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Structural Design Specifications for Concrete Made with Laterite Rock as Coarse Aggregates

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Abstract:
The suitability of Laterite rock aggregate from various geological locations has been investigated in several works as possible alternative to crushed rock granite and gravels. However, there are no unified specifications of laterite rock aggregate for application in design and constructions. This work is therefore intended to provide basic parameters used in the design of laterite rock concrete for beams and other structural works. The experimental procedure conforms with the BS and ASTM standards for testing of materials. Parameters investigated on in this work includes but not limited to physical properties such as PSD, specific gravity, density etc. chemical properties; the flow-ability of laterite rock concrete in its wet state, the compressive, splitting tensile strengths and rate of absorption of water and the stress/ strain relationship were determined in its hardened state. Results showed that an average compressive strength of 15 N/mm^{2}is adequate for use in minor structural works. It was also computed that the splitting tensile strength approximate to about 10% of the compressive strength. However, the water absorption rate is least in the highest grade of LRC of 1:1:2 and the designed mix of 1:1.35:3.15 possesses high propensity of water absorption. A maximum of 10.92%, 12.02%, 11.12% and 10.24% for the four mixes were computed respectively for the four mixes investigated on. And the splitting tensile relationship with compressive strength of LRC for the mixes at 28 days of curing showed progressive increase with respect to the strength of the LRC. Hence concrete made with 1:1:2 has higher resilience to abrasive forces/ action.

Keywords: *Laterite rock aggregate (LRA), Laterite rock concrete (LRC),compressive strength, age, water/cement ratio (w/c), slump, specific gravity, density, workability, splitting tensile strength, durability, water absorption rate, and stress-strain of LRC.*

1. Background of Study

Housing infrastructure deficit and the need for affordable and sustainable housing for the growing population is a topical issue. Several governments have delved into providing affordable and sustainable housing for all in each development plan, yet the success has been challenging. This however, is attributable to the inflationary trend and high cost of conventional construction materials which impacts negatively on the provision of affordable and sustainable houses for the citizenry. This necessitated the search for alternative materials that are locally available. Very copious research works on the use of locally available laterite material in partial replacement for sand as fine aggregates have been carried out by Adepegba (1975,1977); Salau (2003). Further studies on the search for alternate locally available materials include the work of Ukpata et al (2012) by using quarry dust as partial replacement of river sand in a sliding scale of 0 – 25 – 50 – 75 - 100%. Studies on the replacement of coarse granite by rock laterite received attention in recent researches. These include; Madu (1992); Okoli (1987), Amobi (1992), Akpokoje (1992) on the suitability of laterite rock concrete in structural works, and the investigation of the strength performance of laterite concrete by Udoeyo *et al,* (2006). Further study by Ephraim and Adoga (2016), on the strength of laterite rock concrete gave a clear indication of the suitability of LRC in structural works, because the compressive strength is within that of normal or conventional concrete.

2. Materials and Methods

Structural study of concrete made with laterite rock aggregates as an alternative to granite rock, chippings is intended to establish some basic parameters of this material used in design and specification of laterite rock concrete. The absolute volume method of design was used to determine the proportions in which the ingredients are required for 1m^3 of concrete, aimed at achieving a minimum cube strength of 15 N/mm^2 at 28 days curing for use in both plain and structural works. Through this design approach, the formula below determines the composition of materials used for production of 1m^3 of laterite rock concrete.

$$\frac{C}{1000\gamma_c} + \frac{A_{lf}}{1000\gamma_{lf}} + \frac{A_{Lr}}{1000\gamma_{Lr}} + \frac{W}{1000\gamma_w} = 1\,m^3 \text{ of LRC} \qquad (1)$$

Materials used for this study were water, cement and laterite rock aggregates. The following parameters were investigated using various BS and ASTM Standards as listed below;

1. Particle size distribution properties.
2. Specific gravity.
3. Density of Laterite Concrete.
4. Chemical properties of Laterite Rock Aggregate.
5. Workability of Fresh Laterite Rock Concrete.
6. Compressive Strength of Hardened Concrete.
7. Splitting Tensile Strengths.
8. Mean Stress/ strain relationship of LRC Mixes.
9. Rate of water absorption.

