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Experimental Study of Slab Flexural Properties with Replaced Fine Aggregate using Compressed Stabilized Laterite as an Inputs for Sustainable Reinforced Concrete Material in Nigeria

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Abstract: *Reinforced concrete is an inherent material for construction of structural components. Concrete parameters directly affect its utilization for engineering works. However, Reinforced slab of 5mm x 450 x 450mm with BRC mesh and cover of 25mm were cast with river sand and compressed stabilized laterite for designed compaction loads of 6 N/mm² and 8 N/mm². The materials were tested for initial moisture content, and further sieve analysis and compaction test. All mixtures were maintained at moisture content of 6%, 9%, 12%, 15%, and 18% respectively and water/cement ratio of 0.55. The main property investigated was the flexural properties for 7days, 14days, 21days and 28days respectively. With 6 N/mm² load, the values for reinforced slab with river sand are $3.09x10^{-4}$ N/mm², $3.50x10^{-4}$ N/mm², $3.75x10^{-4}$ N/mm², $4.18x10^{-4}$ N/mm², $4.74x10^{-4}$ N/mm², $3.23x10^{-4}$ N/mm², $3.44x10^{-4}$ N/mm², and $3.91x10^{-4}$ N/mm² respectively, while those for compressed stabilized laterite are $2.61x10^{-4}$ N/mm², $3.23x10^{-4}$ N/mm², $3.03x10^{-4}$, $3.71x10^{-4}$ N/mm², $4.06x10^{-4}$ N/mm², $3.44x10^{-4}$ N/mm², $2.88x10^{-4}$ N/mm², and $2.68x10^{-4}$ N/mm² respectively. With 8N/mm² load, the values are $3.91x10^{-4}$, $4.32x10^{-4}$, $4.67x10^{-4}$, $4.94x10^{-4}$, $5.50x10^{-4}$, $4.26x10^{-4}$, $3.97x10^{-4}$, and $4.59x10^{-4}$ while the later are $2.88x10^{-4}$ N/mm², $3.7110x^{-4}$ N/mm², $3.97x10^{-4}$ N/mm², $4.26x10^{-4}$N/mm², $4.53x10^{-4}$N/mm², $3.77x10^{-4}$N/mm², $3.36x10^{-4}$N/mm² and $3.97x10^{-4}$N/mm² respectively. Generally, the flexural strength of reinforced slab with river sand is slightly greater to reinforced CSL. Therefore, the implication is that CSL is an improvised aggregate for concrete despite the small difference in flexural strength; River sand is still the main material in concrete technology works. However, where distance is prohibitive, recourse can be made to compressed stabilized laterite.*

Keyword*: Reinforced Concrete, Flexural Strength, Compressed Stabilized Laterite, River Sand, Structure*

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I. Introduction

Reinforced concrete is an inherent material for construction of structural components. Concrete parameter directly affects its utilization for engineering works. However, concrete produced without compressed materials and homogeneous tensile properties results to the development of micro cracks [1]. Obviously, effective utilization of compressed stabilized laterite (CSL) in rural and urban area has been a challenge for decades to civil engineers [2].

Recently, especially in remote rural villages having in possession compressed stabilized laterite has considered it a waste product. In the older days, stone, sand, laterite, grass, logs, and animal hides were mainly used as building materials in their crude form. As construction technique advances, the crude as well as the partly refined materials were replaced by others, especially made for different purposes such as dressed stones, bricks, cement, different metals, reinforced and pre-stressed concrete which then triggered the rapid development of construction techniques [1].

Sequel to the above, the choice of appropriate building material is one of the important criteria, which determines the flexural strength, and economy of any construction projects [3]. Experience divulged that the use of compressed stabilized laterite has played a significant role in the growth of socio-economic development. The techniques were also sustainable with less menace to the natural resources of the environment neither do their production processes lead to the emission of gases that causes global climate change. [2].

