

## STRENGTH CHARACTERISTICS OF LATERITIC SOIL STABILIZED WITH TERRASIL AND ZYCOBOND NANNO CHEMICALS

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### ABSTRACT

*Laterite is a major material in road construction. However, Stabilization of weak laterite with cement or lime is expensive and well reported. There is a paucity of information on stabilization of weak laterite with Nano chemicals. This study investigates the Geotechnical properties of weak laterites Stabilized with Nano chemicals (Terrasil and Zycobond).*

*Lateritic soil samples were collected from two different burrow pits (Sample A, latitude: 8<sup>o</sup>08'N longitude: 4<sup>o</sup>15'E and (Sample B, Latitude: 8<sup>o</sup>25'N, Longitude: 4<sup>o</sup>.3'E, Altitude: 306). Terrasils and Zycobonds were measured in weight to stabilize the laterites at 5, 10, 15, 20%, respectively. Geotechnical testing, which includes: Particle Size Analysis, Liquid Limit (LL), Plastic Limit (PL), Maximum Dry Density (MDD), Optimum Moisture Content (OMC) and California Bearing Ratio (CBR) were carried out on stabilized and unstabilized samples.*

*Particle size distribution analysis showed that the percentage passing sieve No 200 for Sample A and B were 76.6% and 66.5%, respectively. Using the AASHTO classification system, the soils falls into A-5 - A-7 soils. The LL, PI, MDD and OMC for Terrasil stabilized samples A ranges from (36 -52)%, (8 -32)%, (1.73 - 2.34)g/cm<sup>3</sup>, (7.20 - 10.8)% Sample B values range from (36 - 58)%, (15-34)%, (1.8 - 2.63)g/cm<sup>3</sup>, (10.5 - 14.0)%. Zycobond Stabilized samples A varies from (45 - 50)%, (14 -30)%, (2.21 - 1.92)g/cm<sup>3</sup>, (11.5 - 24.0)%. Sample B values vary from (37 - 56)%, (11-38)%, (1.79 - 2.09)g/cm<sup>3</sup>, (9.6 - 12.4)%. The average CBR (soaked and unsoaked) for Terrasil stabilized samples ranges from (5 - 6)%, (13-17)% and (4 - 6)%, ( 20 - 25)%. The CBR for Zycobond samples ranges from (5 -7)%, (20-29)% and (3-14)%, ( 22-55)% for samples A and B, respectively.*

*This Study showed that the Optimum percentage of Nano Chemicals that gave the highest Compressive Strength was 15%. Nano Chemicals (Terrasil and Zycobond) enhanced the Geotechnical properties of weak lateritic soil.*

**KEYWORDS:** *Laterite, Nano Chemicals, Geotechnical Properties, Terrasil and Zycobond*

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### Article History

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### INTRODUCTION

Soil stabilization refers to the process of changing soil properties to improve on the strength and the durability of lateritic soils. It involves modifying the ground before construction begins to make it a viable construction, surface (Abu-Farsakh, 2004). Soil stabilization can also be defined as any treatment (including technically, compaction) applied to

a soil to improve its strength and reduce its vulnerability to water (Zhang, 2006). If the treated soil is able to withstand the stresses imposed on it by traffic under all weather conditions without deformation, then it is generally regarded as stable (Yasui *et al.*, 2005). This definition applies irrespective of whether the treatment is applied to a soil *in situ* or after the soil has been removed and placed on a pavement or embankment (Al-Mukhtar, 2010).

Lateritic soils are the most common construction materials due to their relative abundance, lack of good quality classified aggregates from other sources and their economic attractiveness. Lateritic soils are found in the tropical environment where there is an intense chemical weathering and leaching of soluble minerals (Butalia *et al.*, 2003). Lateritic soils are reddish brown well graded and sometimes extend to a depth of several tens of meters. They are found almost everywhere in the tropics with wide applications in the construction industries. This makes the study of the characteristics important in the areas of consistency limit, grain size distribution, permeability compaction, consolidation and shear strength (Al-Mukhtar, 2010).

Nano chemicals (terrasil and zycobond) can be used to treat soils in order to improve their workability and load bearing characteristics in a number of situations. Nano chemicals (terrasil and zycobond) can substantially increase the stability, impermeability, and load bearing capacity of the subgrade. Application of nano chemicals (terrasil and zycobond) to subgrades can provide significantly improved engineering properties (Beeghly, 2003). Terrasil is water soluble, easy to apply nano chemical. It is a heat stable reactive soil modifier to stabilize the subgrade and made it waterproof. It eliminates capillary rise and water ingress from the top, it also reduces water permeability of soil bases and reduces expansivity and free swell. Terrasil also retains the strength of road bases and increases resistance to deformation by maintaining frictional values between silt, sand, clay particles (Mallela, 2004). It also controls erosion of soil inside shoulders and slopes (Maher, 2004).