3. Results and Discussion

Comparative Particle Size Distribution of LR Aggregates/ River Sand Fine/ Crushed Granite. Figure 1 shows the particle size distribution of laterite fine and Laterite Rock by Okoli and all in-aggregate size distribution by Asigo. Also shown is the particle size distribution of fine river sand and crushed granite. The behaviour of these distributions is similar in characteristics, which is indicative of their structural applicability and interchangeability. The sieve analysis for each of the sample was carried out using the decantation method as specified in BS 812. It is clearly shown that the coarse Laterite or crushed stone/granite was retained on sieve not less than 5mm which was worked as a percentage of the overall weight of the samples used. Equally, the Laterite fines and fine river sand were between 0.05 to 4.75mm, which ranges from fine to medium of sand and partly fine gravel. Studies have shown a correlation of the material properties used in the production of NC and LRC. This is depicted in the particle size distribution of these materials. The particle size grading of wet and dry laterite fines; Rivers sand fines; All-in-aggregates; Laterite rock and Crushed granite is shown in Table 1 and plotted in Fig. 1Curves I and II are the gradation of wet and dry laterite fines which compares favourably with the curve III for River sand fines. All of these curves terminated at 100% passing with a maximum size of about 4.75mm which is in agreement with BS 812.

The Figure further showed a plot of all-in-aggregate where both Laterite fines and rock were sieved together using the decantation method. This curve indicated that the Laterite fines stop at about 5mm size and progress further to 37.5mm; while other independent studies on Laterite rock and crushed granite gradation showed that the curves propagated from 5mm particle size to a maximum of 19mm particle size at 100% passing. The orientation of these curves are similar, hence interchangeability is quite possible.

All in-aggregate		**Wet Laterite**		**Dry Laterite**		**River Sand**		**Rock Laterite**		**Crushed granite**	
% Passing	**Particle size mm**	**% Passing**	**Particle size mm**	**% Passing**	**Particle size mm**	**% Passing**	**Particle size mm**	**% Passing**	**Particle Size mm**	**% Passing**	**Particle size mm**
100.00	37.50	100.00	5.00	100.00	19.00	100.00	19.00	100.00	5.00	100.00	5.00
99.80	20.00	84.00	2.00	75.00	13.20	75.00	13.20	73.00	2.00	100.00	2.00
78.30	14.00	66.00	1.00	38.00	9.50	35.00	9.50	53.00	1.00	68.00	1.20
49.80	10.00	53.00	0.75	0.00	4.75	0.00	4.75	35.00	0.70	49.00	0.60
31.40	6.30	44.00	0.50					18.00	0.50	22.00	0.30
29.20	5.00	36.00	0.20					6.00	0.20	1.00	0.20
15.60	2.36										
7.20	1.18										
4.50	0.85										
2.50	0.60										
0.60	0.30										
0.30	0.15										
0.20	0.075										

Table 1: Particle Size Distribution of Laterite Fine/Rock and Crushed granite

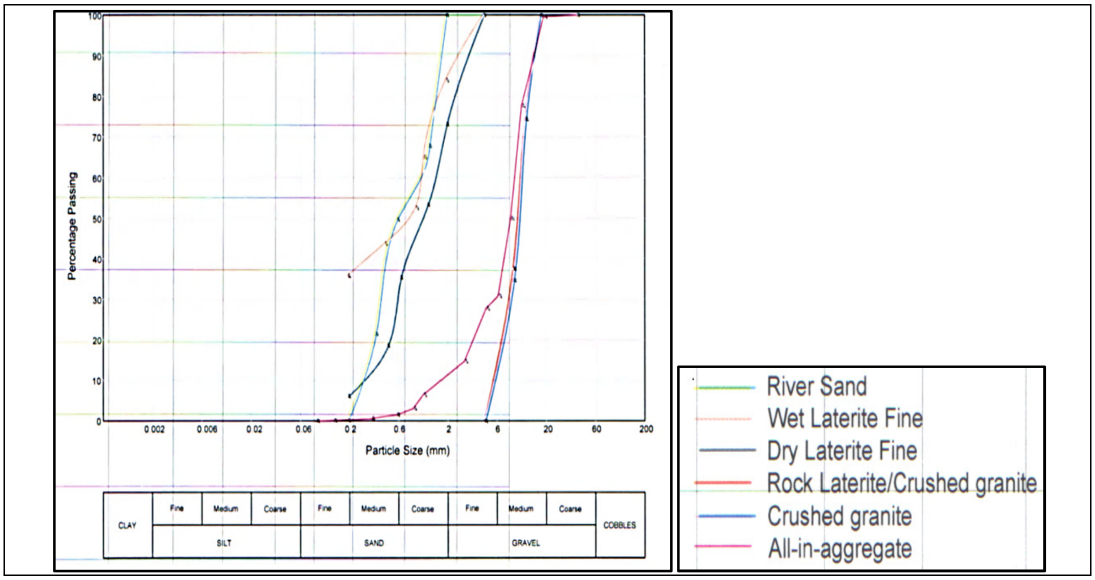

Figure 1: Particle size distribution curve for Laterite fines (wet and dry) River sand, Laterite rock and Crushed granite