From civil engineering perspective, concrete remains the main construction material used in construction industries [4]. However, the basic constituents of concrete are cement and aggregates. While water is used for proportional mixing to gain the target strength and perform well in any exposure conditions; cement is a substance that binds alternative materials together; thus aggregates act as inert filler of voids in concrete [4].

Cursory observation and field data revealed that concrete is a composite material which is commonly used for construction purposes. Additionally, Concrete is a relatively brittle material that performs well in compression, but is considerably less effective in tension. Its tensile strength is approximately one tenth of the compressive strength. Tensile stresses are induced in concrete due to its shrinkage in both plastic and hardened stage thus resulting to cracking of concrete [5]. Historically, steel reinforcement is used to absorb these tensile stresses and to prevent the cracking to some extent. The addition of steel reinforcement significantly increases the flexural properties of reinforced concrete [6].

However, to produce reinforced concrete with homogeneous flexural properties, the micro crack that develops in concrete must be suppressed [5]. The use of compressed stabilized laterite was introduced as a proffer technique for reinforced and unreinforced concrete technology in view of enhancing its serviceability in terms of flexural properties. The compressed stabilized earth is the developed form of moulded earth, more commonly known as the laterite [2]. This technology offers an economic, environmental-friendly-masonry system. The stabilized compressed laterite has a wide spectrum of application in construction starting from walling, roofing, arched openings, corbels etc [7]. Compressed stabilized earth is manufactured by compacting raw material (earth mixed with a stabilizer such as cement or lime) under a pressure of 20 – 40 kg/cm using manual soil press [8]. It becomes imperative to experiment this technique for the purpose of socio-economic and sustainable infrastructure development in Nigeria.

Objective

The objective of this study is to determine the maximum effect of compressed stabilized earth (laterite) on slab flexural properties in concrete technology using compaction load of $6N/mm^2$ and $8N/mm^2$ distributed uniformly over the slab area.

II. Material and Methods

Sample Collection Area

The sample collection area includes the borrow pit adjacent to the dump site located in Nekede along Federal Polytechnic Nekede-Ihiagwa road (Fig 1). It is about 2km away from Federal University of Technology Owerri. It lies between the Nworie River and the Otamiri River with chainage (4+473) taking Naze junction as the starting point (0+000). The population of Nekede is fast developing into a city due to the citing of the two federal government-owned higher institutions. The borrow pit of Isuikwuato LGA of Abia State (Fig 2). It si situated in Iyiezi, the Umuasua Autonomous community.

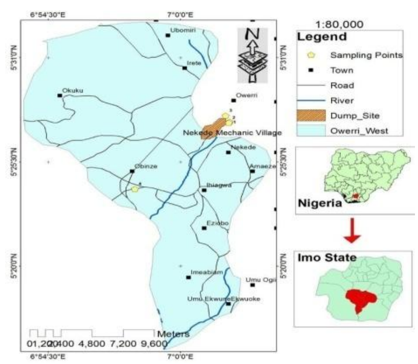

Figure 1: Map of the dump site near borrow pit in Nekede Ihiagwa Road **Figure 2:** Map of Abia showing Isiukwuato LGA

Sample Collection and Preparation

The experimental materials used in this study include cement, fine aggregate (river sand), water, laterite, and BRC mesh. While some of the materials were purchased at civil engineering material outlets, however, others were locally sourced from various borrow pits. The purchased materials were Portland Limestone Cement (PLC) along Nekede Ihiagwa road, Owerri, of grade N42.5 and its quality was in conformity with NIS 444-1:2003 specifications; the BRC mesh of about 5mm x 750mm x 750mm with strength of $250N/mm^2$, from Naze timber (Ogbo Osisi) market, Owerri. The fine aggregate (river sand) was locally sourced from Otamiri River. The soils were free of debris, silt and other organic impurities. However, water was collected from water distribution system in Federal Polytechnic, Nekede, Owerri, Imo, Nigeria. Laterite was sourced at Iyiezi borrow pit, along Isi-iyi road in Umuasua Autonomous community, in Isuikwuato LGA of Abia State. The materials were transported to Federal Polytechnic Nekede, Owerri concrete laboratory for testing. The BRC mesh was unrolled, straightened and cut into 450 x 450mm sizes; it was kept cleaned and packed off the ground prior to usage. The cement and aggregate were prepared in accordance with the standard specification, procedures and mixed design to ascertain the desired quantities.

