Fire resistance is the capacity to retain structural integrity under fire. It is reported in literature that in industrialized countries, more than 40% of the total resources of the building industry is spent on repairs and maintenance of concrete structures parts [3, 10, 16, 23, 26].

Fire resistance of concrete is measured by the load carrying capacity of concrete under elevated temperatures, resistance to flame penetration and resistance to heat transmission. Fire generally induces high temperature gradients on materials and, as a result the hot surface layers tend to separate and spall from the cooler interior of the body [11,12,20]. Structural concrete must have adequate fire rating, expressed as its capacity to retain its structural integrity over a desired length of time. In 1999, the World Fire Statistics Centre in its study of 16 industrialised nations published that the number of people killed yearly by fires was 1 to 2 persons per 100,000 inhabitants and the total cost of fire damage amounted to 0.2 to 0.3% of gross national product (GNP) [18,20]. Numerous studies have shown that the response of concrete to high temperature its fire rating of concrete are strongly dependent on the type of aggregates used. The loss of strength is considerably lower when the aggregate does not contain silica. David and Kamara [13], in their study of the effect of high temperature on the compressive strength of concrete made with three different coarse aggregates, concluded that the strength of concrete containing siliceous aggregate begins to drop off at about 800 °F and is reduced to about 55% at 1200°F.

Concrete produced using laterite rock and sand as coarse and fine aggregates is fittingly referred to as laterite rock concrete [24,28]. This is in contrast with laterised concrete in which only the fine fraction is wholly or partially replaced with laterite fines. Laterite occurs in most parts of the world with tropical climate characterized by heavy rainfall and persistently high temperatures. The prominent regions having laterite include India, Burma, Indonesia, Malaysia, Australia, Africa and interior parts of South America [24]. In Nigeria, laterite rocks abound in most geological zones, especially 2A, B and 3A. However, the authors observe that while numerous studies are available in technical literature on the strength properties of laterized concrete and little on laterite rock concrete [1,14,17,22,24,28], there are virtually no studies on the durability and fire resistance of laterite rock concrete (LRC) [1,14,22]. Therefore, this paper presents an effort towards filling that gap.

2. Materials and Methods

The materials used for this research included laterite rock and river sand, obtained from Auchi in Edo State of Nigeria, was used as coarse and fine aggregates for the concrete mixes considered in the study . The water used was obtained from the University main supply; it is fit for drinking and conforms to BS3148 (1970). The cement was the ordinary Portland cement, produced by Dangote Cement Company and conforming to EN 196-1:1987; 196-6:1989.

The laterite rock and sand materials were air dried in the open laboratory. The laterite rock contained a reasonable proportion of large particles which were first crushed to smaller fractions and sieved. The proportion passing through the 20 mm sieve and retained on the 5 mm sieve was used as coarse fraction in all experiments. The fine aggregates comprised sand passing 5 mm and retained in 150 μm sieves. The following specimens were produced, cured and tested in the course of the investigation:

12 standard cubes of dimensions 150x150x1500 mm; 6 cylindrical specimens of diameter 150mm and height 600 mm and 60 beams of 150x75x300 mm. Two standard mixes 1:2:4 and 1:1½:3 were considered in the study and tests conducted included water absorption (BS 1881:1983), shrinkage (BS812-1999.) and fire resistance tests (BS8110 -1997).

2.1. Water Absorption Test

This test was conducted on standard laterite rock concrete cubes from 1:2:4 and 1:1½:3 mixes with water-cement ratios of 0.6 and 0.55 respectively at the ages of 28 and 365 days. The choice of water cement ratio was informed by two factors, the maximum strength and acceptable workability. The original weights of the laterite rock concrete cubes were taken at the start of the experiment. The cubes were then immersed in water for 1 hour, 24 hours, 3 days and 7 days and their weights determined after each immersion in accordance with BS1881-1983.