3.1. Specific Gravity of Laterite Rock Concrete

Studies from ten different works were evaluated and their mean values, standard deviation and the variability from various locations across the country were determined as follows:

Mean Value = 2.81
Standard deviation σ = 0.1205
Co-efficient of variation V = 0.042

3.2. Density of Laterite Rock Concrete

Various studies on this material had shown varying ranges of densities for different locations across the country. Data available so far from four major studies have been used to determine a mean value of the density of Laterite rock concrete.

Mix	**1:2:4**	**1:1.35:3.15**	**1:1.5:3**	**1:1:2**
w/c	1.10	0.85	0.85	0.65
Density (KN/m^3)	2356.09	2429.4	2476.05	2491.34

Table 2: Density of LR Concrete From Three Prescribed/ Designed Mix Proportions

Table above showed that the density of laterite rock aggregate varies with water/cement ratio and it is maximum at optimum water/cement ratio of 1.10, 0.85, 0.85, and 0.65 respectively for 1:2:4, 1:1.35:3.15, 1:1.5:3 and 1:1:2. From the results, it can be concluded that the amount of water in the mix, dictates the cement paste during hydration, the voids and affects the strength of the resulting concrete. This is indicative of the critical role of water/cement ratio in the overall performance of concrete. It is shown that in each mix proportion, the lower the w/c ratio, the higher the density of the LRC since voids are minimal due to excess cement paste.

3.3. Chemical Properties of Laterite Rock Aggregate

The Table below shows the chemical properties of laterite rock aggregate from various works and it was observed that the rock laterite aggregate are made of Silica, Alumina and Ferrite.

Compound	**Okoli**	**Amobi**	**Mean**
	%	%	%
Silica (SiO_2)	67.00	66.80	66.90
Alumina (Al_2O_3)	16.65	16.15	16.40
Ferrite (Fe_2O_3)	8.65	9.55	9.10
Titanium Oxide (TiO_2)	0.55	0.65	0.60
Magnesium Oxide (MgO)	0.08	0.12	0.10
Potassium Oxide (K_2O)	0.25	0.26	0.255
Calcium hydroxide (CaOH)	1.00	1.10	1.05
Sulphur trioxide (SO_3)	0.35	0.25	0.30
Organic Impurities	0.02	0.03	0.025
Ignition loss	5.60	5.07	5.34

Table 3: Mean chemical properties of Laterite Rock Aggregate

3.4. Workability of Fresh LRC with Water/Cement Ratio

Concrete must always be made to be workable, that is, consistent and plastic. Workability is a measure of the ease with which the concrete is placed, consolidated or compacted for a finished concrete work. Consistency on the other hand is the ability of a freshly mixed concrete to flow, while plasticity determines the mould ability of the concrete. The presence of more aggregates and less water result to stiff concrete, that is, less plastic mix which is less workable and difficult to mould.

	Slump (mm)			
Proportion	1:2:4	1:1.35:3.3	1:1.5:3	1:1:2
Water/Cement				
0.65				56
0.75		25	15	100
0.85	3	60	41	163
0.95	18	160	136	
1.05	38			
1.15	70			
1.25				