Procedure Methodologies

Moisture Content Test

The container was cleaned, dried, weighed and recorded as W. The sample was crumbled of the lumps. It was poured into the containers. The wet samples and container were weighed and recorded as W_1. The weighed samples were oven-dried at 115˚C at 24hours. After 24 hours, the dried samples were removed. The samples were cooled in desiccators. The samples were weighed and the values were recorded as W_2. The moisture content (MC) was calculated. Mathematically, the moisture content in equation 1 is expressed in percentage.

$$MC = \frac{W_1 - W_2}{W_2 - W} * 100\% \quad (1)$$

Where mc is the moisture content, $w_{1,}$ $w_{2,}$ and w are weight of wet soil plus empty container, weight of dry soil plus container and weight of empty container.

Sieve Analysis

The set of sieves were cleaned and nested in accordance to IS sieve specification. The sieves sizes were recorded in stacked order. 5000g river sand sample was poured into stacked sieves and was placed on the sieve shaker. The three armed bracket on the lid-stack were fixed on the sieve. The straight-arm bracket was lowered. The end pins were penetrated through the holes on the frame to ensure firmed and secured stacks. The sieve shaker was timed for 15 minutes. The same procedures were applied to laterite sample. Afterwards, the machine was switched off. The mass of the sample retained in each sieve were determined and recorded. The particle size distribution was estimated. Mathematically, the sieve analysis in equation 2-4 is expressed in percentage.

$$G = \frac{m1}{m2} x100\% \quad (2)$$

$$Pp = 100 - Pcp \quad (3)$$

$$Rpp = pp + Aggregate\ correctin\ factor \quad (4)$$

Where G is the particle size distribution, $m_{1,}$ and $m_{2,}$ are mass of soil retained, and mass of soil retained in the pan weight of dry soil plus container and weight of empty container while Cpp, Pcp, and Rpp are calculated percent passing, previous calculated percent passing and Reported percent passing per 100% of the cumulative percentage.

Compaction Test

Air-dried samples of 7kg by weight were collected from sieved samples. laterite was replaced with cement for dehydration. The weighed samples were poured on the tray, thoroughly mixed, with water added to a fairly low moisture content of 6%, 9%, 12%, 15%, and 18%. The mixed samples were scooped into 450mm diameter metal moulds. The samples were compacted with 4.5kg rammer of 50mm diameter. The rammer fell freely at 450mm above the top of the sample. Compaction was effected in five layers of approximately equal depth, each depth were 27 blows spread evenly over the sample surface. The mould surfaces were leveled. The base of mould was removed. The sample was weighed. Specimens were collected from the soil samples for water content determination. It was oven dried for 24 hours. The rest of the soil sample was removed from the mould, broken and was retested until the weight of the wet soil in the mould attains a maximum value and begins to fall. The maximum dry density (MDD) and optimum moisture content (OMC) were calculated.

Table 1: Percentage mixture proportion and the OMC versus MDD

Mix No	Laterite (%)	River sand (%)	Cement (%)	OMC (%)	MDD
1	52.25807	37.74193	10	0.075	1.82
2	57.64977	32.35023	10	0.08	1.81
3	63.04147	26.95853	10	0.094	1.88
4	68.43318	21.56682	10	0.102	1.78
5	73.82489	16.17511	10	0.097	1.77
6	79.21659	10.78341	10	0.119	1.76
7	84.60829	5.391705	10	0.097	1.83
8	90	0	10	0.128	1.79