2.2. Shrinkage Test

This test was carried out on four laterite rock concrete cubes, two of each mix and water-cement ratios of 0.6 and 0.55 for the 1:2:4 and 1:1:½:3 respectively. The experiment was carried out for a period 365days.

Plate 1. Shrinkage Measurement with Digital Veneer Calipers

The concrete cubes were wet cured in a curing tank for 28 days, followed by open air curing in the Structural Engineering Laboratory of the Rivers State University of Science and Technology, Port Harcourt, Nigeria. The original dimensions of the cubes were taken with the aid of a digital veneer caliper of 0.01 mm precision (Plate 1). Thereafter, daily measurements were taken for 35 days and then at the end of each month for a total duration of twelve months. The weights were also taken for the purposes of tracking the variation of the densities with time. At the expiration of 1 year, the samples were put back into water in the curing tank and the dimensions as well as weights were taken after 1 hour, 24 hours, 3 days and 7 days, in accordance with BS812-1999.

2.3. Fire Resistance

A total of 60 prisms, measuring 75 x 150 x 300 mm reinforced with T10 mm diameter rods were prepared together with additional 4 beams of plain concrete of the same dimensions. The samples were wet cured for 28 days and sun dried for one day before testing. The choice of dimensions was to ensure that the specimen fits into the furnace with opening dimensions of 100x200x400 mm. Specimens of each cover and concrete mix were fired for two hours at 600 C using the temperature regulating furnace with a capacity of 1200°C. The time for the first crack to appear and final collapse of the specimen were recorded. The specimens were prepared according to the schedule shown in Table 1.

Table 1. Description of Test Specimens for Fire Resistance test

Test Parameter	Water/Cement Ratio	Mix proportion	Concrete cover	Number of samples
Firing to destruction	0.6	1:2:4	25	9
			30	9
			40	9
Tensile Test after Firing	0.55	1:1½:3	25	9
			30	9
			40	9
Firing to destruction	0.6	1:2:4	Plain	3
	0.55	1:1½:3	Plain	3

The heated specimens were brought out from the oven using steel bars and hand gloves and tested for tensile strength. Three other specimens of each cover and mix were fired to destruction and the time for the first crack to appear and the time of the final collapse of the specimen were recorded. Three other samples of each cover and mix were tested for strength without firing. Two plain samples of each mix proportion were also fired to destruction and the respective timing for first crack and final collapse taken.

3. Discussion of Results

The results of the tests conducted in this study are presented, analysed and discussed in the relevant subsections which follow.

3.1. Water Absorption Test

Water absorption property of concrete is critical to its durability and is an important consideration in the design of for water-retaining structures and other containment structures.

The results of the water absorption tests are presented in Table 2 and plotted in Figure 1.

Table 2 shows that the water absorption test results ranged from 1.46 to 3.46% and 9.52 to 17.83% for the 1:2:4 laterite rock concrete mix after 28 days and 1year respectively. The corresponding values for the 1:1½:3 mix consisted 0.78 – 1.95% and 5.35-11.13%. Hence, water absorption capacity of laterite rock concrete is low compared to the results of other researchers [1,18,22,24].

Table 2. Results of Water Absorption Test on Laterite Rock Concrete Specimen

Age of LRC (days)	Water/cement Ratio	Mix proportion	Initial Weight	Weight After Immersion (g)			
				1 hour	2hours	3 days	7 days
28	0.6	1:2:4	7.52kg	7.63	7.70	7.73	7.78
			% increase	1.46	2.39	2.79	3.46
	0.55	1:1½:3	7.70kg	7.76	7.81	7.83	7.85
			% increase	0.78	1.43	1.69	1.95
365	0.6	1:2:4	6.62kg	7.25	7.62	7.72	7.80
			% increase	9.52	15.10	16.62	17.83
	0.55	1:1½:3	7.10kg	7.48	7.76	7.83	7.89
			% increase	5.35	9.30	10.28	11.13