Table 4: W/C Ratio and Slump of LRC for Prescribed/ Designed Mixes

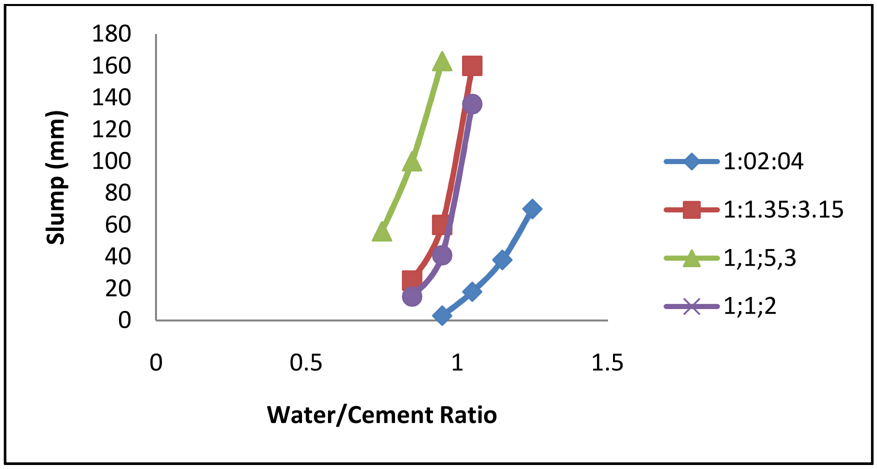

Figure 2: Relationship between Slump and W/ C Ratio of LRC

The laboratory values of slump for four typical mixes of LRC are stated in Table 4 above and plotted in Figure 2. The graph illustrates the relationship between slump (workability) of laterite rock concrete and water/cement ratio for the various mix proportions obtained from experimental tests conducted in this study. The plot showed that the workability, consistency and plasticity of LRC increase within a range 0.65 – 0.85 for 1:1:2 mix, water/cement ratio of 0.75 – 0.95 for 1:1.35:3.15 and 1:1.5:3 mixes and 0.95 – 1.15 for 1:2:4 mix. Within these intervals the slump was observed to fall in the sheared slump. Beyond these ranges the slump predominantly collapses, slump accompanied by bleeding of the LRC, where the cement paste is bled out of the mixture resulting to weak concrete. This behavior however, is also a characteristic of normal concrete (NC). It was observed that there is no correlation between the slump of the various mix proportions used empirically. Yet obviously, the graph showed a trend of behavior in terms of measuring workability of LRC with respect to the water/cement ratios.

The following are therefore recommended for achievement LRC with compressive strengths suitable for structural works in buildings for the four mix proportions considered.

The relationship between slump and w/c ratio of LRC for the mix proportion of 1:2:4, 1:1.35:3.15, 1:1.5:3 and 1:1:2 showed that, lower water/cement ratio produces higher compressive strength of Laterite Rock aggregate concrete.

3.5. Dependence of Compressive Strength with Water/ Cement Ratio

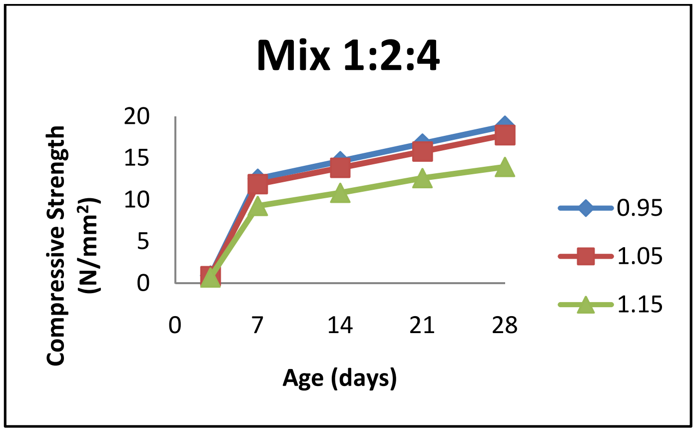

Figure 3a: Relationship between Compressive Strength and Age for different w/c ratios

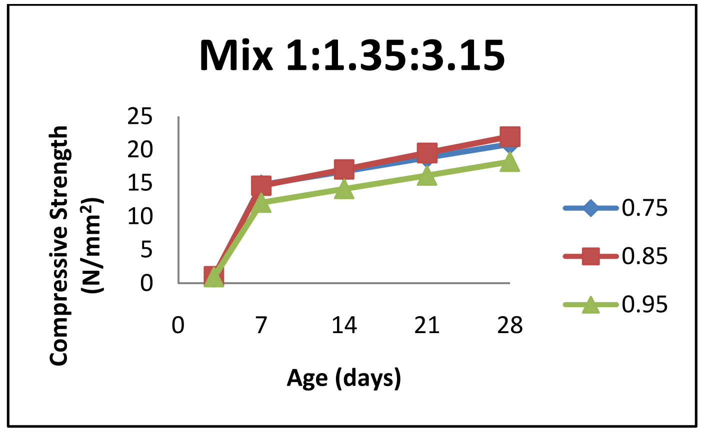

Figure 3b: Relationship between Compressive Strength and Age for different w/c ratios