Casting and Crushing of Compressed Stabilized Laterite Slabs

The steel slab moulds were cleaned of old impervious pebbles. The moulds internal surface was lubricated. Proportioned mixed design was followed (table 1). The desired quantities of mixed composition for compaction load of $6N/mm^2$ and $8N/mm^2$ as well as the set height in magnus framework was determined. Trial test was conducted to ascertain the quantity of the estimated mixed sample. A concrete cover of 25mm and 5mm x 450mm x 450mm BRC mesh reinforcement were set in the moulds. The mixed samples were poured into the moulds and was tamped with a tamping rod in three layers of 27 blows each layer. It was centralized between the ram and the support frame. Thick plate was placed on the sample. The compaction load was applied for 10minutes. The sample was unloaded; marks were inscribed on the samples for identification. The experimented procedures were repeated with compressed stabilized laterite. It was cast in the same manner. The slabs were kept for 24 hours undisturbed. After 24 hours, the samples were removed off the moulds were cured at aged intervals for 28 days in the curing tank.

Figure 3: Casting stage of compressed stabilized laterite slab **Figure 4:** Reinforced compressed stabilized laterite slab

Compressive Strength Test

The slabs were tested for compressive strength ranging from 7-28 days as stipulated in BS EN 12390 – 3:2009. The slabs were crushed with electric powered concrete compressive testing machine with a capacity of up to 2500KN. The reinforced compressed stabilized laterite slabs were placed on supports within the Magnus frame. The ram was applied with centralized force on the reinforced compressed stabilized laterite slab. The thick plate was placed on the sample to ensured uniformly distributed load. The destructed value from Bourdons gauge was recorded. These procedures were repeated for ninety six cured slabs. The machine factor was calibrated at 160 Bars.

III. Results

Moisture Content

The result of average moisture content of river sand and laterite soil is 5.89% and 9.61% (Table 2). This is an indication of more water in lateritic soil than river sand.

Table 2: Moisture content of river sand and laterite soil.

NATURAL MOISTURE DETERMINATION								
Soil sample	Can no.	Wt. of empty can (g). W	Wt. of wet sample + can(g) W_1	Wt. of dry sample + can(g) W_2	wet of dry sample(g)	Wt. of water (g)	Moisture Content (%)	Average moisture Content (%)
River sand	1	11	67	64	53	3	5.660377	5.8914132
	2	11	63	60	49	3	6.122449	
Laterite	3	14	58	55	41	3	7.317073	9.6109175
	4	14	61	56	42	5	11.90476	

Sieve Analysis

Sieve analysis is important for analysing material aggregates (Tables 3&4). These particle sizes affect a wide range of properties. Significantly, the degree material coefficient of uniformity contributes greatly to its strength properties. Nevertheless, coefficient of curvature determines the extent of modulus of rupture in slab. The Gradation is essential to achievable desired properties (figs 1&2) as in the case of reinforced concrete. The coefficient of uniformity and curvature of river sand were 3.7 and 0.78 while that of laterite were 2.2 and 0.8. Its grading presents a quick fell in the range of 0.075mm to 4.75mm which is an indication of solubility of mixture and surface area in zone 1, 2 and 3.

Table 3: The sieve analysis of river sand

SAND (500g)							
Sieve No	Sieve opening diameter (mm)	Mass of empty sieve (g)	Mass of sieve + retained soil (g)	Mass of retained soil (g)	% Retained	Cumm. % of soil retained (g)	% Passing
4.75mm	4.75	362	381	19	3.8	3.8	96.2
2.36mm	2.36	340	375	35	7	10.8	89.2
1.18mm	1.18	334	460	126	25.2	36	64
600µm	0.6	318	440	122	24.4	60.4	39.6
425µm	0.425	326	426	100	20	80.4	19.6
300µm	0.3	303	352	49	9.8	90.2	9.8
212µm	0.212	302	340	38	7.6	97.8	2.2
150µm	0.15	332	338	6	1.2	99	1
75µm	0.075	284	284	0	0	99	1
Pan	0	265	270	5	1	100	0
			TOTAL	500			