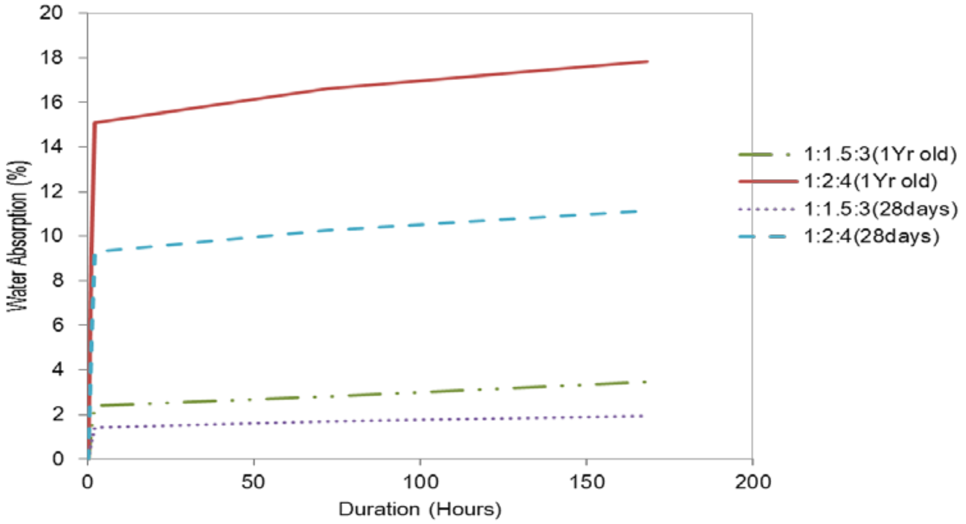

Figure 1. Plot of Variation of Water Absorption versus Duration of Immersion in Water

From Figure 1, it can be seen that the water absorption decreases with increase in age of concrete and that the 1:2:4 mix possesses a greater capacity to absorb water than the 1:1½:3 mix. About 85% of the total amount of water was absorbed within the first 2 hours, followed by a rather insignificant increase in the water absorption during the remaining days of immersion of specimen in water. The greater absorption capacity of the 1:2:4 mix over

1:1½:3 mix can be attributed to the presence of a higher percentage of coarse aggregate in the concrete matrix and lesser percentage of cement paste. Mix 1:1½:3 absorbed less water and therefore has lower permeability because the higher cement gel content prevents water from ingress into the aggregate.

A comparison with results from previous studies shows that the water absorption of Laterite Rock Concrete is slightly higher than for conventional concrete. However, the values for Laterite Rock Concrete fall within the acceptable range [18].

3.2. Environmental Compatibility

Environmental compatibility is considered here in terms of the permeability through the combination of density of laterite rock concrete and water absorption, factors which strongly affect the possibility of weathering and washing of cement based compounds as well as leaching. From the discussion of absorption results in section 2.1, it was concluded that the laterite concrete definitely possesses low water absorption. The results of density of the Laterite Rock Concrete cubes are presented in Table 3.

Table 3. Experimental Values of Density of Laterite Rock Concrete

	1:2:4mix (w/c=0.60)		1:1½:3 mix (w/c=0.55)	
Age (Days)	Density kg/m^3	Compressive strength N/mm^2	Density kg/m^3	Compressive strength N/mm^2
7	2279	9.46	2430	12.60
14	2271	14.01	2412	16.43
21	2236	17.47	2390	20.80
28	2210	18.69	2387	22.88

From Table 3, it can be seen that the density of laterite rock concrete reduces with increasing age of concrete. The data of Table 3 further shows that the aggregate/cement (a/c) ratio has a significant effect on density of laterite rock concrete. The 1:2:4 mix with aggregate/cement ratio of 6 had an average density of 22 kN/m^3, while 1:1½:3 mix with aggregate/cement ratio of 4.5 had an average density of 24kN/m^3, same as for normal conventional granite concrete. In accordance with BS5238 (1997), part1, concrete with densities between 20 kN/m^3 and 26 kN/m^3 are classified under normal weight concrete. The obtained experimental values agree with those declared by Madu [ ], Raju [ ], Akpokodje [ ]. Akpokodje et al [1] gave the density in kg/m^3 for laterite concrete based on laterite rock from various parts of Nigeria as follows: Ngbo – 2472, Jos 2424, Nsukka 2435, Enugu 2394, Wudil 2398, Bukuna 2192, Ilorin 2351, Maiduguri 2246, Okene 2344.