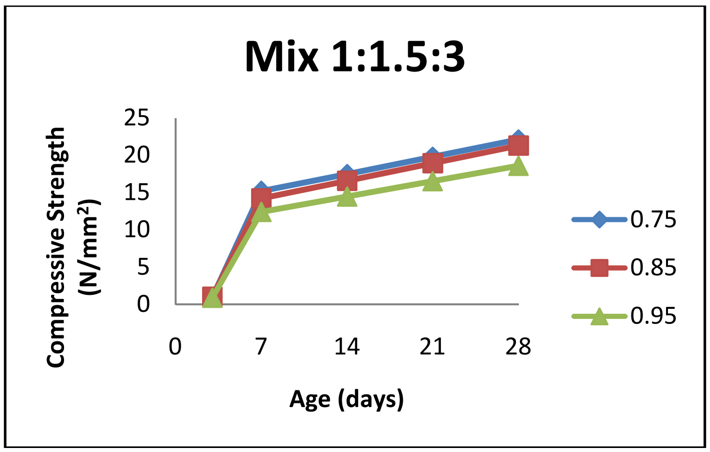

Figure 3c: Relationship between Compressive Strength and Age for different w/c ratios

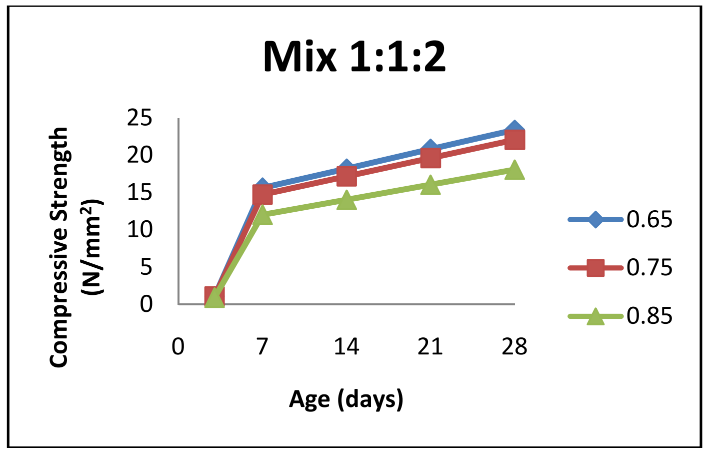

Figure 3d: Relationship between Compressive Strength and Age for different w/c ratios

Figures 3a, 3b, 3c and 3d are plots of compressive strength for various durations of wet curing and w/c ratios for prescribed/designed mixes of LRC. For 1:2:4 mix the maximum 28 days compressive strength at various water/cement ratios is below 20 N/mm^2. The optimum water/cement ratio observed from strength perspective is 0.95, below which the concrete is too dry making it to be stiff, non-plastic and difficult to mould. From workability point of view a water/cement ratio of 1.15 is desirable, beyond which the concrete becomes too wet and collapses. Hence a water/cement ratio of 1.05 is recommended if this proportion is to be used.

W/c ratio	Compressive Strength (N/mm^2)				
	3days	7days	14days	21days	28days
0.95	0.9	12.53	14.63	16.73	18.83
1.05	0.84	11.87	13.83	15.79	17.75
1.15	0.67	9.27	10.83	12.59	13.95

Table 5a: Compressive Strength, W/C ratio with age for mix 1:2:4

The graphs for 1:1.35:3.15 and 1:1.5:3 mixes show that a water/cement ratio of 0.75 would produce a concrete too dry that cannot be considered for concrete works. The least water/cement ratio required which can produce a strength comparable with normal concrete is 0.95. However, for minor jobs, a water/cement ratio of 0.85 could equally be used and decreases with higher water/cement ratio till it becomes too wet and collapse.

W/c ratio	Compressive Strength (N/mm^2)				
	3days	7days	14days	21days	28days
0.75	0.87	14.73	16.76	18.79	20.82
0.85	1.05	14.6	17.05	19.5	21.95
0.95	0.87	12.07	14.1	16.13	18.16

Table 5b: Compressive Strength of LRC W/C ratio with age for mix 1:1.35:3.15.

Fig. 3d for 1:1:2 showed similar characteristics as for the other mix proportions earlier discussed. To achieve maximum strength at 28days for LRC by weight, a water/cement ratio of 0.65 is required however; the slump relationship revealed a ratio of 0.75 from workability perspective hence, any water/cement ratio lower than 0.75 may lead to segregation of the LRC. Concrete becoming too stiff to flow and mould to shape, though may produce higher strength characteristics. And equally observed is the fact that for workability of the LRC made with this mix proportion, 0.85 suffices and that beyond this, the LRC becomes too wet and collapses.