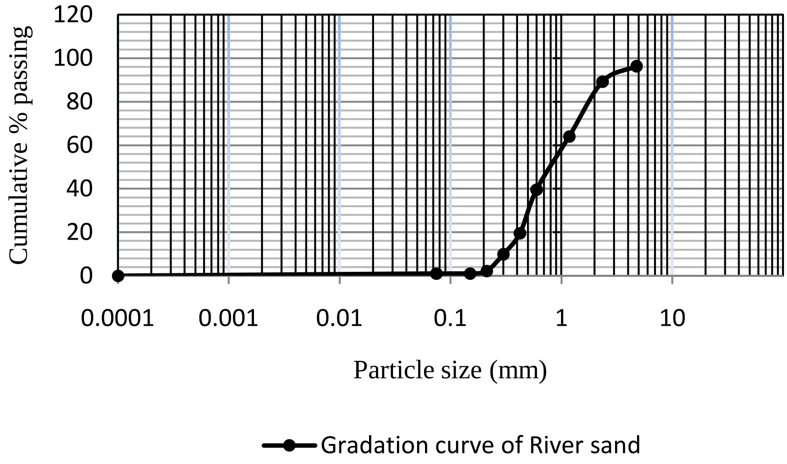

Figure 5: Gradation curve of river sand

From the gradation curve, D_{60} = 1.1, D_{30} = 0.5 and D_{10} = 0.3 and coefficient of curvature and uniformity is calculated using D_{60} and D_{30}.

$$Cu = \frac{1.1}{0.3} = 3.71$$

$$Cc = \frac{0.5^2}{1.1 * 0.3} = 0.76$$

Table 4: The result of sieve analysis of laterite

LATERITE (500g)							
Sieve No	Sieve opening diameter (mm)	Mass of empty sieve (g)	Mass of sieve + retained soil (g)	Mass of retained soil (g)	% Retained	Cumm. % of soil retained (g)	% Passing
4.75mm	4.75	362	362	0	0	0	100
2.36mm	2.36	340	343	3	0.6	0.6	99.4
1.18mm	1.18	334	351	17	3.4	4	96
600µm	0.6	318	410	92	18.4	22.4	77.6
425µm	0.425	326	447	121	24.2	46.6	53.4

300µm	0.3	303	404	101	20.2	66.8	33.2
212µm	0.212	302	442	140	28	94.8	5.2
150µm	0.15	332	342	10	2	96.8	3.2
75µm	0.075	284	285	1	0.2	97	3
Pan	0	265	280	15	3	100	0
			TOTAL	500			

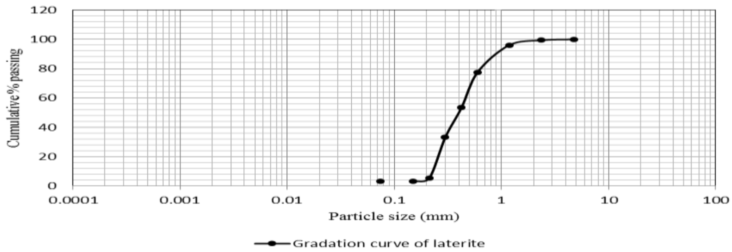

Figure 6: Gradation curve of river sand

From the gradation curve, D_{60} = 0.48, D_{30} = 0.29 and D_{10} = 0.22

$$Cu = \frac{0.48}{0.22} = 2.21$$

$$Cc = \frac{0.29^2}{0.48 * 0.22} = 0.8$$

Compaction Test

Compaction test result yield a slight increase in soil shear strength and decreases it permeability. These properties are significant to void reduction in aggregates. Decrease in compressibility and permeability, the more difficult for passage of water through the soil hence the baseline of optimal moisture content and achievable dry density (Figs 3-9) are for specific compaction effort.