From the above results, it can be concluded that the water absorption and density of laterite concrete compare favourably with that of normal dense concrete. Therefore, agreeing with Hohberg et al [12] and other authors, it can be concluded that laterite rock concrete does not pose any danger to the soil, water and air [17]. And, this confirms the environmental compatibility and sustainability laterite rock concrete.

3.3. Shrinkage Test

Volume change is one of the most detrimental properties of concrete, which affects the long-term strength and durability. The commonest manifestation is the appearance of unsightly cracks in concrete.

The observed values of shrinkage for the 1:2:4 and 1:1½:3 mixes are presented in Appendix 1, while Figure 2 and Figure 3 show the plots of linear shrinkage and volumetric shrinkage versus time respectively. It can be observed from the plots that the shrinkage of laterite rock concrete increases rapidly and linearly in the duration of the first 35 days. A similar trend was observed for volumetric shrinkage, which gave a maximum value of 4.1x10^{-4} percent of the original volume in first 35 days and 2.0x10^{-3} percent in 1 year.

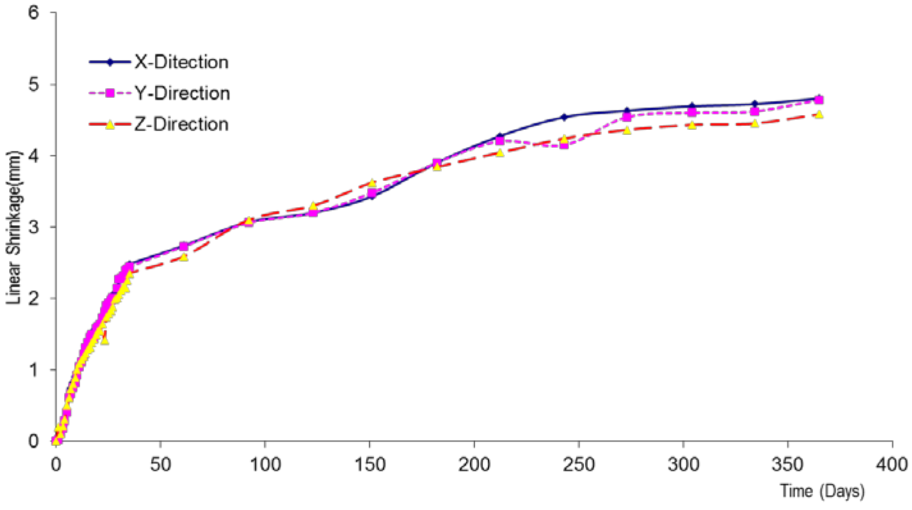

Figure 2. Relationship between linear shrinkage and time

The summary of observations by other researchers confirms the above trend of rapid decrease of the rate of shrinkage with time after 35 days of drying exposure. Authoritative reference [23] specifically show that about 14 to 34 per cent of the 20 - year shrinkage occurs in 2 weeks, 40 to 80 per cent of the 20 - year shrinkage occurs in 3 months and 66 to 85 per cent of the 20 - year shrinkage occurs in one year.

The ultimate volumetric shrinkage S_{ult} can be predicted in accordance with formula in ACI 209R-92

$$S_{ult} = S_t\left(\frac{35+t}{t}\right) = 106.67mm^3.$$

The predicted ultimate shrinkage is less than the corresponding values indicated in international standards including BS8110-2, 1985.