W/c ratio	**Compressive Strength (N/mm^2)**				
	3days	7days	14days	21days	28days
0.75	0.99	15.17	17.48	19.79	22.1
0.85	1.02	14.2	16.57	18.94	21.31
0.95	0.89	12.4	14.47	16.53	18.6

Table 5c: Compressive Strength of LRC W/C ratio with age for mix 1:1.5:3

	Compressive Strength (N/mm^2)				
W/c ratio	3days	7days	14days	21days	28days
0.65	1.11	15.6	18.2	20.8	23.4
0.75	1.05	14.73	17.18	19.63	22.08
0.85	0.87	12.0	14.03	16.06	18.09

Table 5d: Compressive Strength of LRC W/C ratio with age for mix 1:1:2

Table 5b, 5c and the corresponding Fig 3b and Fig. 5c for mix proportion at 28days curing showed that the strength of the Laterite Rock Concrete decreases with increase in the w/c ratio of 1.05 and 1.15 which gave lower strengths, hence lower grades of LRC concrete which can be used as blinding concrete that is non-structural works. W/C ratios between 0.75 and 0.95 produced higher strength for LRC. Considering workability, segregation and bleeding of LRC, a w/c ratio of 0.85 is quite appropriate to produce strength above 20N/mm^2, using 1:1.35:3.15 and 1:1.5:3 mix proportion at 28days. Table 5d and Fig 3d is a representation of the behavior of compressive strength of LRC with w/c ratio and age of curing for 1:1:2 mix proportion. The plots showed that higher strength develops with lower w/c ratio but will be too dry. Thus, inhibits compaction and produces segregated concrete, and no proper bonding. In this mix proportion, a w/c ratio of 0.75 would suffice to produce concrete strength of 19.625N/mm^2 which can be used for structural works such as lintel and minor partitions in buildings.

Table 5a and Fig. 3a showed the relationship between the effect of w/c ratio on the compressive strength of LRC with age of curing and they clearly explained the behaviour that w/c ratio lower than 0.95 will make the concrete to be too dry, hence leads to segregation; and W/C higher than 1.15 leads to bleeding where the cement paste is reduced, thus lower strength.

The plot shows, that a W/C of 1.05 would be quite amenable to produce concrete strength of about 17.9N/mm^2. This strength and mix proportion is not quite good for structural works but can be used as mass concrete. At 28 days for minor jobs, a w/c ratio of 0.85 could equally be used and decreases with higher w/c ratio till it becomes too wet and collapse.

3.6. Tensile strength of LRC/Age

Table 6 and Fig. 4 showed the splitting tensile strength of LRC at 28days optimum curing, It was observed that the tensile strength of LRC increased with age. The mix proportions of 1:2:4; 1:1.35:3.15; 1:1.5:3 and 1:1:2 gave maximum splitting tensile strength of 0.89, 0.93, 0.94 and 0.99 N/mm^2 respectively which indicates the resilience of LRC to withstand abrasive forces. The splitting tensile strength of LRC for the prescribed/designed mixes approximate closely to less than 10 percent of the compressive strength as specified in various standards.

Days	**Splitting tensile strength (N/mm^2)**			
	1;2;4	1:1.35:3.3	1;1.5;5	1;1;2
3	0.65	0.68	0.69	0.71
7	0.7	0.71	0.72	0.74
14	0.81	0.78	0.79	0.85
21	0.85	0.86	0.87	0.88
28	0.89	0.93	0.94	0.99

Table 6: Tensile strength of Laterite Rock Concrete and age

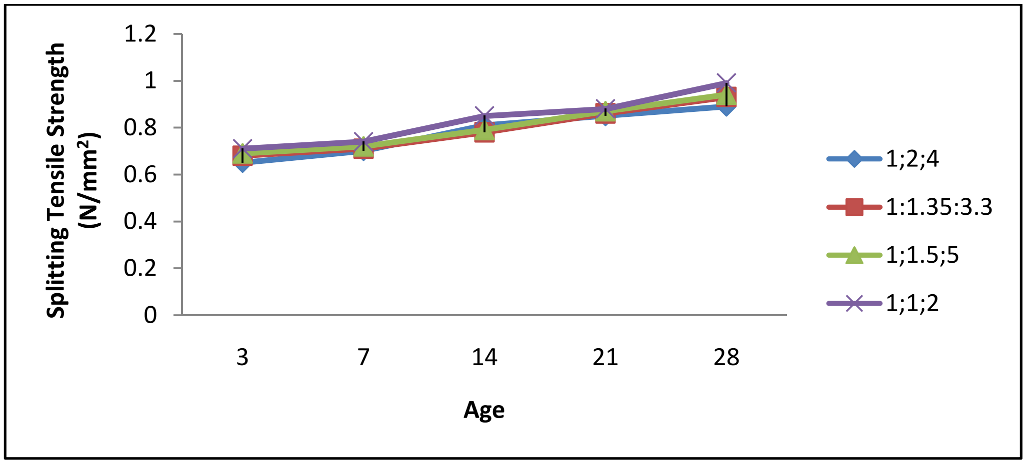

Figure 4: Relationship between splitting tensile strength and age in days for prescribed/ designed mix proportions