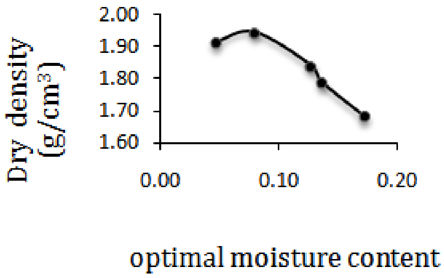

Figure 7: OMC vs MDD for 12.6% fines

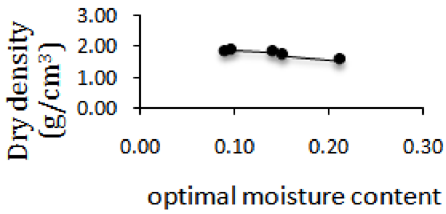

Figure 8: OMC vs MDD for 13.9% fines

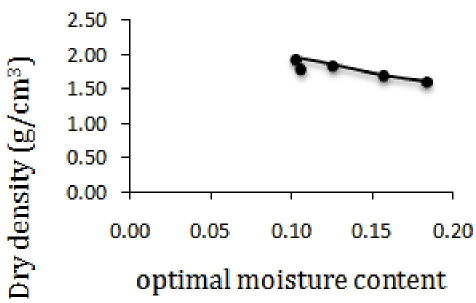

Figure 9: OMC vs MDD for 15.2% fines

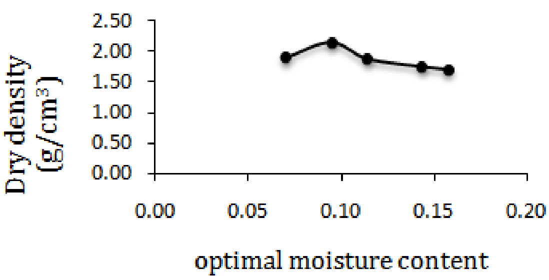

Figure 10: OMC vs MDD for 16.5% fines

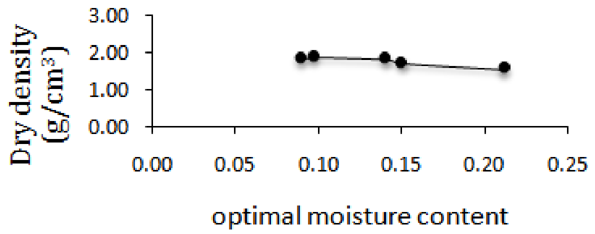

Figure 11: OMC vs MDD for 17.8% fines

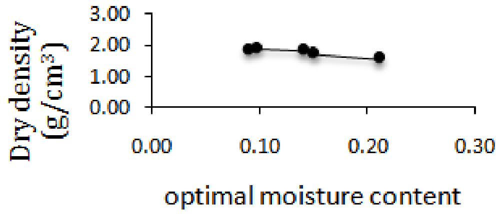

Figure 12: OMC vs MDD for 19.1% fines

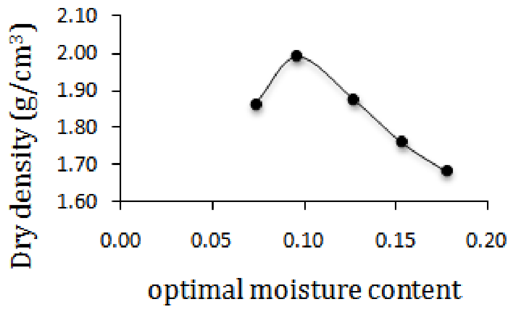

Figure 13: OMC vs MDD for 20.4% fines

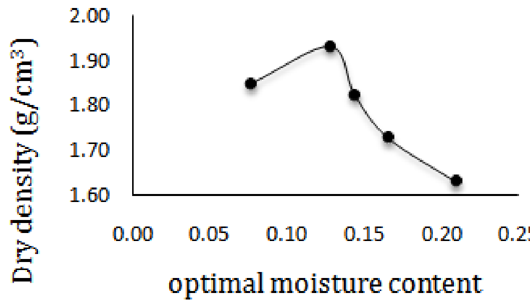

Figure 14: OMC vs MDD for 21.7% fines

Table 5: Flexural strength of reinforced compressed stabilized earth slab of 6N/mm^2