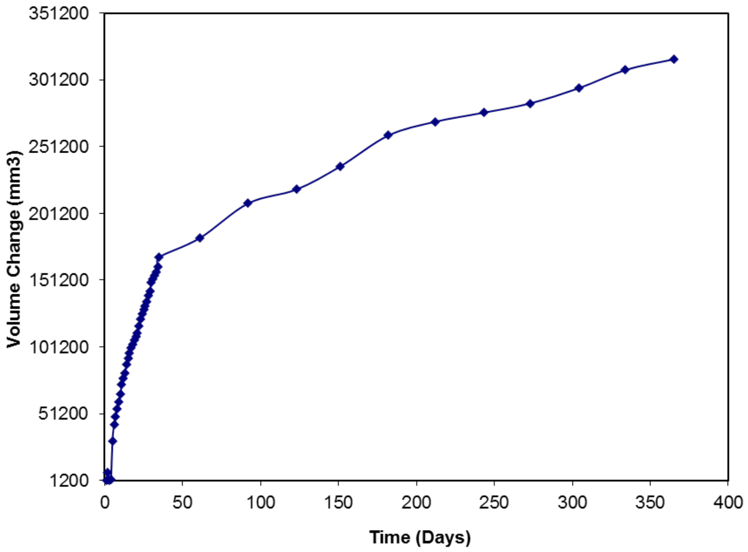

Figure 3. Relationship between volumetric shrinkage and age

3.4. Fire Resistance

The results of the fire resistance tests are presented in Appendix II. The variations of tensile strength with concrete cover for unfired and fired specimens are graphically represented in Figure 4 and Figure 5. The relationships show that, a higher the concrete cover corresponded to a lower strength in the unfired condition, the concrete being left to withstand the tensile thermal stresses alone without the participation of the reinforcement. However, the reverse was observed to be the case in the fired specimens where lighter cover permitted heat into the steel, which allows the concrete to crack faster leading eventually to the lower strength recorded.

In Table 4, the values of the retained strength for both 1:2:4 and 1:1½:3 mixes appear to be in the same range of above 90% but slightly lower for 1:1½:3.

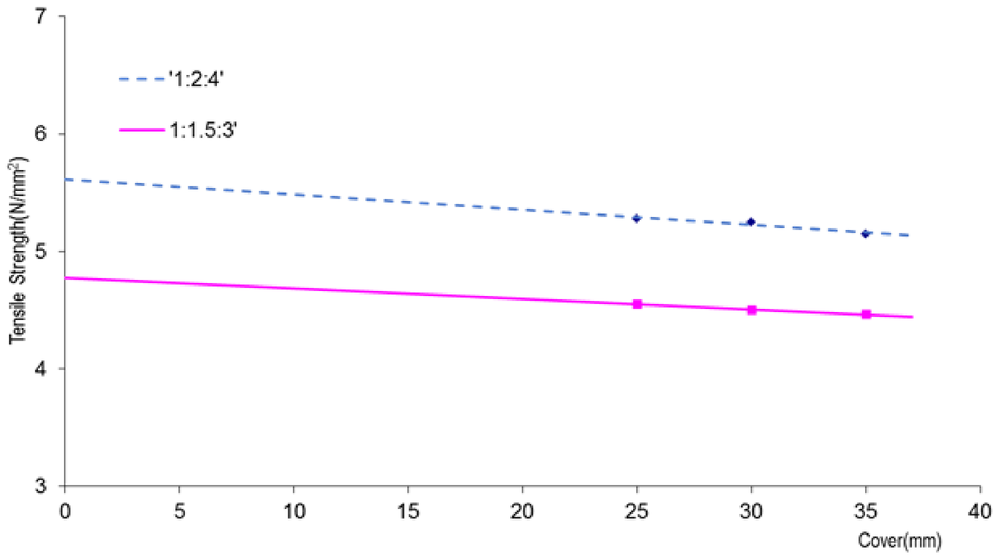

Figure 4. Relationship between strength and cover to reinforcement (unfired)