3.7. Permeability of LRC

w/c ratio	Mix proportion	1hr	24hrs	36hrs	84hrs	Mean In %	Range in %
1.05	1:2:4	7.61	11.6	12.07	12.41	10.92	7.61 – 12.41
0.85	1:1.35:3.3	8.48	12.69	13.36	13.54	12.02	8.48 – 13.54
0.85	1:1.5:3	7.39	11.93	12.36	12.78	11.12	7.39 – 12.78
0.75	1:1:2	7.15	11.15	11.21	11.44	10.24	7.15 – 11.44

Table 7: Percentage Absorption of LRC in Water

Table 7 and Fig. 5 show the permeability of the hardened LRC which is a measure of the durability of the concrete. From the four mix proportions subjected to 1hr, 24hrs, 36hrs and 84hrs, the permeability test showed the relative levels of absorption of water. Results indicated that the design mix proportion of 1:1.35:3.15 absorbed more water than the prescribed mix proportions of 1:2:4, 1:1.5:3 and 1:1:2 respectively possessing ranges between (7.61 – 12.41) %, (8.48 – 13.54) %, (7.39 – 12.78) % and (7.15 - 11.44) % with mean values of 10.92%, 12.02%, 11.12% and 10.24%. Results showed that the water absorption rate is least in the mix proportion of 1:1:2 at 28 days curing. And in all mix proportions, the duration or age of soaking the LRC affected significantly on the absorption rate.

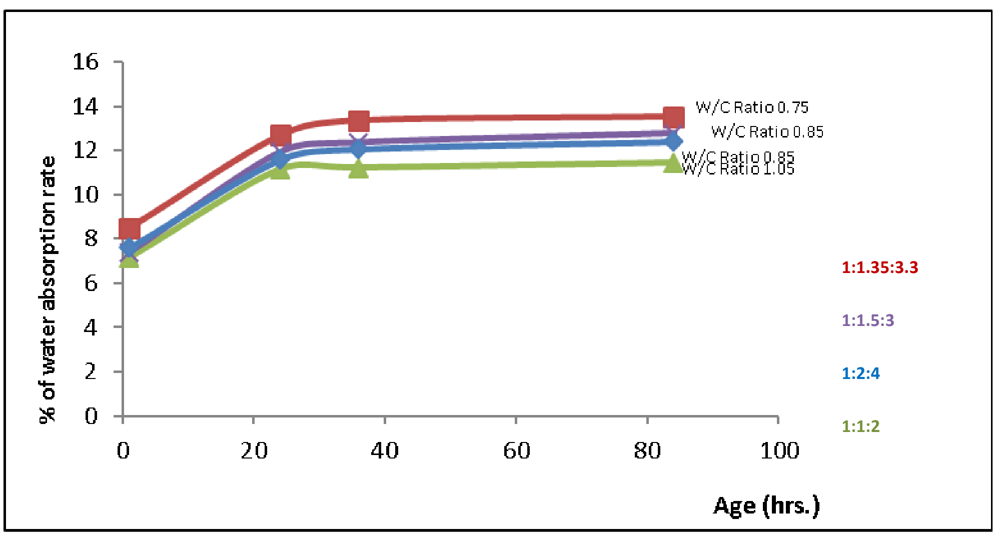

Figure 5:Percentage increase of water absorption of LRC with age

The rate of liquid ingress to LRC primarily depends on the ability of the liquid to penetrate the material through capillary action, which depends largely on the total volume of the space occupied by air or water between the voids present in the hardened form of LRC. Various mix proportions used for the study indicate their level of porosity that determines the rate of absorption. Permeability results particularly due to pressure differential on opposite faces of the LRC which depends on the size of the largest voids, and the size of the channels connecting the voids. As a result of this, concrete made with laterite rock as aggregates should be thoroughly compacted to reduce the presence of voids to a minimal, and for reinforced LRC structures, appropriate cover to the reinforcement rod should be made to ensure durability.