%fine soil	% sand	Reinforced		
		Force (N)	Uniformly Distributed load (N/mm^2)	Flexural strength (N/mm^2)
12.6	77.4	14254.98	0.05702	3.09x10^{-4}
13.9	76.1	16155.64	0.06462	3.50x10^{-4}
15.2	74.8	17296.04	0.06918	3.75x10^{-4}
16.5	73.5	19296.04	0.07717	4.18x10^{-4}
17.8	72.2	21857.64	0.08743	4.74x10^{-4}
19.1	70.9	14920.21	0.05968	3.23x10^{-4}
20.4	69.6	15870.54	0.06348	3.44x10^{-4}
21.7	68.3	18056.31	0.07223	3.91x10^{-4}

Table 6: Flexural strength of unreinforced compressed stabilized earth slab of 6N/mm^2

%fine soil	% sand	Unreinforced		
		Force (N)	Uniformly Distributed load (N/mm^2)	Flexural Strength (N/mm^2)

12.6	77.4	12069.22	0.04828	$2.61x10^{-4}$
13.9	76.1	13969.88	0.05588	$3.03x10^{-4}$
15.2	74.8	14920.21	0.05968	$3.23x10^{-4}$
16.5	73.5	17105.98	0.06842	$3.71x10^{-4}$
17.8	72.2	18721.54	0.07489	$4.06x10^{-4}$
19.1	70.9	12354.32	0.04942	$2.68x10^{-4}$
20.4	69.6	13304.65	0.05322	$2.88x10^{-4}$
21.7	68.3	15870.54	0.06348	$3.44x10^{-4}$

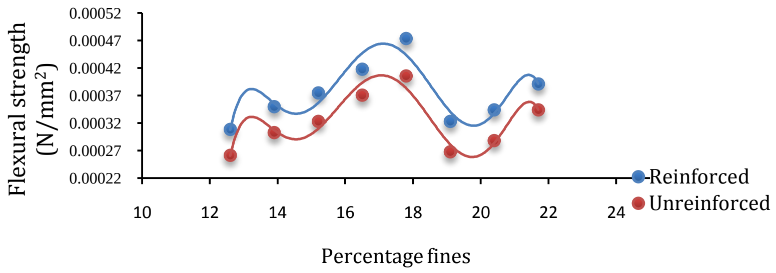

Figure 15: Percentage fines vs flexural strength for load $6N/mm^2$

Table 7: Flexural strength of reinforced compressed stabilized earth slab of $8N/mm^2$

%fine soil	% sand	Reinforced		
		Force (N)	Uniformly Distributed load (N/mm^2)	Flexural Strength N/mm^2
12.6	77.4	18056.31	0.07223	$3.91x10^{-4}$
13.9	76.1	19956.97	0.07983	$4.32x10^{-4}$
15.2	74.8	21572.54	0.08629	$4.67x10^{-4}$
16.5	73.5	22807.97	0.09123	$4.94x10^{-4}$
17.8	72.2	25373.86	0.10150	$5.50x10^{-4}$
19.1	70.9	19671.87	0.07869	$4.26x10^{-4}$
20.4	69.6	18341.41	0.07337	$3.97x10^{-4}$
21.7	68.3	21192.40	0.08477	$4.59x10^{-4}$

Table 8: Flexural strength of unreinforced compressed stabilized earth slab of $8N/mm^2$

%fine soil	% sand	Unreinforced		
		Force (N)	Uniformly Distributed load (N/mm^2)	Flexural Strength (N/mm^2)
12.6	77.4	13304.65	0.05322	$2.88x10^{-4}$
13.9	76.1	17105.98	0.06842	$3.7110x^{-4}$
15.2	74.8	18341.41	0.07337	$3.97x10^{-4}$