Table 4. Ratio of Fired and Unfired LRC

Mix proportion	Concrete cover	Unfired strength N/mm^2	Fired strength N/mm^2	Ratio of fired to unfired strength	Strength retained %
1:2:4 (A)	25	5.28	4.82	0.91	91
	30	5.25	5.00	0.95	95
	35	5.15	5.05	0.98	98
1:1½:3 (B)	25	4.55	4.15	0.91	91
	30	4.50	4.25	0.94	94
	35	4.46	4.28	0.96	96

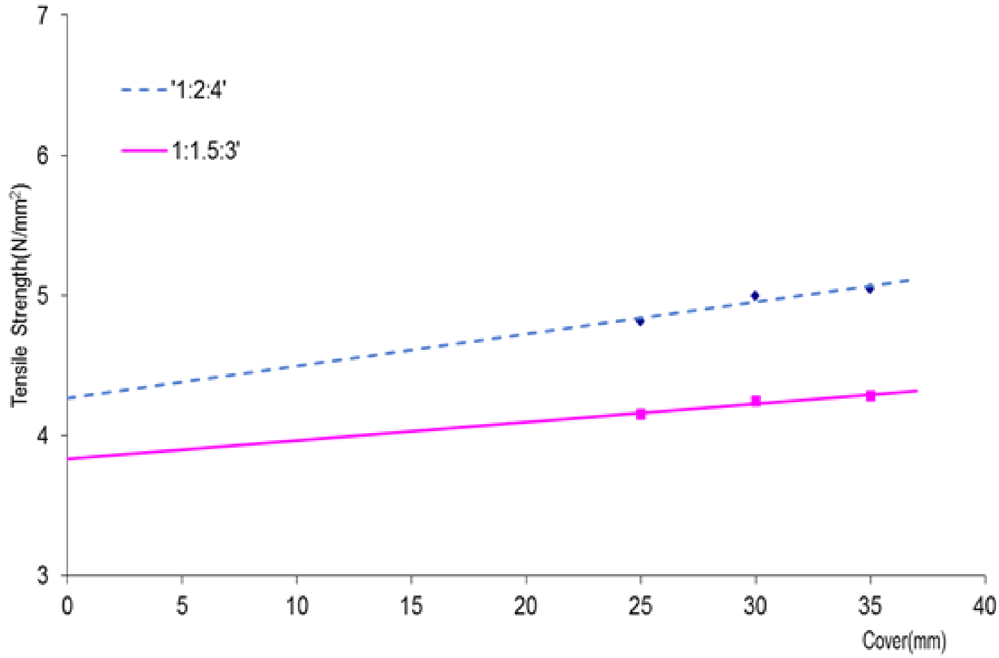

Figure 5. The relationship between strength and cover to reinforcement (fired)

Figure 6 shows the relationship between cover and time of first crack. From the plot, it is observed that both 1:2:4 and 1:1½:3 mixes have about the same slope. The 1:2: 4 mix gives an intercept of 10 mm on the vertical (cover) axis while the 1:1½:3 mix gives an intercept of 11.5 mm. It follows then that for zero hour fire resistance, the cover for the 1:2:4 mix is equal to 10 mm with a corresponding value of 11.5 mm for a 1:1½:3.

From the Figure 6, the following linear relationship between concrete cover and time of first crack can be deduced

$$C = u + kt \quad (1)$$

Where C = cover in mm; u = the intercept represent the minimum cover (10 mm for grade15 and 12 mm for grade 20 respectively); k = constant obtained from the slope of the graph (6 for grade15 and 6.5 for grade 20 respectively); t = time in hours.

Using equation 1, for 1:2:4 mix, 1hour fire resistance gives a cover of 16mm which is less than 20 mm recommended in Table 3.4 of BS.8110 part 1 (1997).