3.8. Stress-Strain of Laterite Rock Concrete (LRC)

The stress strain characteristics of the various mix proportions showed an upward movement of the curve. This behaviour indicates that increase in the load applied, is related directly to the stress with an inverse coefficient of proportionality that leads to a progressive increase of strain induced in the laterite rock concrete. This increment with time leads to failure of the LRC structure.

Mean Stress (N/mm^2)	**0**	**11**	**22**	**34**	**45**	**56**	**68**	**79**	**90**	**102**	**113**	**125**	**137**	**147**	**160**	**170**
Mean Strain (x10-5)	**0**	**0.73**	**1.4**	**3.1**	**3.8**	**4.98**	**6.75**	**8.03**	**9.33**	**10.9**	**12.7**	**13.8**	**16.63**	**18.85**	**21.95**	**22**

Table 8: Stress – Mean strain relationship of Laterite Rock Concrete

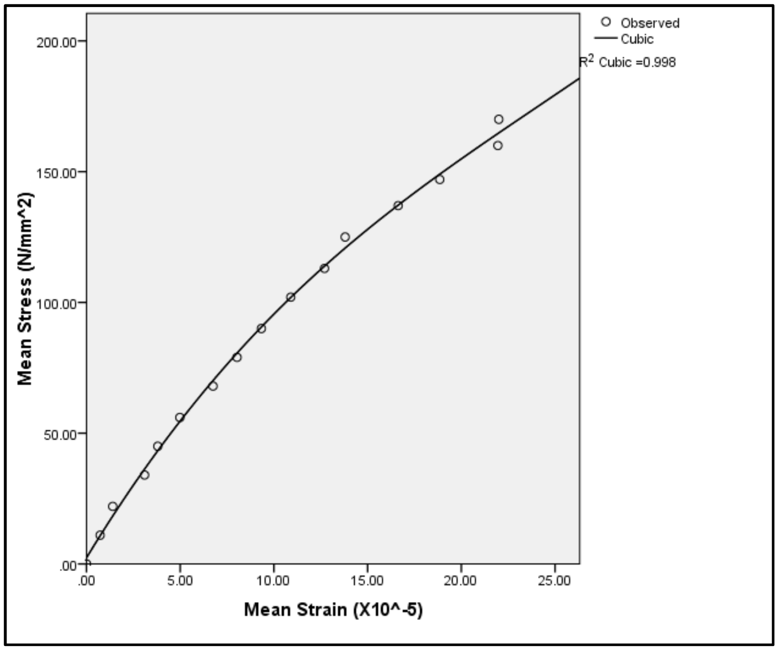

Figure 6: Mean Stress/ Strain Relationship of LRC for the Prescribed/ Designed Mix Proportions.

The Table 8 and Fig 6 represents mean values of all data computed for the prescribed/ designed mixes. A model equation was developed from the plot as;

$$y = 2.36 + 11.806x - 0.287x^2 + 0.04x^3 \quad (2)$$

The model was evaluated, using second derivative of

$$\frac{d^2y}{dx^2} = 0 \quad (3)$$

to determine the resultant stress and strain values, the young Modulus of elasticity (E_{LRC}) was derived to be approximately 12 N/mm^2. The value obtained is quite low compared to Normal Concrete.

4. Conclusions and Recommendations

4.1. Conclusion

Laterite Rock Concrete (LRC), from various studies is comparable to Normal concrete as discussed earlier for both short and long term in various perspectives.

i. The specific gravity of LRC had a mean value of 2.81 with standard deviation of 0.1205 and co-efficient of variation 0.042.
ii. Density of concrete made with Laterite rock aggregates classified the material to be normal weight which can be used in place of normal concrete and a range of 2192 – 2512.67. kg/m^3
iii. Compressive strength of LRC is maximum for the mix proportion at 28days at about 23.4N/mm^2 with w/c of 0.85 and decreased to 18N/mm^2. This characteristic was exhibited in all other mixes.
iv. The workability of the Laterite Rock Concrete measured through slump showed that at different water/cement ratios, the workability, plasticity and mould ability of the concrete changes. Hence a w/c of 0.95 and 1.05 are recommended for 1:2:4 mix ratio; while 0.85 for 1:1.35:3.15and 1:1.5:3 and 0.75 and 0.85 for 1:1:2 mix proportions.
v. The stress/ strain behaviour of laterite rock concrete (LRC) is similar to normal concrete (NC) and the model equation of; $y = 2.339 + 11.806x - 0.287x^2 + 0.04x^3$ can be used to determine the young modulus of elasticity

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