16.5	73.5	19671.87	0.07869	4.26×10^{-4}
17.8	72.2	20907.30	0.08363	4.53×10^{-4}
19.1	70.9	17391.08	0.06956	3.77×10^{-4}
20.4	69.6	15490.41	0.06196	3.36×10^{-4}
21.7	68.3	18341.41	0.07337	3.97×10^{-4}

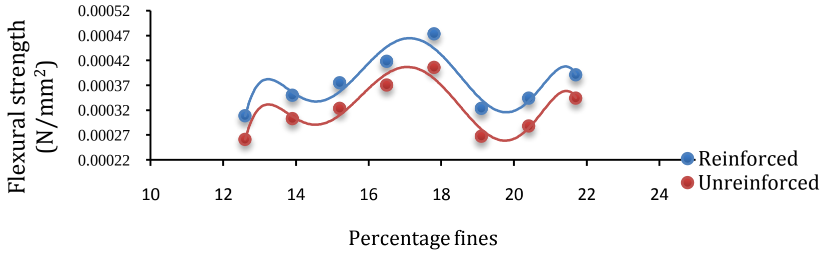

Figure 16: Percentage fines vs flexural strength for 6N/mm^2

IV. Discussion

The values of average moisture content for river sand and laterite soil is 5.89% and 9.61% (Table 2). This is an indication of more water in lateritic soil than river sand. The optimum moisture contents of the eight mixed proportions in (table 1) were read off from the graphs (figs 7-14) of optimal moisture content- maximum dry density. The optimum moisture contents were 0.08, 0.094, 0.102, 0.097, 0.119, 0.097 and 0.128 respectively with corresponding MDD of 1.82g/cm^3, 1.81g/cm^3, 1.88g/cm^3, 1.78g/cm^3, 1.77g/cm^3, 1.76g/cm^3, 1.83g/cm^3, and 1.79g/cm^3 respectively.

However, the stress-bearing restoration of material varied depending on the compaction loads and conventional technique of slab produced (Table 5-8) [10]. Flexural strength of slab (Fig 15) depicts the behavior of fines and sand versus flexural strength, when compaction load of 6N/mm^2 were applied on reinforced and unreinforced compressed stabilized laterite slab [1].

Patently, the values of 17.8% fines and 72.2% sand for compaction load of 6N/mm^2 has the flexural strength of reinforced compressed stabilized laterite slab is 4.74×10^{-4} N/mm^2 in table 5 [9] At 12.6% fines and 77.4% sand, it has a minimum flexural strength of 3.09×10^{-4} N/mm^2 table 7. Similarly, the percentage of fines and sand at the maximum and minimum flexural strength of unreinforced compressed stabilized laterite slab are 4.06×10^{-4} N/mm^2 and 2.61×10^{-4} N/mm^2 respectively. In Fig 16, it depict that at 17.8% fines and 72.2% sand for compaction load of 8 N/mm^2, the flexural strength of reinforced compressed stabilized laterite slab was at its maximum, of 5.50×10^{-4} N/mm^2.

The flexural strength of reinforced compressed stabilized laterite slab was slightly greater when compare with unreinforced compressed stabilized laterite slab. The implication is therefore that the higher the compaction load, the higher the flexural strength of compressed stabilized laterite slab. Compressed stabilized earth is an improvised aggregate for concrete.

V. Conclusion

Reinforced compressed stabilized laterite yields linearly to homogeneous flexural properties with less micro cracks development. However, less modulus of rupture depends to a very large extent on compaction loads distributed uniformly over the slab area. The experimental result of compressibility and permeability anchored that, decrease in compressibility and permeability, the more difficult for passage of water through the soil. Additionally, the stress-bearing restoration of material varied on the compaction loads and conventional technique of slab produced either in precast or cast in-situ. The implication is therefore that compressed stabilized is an improvised aggregate for concrete technology and should be encouraged in all civil engineering construction works.

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