Therefore, to meet the recommended BS standard requirement, for designing with LRC, a factor of safety of 20/16 =1.25 is required. However, adopting a more convenient value of 1.5, equation 1 becomes:

$$C = 1.5(u + kt) \quad (2)$$

Using equation 2 and other practical considerations, the values of concrete cover for laterite rock concrete were computed. These are presented in Table 5.

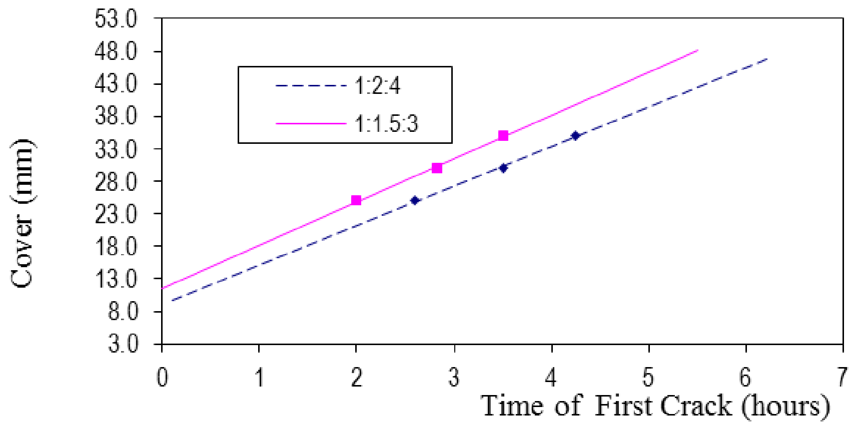

Figure 6. Relationship between cover and time of first crack

4. Conclusion

On the basis of the analysis of the laboratory test results obtained in this study, the following conclusions and recommendations can be drawn in respect of laterite rock concrete.

1. From Ephraim et all (14), Laterite Rock Concrete has an appreciable characteristic strength of 18.69 N/m^2 for 1:2:4 mix at w/c of 0.60 and 22.88 N/mm^2 for 1:1½:3 at w/c of 0.55. The abrasion value of 26.48% satisfies the BS EN12620 part 1 standard which recommends a value not more 45% for concrete wearing surface. It is therefore classified as structural concrete.

2. Laterite rock concrete possesses high density and low water absorption. Its low permeability would not permit the release of cement based compounds that may arise from leaching when in contact with the soil. Thus, laterite rock concrete is environmentally compatible.
3. The ultimate volumetric shrinkage of laterite rock concrete is lower than that given by BS 6073 (1982) for conventional concrete. The material is therefore stable in long tern application.
4. Laterite rock concrete has a relatively high fire resistance capacity of 4.25 hours. The variation of cover with time of first crack is practically linear which compares to similar trend for conventional concrete.

From the results of the study, the following recommendations can be made:

a. Laterite Rock Concrete is suitable for general structural applications and especially for erosion control by virtue of high density and low water absorption. Its impact resistance capacity makes it suitable for floors subjected to impact loads.
b. Its good fire resistance quality makes it suitable kitchens (even where fuel woods are used).
   The recommended values of concrete cover for LRC is presented here as Table 5.

Table 5. Computed Values of Cover to Reinforcement for Laterite Rock Concrete

Type	Fire Resistance (h)	Nominal cover (mm)						
		Beam		Floor		Ribs		Column
		Simply supported	Continuous	Simply supported	Continuous	Simply supported	Continuous	
A	0.5	20	20	20	20	20	20	20
B	0.5	25	25	25	25	25	25	25
A	1.0	25	25	25	25	25	25	25
B	1.0	30	30	30	30	35	25	25
A	1.5	30	30	30	30	35	25	25
B	1.5	35	35	35	35	40	30	30
A	2.0	30	25	30	25	35	30	25
B	2.0	40	30	35	30	40	35	30
A	3.0	40	30	30	30	40	30	25
B	3,0	45	35	35	35	45	35	30
A	4,0	50	40	40	40	50	40	25
B	4.0	55	45	45	45	55	45	30

c. More studies are recommended into the possibility of developing high strength Laterite Rock Concrete.

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APPENDIX I. Experimental Values of Linear Shrinkage (mm)

Direction	Linear Shrinkage (mm) for days								
	1	2	3	4	5	6	7	8	9
X	0.02	0.10	0.2	0.29	0.43	0.62	0.74	0.83	0.12
Y	0.02	0.10	0.19	0.29	0.40	0.61	0.66	0.25	0.82
Z	0.20	0.10	0.21	0.31	0.50	0.61	0.73	0.81	0.89
Direction	Linear Shrinkage (mm) for days								
	10	11	12	13	14	15	16	17	18
X	0.94	1.04	1.13	1.16	1.31	1.38	1.46	1.51	1.55
Y	0.93	1.05	1.11	1.22	1.31	1.38	1.46	1.50	1.43
Z	1.0	1.09	1.14	1.19	1.23	1.28	1.32	1.38	1.43
Direction	Linear Shrinkage (mm) for days								
	19	20	21	22	23	24	25	26	27
X	1.59	1.63	1.66	1.74	1.83	1.90	1.94	1.98	2.03
Y	1.58	1.61	1.64	1.73	1.82	1.90	1.94	1.98	1.01
Z	1.49	1.54	1.59	1.64	1.41	1.74	1.78	1.83	1.88
Direction									
	28	29	30	31	32	33	34	35	61
X	2.08	2.14	2.25	2.30	2.34	2.39	2.44	2.48	2.74
Y	2.01	2.14	2.27	2.28	2.32	2.39	2.41	2.445	2.73
Z	1.99	2.01	2.05	2.11	2.16	2.14	2.25	2.35	2.59
Direction	Linear Shrinkage (mm) for days								
	92	123	151	182	212	243	273	304	334
X	3.07	3.20	3.43	3.90	4.27	4.54	4.63	4.69	4.72
Y	3.06	3.20	3.48	3.90	4.20	4.15	4.54	4.60	4.62
Z	3.10	3.30	3.62	3.84	4.04	4.24	4.36	4.43	4.45
Direction	Linear Shrinkage (mm) for days								
	365								
X	4.80								
Y	4.78								
Z	4.58								

Volumetric Shrinkage (mm^3)

Days	1	2	3	4	5	6	7	8
Shrinkage	1384	6916	11755	20493	30597	45028	48910	68573
Days	9	10	11	12	13	14	15	16
Shrinkage	37475	65796	50124	77399	81715	88066	92373	96902
Days	17	18	19	20	21	22	23	24
Shrinkage	100298	108214	103013	107536	111601	96018	99187	126252
Days	25	26	27	28	29	30	31	32
Shrinkage	128953	131877	134800	94499	143109	149385	151850	154985
Days	30	34	35	61	92	123	151	182
Shrinkage	157221	163487	165273	182666	208649	219049	245495	257557
Days	212	243	273	304	334	365		
Shrinkage	271786	277248	283577	294906	308591	316612		

APPENDIX II. Experimental Results of Fire Resistance Tests

Water / Cement Ratio	Mix proportion	Concrete cover	Unfired Strength N/mm^2	Fired strength N/mm^2	Time of first crack	Time of collapse
0.6	1:2:4	25	5.28	4.82	3hrs	4hrs 25min
		30	5.25	5.00	3hrs 30 min	4hrs 50min
		35	5.15	5.05	4hrs 15min	5hrs 30min
0.55	1:1½:3	25	4.55	4.15	2hrs 30min	3hrs 45min
		30	4.50	4.25	2hrs 50min	4hrs 15min
		35	4.46	4.28	3hrs 30min	5hrs
0.6	1:2:4	Plain	N.A	N.A	5hrs 25min	6hrs 30mins
	1:1½:3	Plain	N.A	N.A	5hrs	6hrs 10mins