It is a reactive and penetrating nanotechnology ,which goes inside the pores of substrates. It is not a water repellent solution, but a long lasting waterproofing solution (Leong, 2013). Zycosol is easy to apply and waterproofing for cement concrete. Zycobond is an acrylic co-polymer dispersion for bonding soil particles, It is sprayed on compacted soils and waterproofing for enhancing the strength of soil layer (Hicks, 2002). Zycobond controls soil erosion and quick drying of soil layers/dirt road after rains, it mitigates dust on dirt roads and reduced undulations (wavy surface) and low maintenance costs.

Stabilization of weak lateritic soil is has been done using lime, cement, and pozzolanas but there is little or less work reported with stabilization using nano chemicals. The cost of stabilization with cement that gives a maximum strength is high. Alternative materials like nano chemical is contemplated to reduce the cost. Therefore, this study investigates the effect of nano chemical on weak lateritic soils stabilize with Nano chemicals.

The Objectives of the study are: to determine the Geotechnical properties of the lateritic soil, to stabilize different samples of the lateritic soil with 5, 10, 15 and 20% of Nano chemicals (Terrasil and Zycobond), to determine California Bearing Ratio (CBR), to determine the type and concentration of Nano chemicals that produces the maximum strength.

## **METHODOLOGY**

**Soil:** Weak Lateritic soils are reddish brown soil well graded and mostly found in the tropical environment, where an intense chemical weathering and leaching of soluble minerals occurs.

Lateritic soil samples were collected from two different locations, sample A (a burrow pit at Yoaco area, Ogbomoso, latitude, 8<sup>0</sup>08<sup>1</sup>N longitude: 4<sup>0</sup>15 E) and sample B (Igbon, Ogbomoso Latitude: 8<sup>0</sup>.25 N, Longitude: 4<sup>0</sup>.3 E, Altitude: 306

### Stabilizers

Terrasil and Zycobond is a commercially available chemical stabilizer which is used in the present investigation. It is available in the concentrated liquid form and is to be mixed with water in specified proportion before mixing with the soil. Technical specifications are shown in Table 1.

### The Chemistry of Nano Chemicals (Terrasil and Zycobond)

Terrasil and Zycobond are nanotechnology based 100 percent organosilane, water soluble, ultraviolet and heat stable, reactive soil modifier to waterproof soil subgrade. It reacts with water- loving silanol groups of sand, silt, clay, and aggregates convert it to highly stable water repellent alkyl siloxane bonds and forms a breathable in-situ membrane. It resolves the critical sub-surface issues. Table 1 shows the technical Specifications of Terrasil and Zycobond.

**Table 1: Technical Specifications of Terrasil and Zycobond**

Property	Description
Appearance	Pale yellow liquid (Terrasil), whitish liquid (Zycobond)
Solid content	68±2%
Viscosity at 25°C	20-100cps
Specific gravity	1.01
Solubility	Forms water clear solution
Flash Point	Flammable 12°C
Terrasil : water	1 kg : 400 liters

## EXPERIMENTAL INVESTIGATION

### Laboratory Test

The laboratory tests that were performed to determine the Engineering properties of Lateritic soil in this study are sieve analysis, Atterberg limit (Liquid Limit, Plastic Limit), Compaction Test, California bearing ratio (CBR) Test.

### Sieve Analysis

The apparatus used is :-set of sieves, washing pan, weighing balance, oven, pulverizer, wash bottle, mechanical sieve shaker, measuring can and porcelain dish.

The sieve analysis was carried in accordance with the provision of BS1377: Part 2, 1990. The sample of the soil was oven dried for about three hours. After proper drying, the sample was pulverized by means of wooden mortar and rubber pestle. A Suitable quantity of soil sample was taken and sieve through BS 4.75mm sieve. The soil retained on the 4.75mm sieve was subjected to a coarse analysis consisting of the soil through the net of the sieve of 4, 10, 20,40,60,80,100 mm sieve. Each set of sieve was Electronically shaken for about 20 minutes through the various sieves. The particles retained on each sieve were weighed, expressed in gram and percentage weight of the sample. Equation 3.1-3.3 were used for the computation of percentage weight retained and it cumulative.

$$\% \text{ Weight Retained} = \left( \frac{\text{Weight Retained}}{\text{Total dry weight of sample}} \right) \times 100\% \quad 3.1$$

$$\% \text{Weight Passing} = 100\% - \text{Percentage Retained}$$

$$\text{Cumulative \% Weight Retained} = \left( \frac{\text{Cumulative Weight}}{\text{Total dry weight of sample}} \right) \times 100\% \quad 3.3$$

### Consistency Limit Test

**The Apparatus Used Are:** Liquid- limit device with grooving tool, moisture cans, plastic limit plate, Balance sensitive to 0.01g for mass determination, sieve, pan (BS No.35).

To determine Liquid limit test of lateritic soil, the soil sample was air dried not less than 120 g weight and were placed up on the glass plate. The spatula was used for mixed soil thoroughly with Nano chemicals (Terrasil and Zycobond) as the additive at 5, 10, 15 and 20%, respectively until the mass acquires the consistency of a thick paste. The cup of the apparatus was half filled with the wet soil and the top was symmetrically leveled with the spatula. The soils were allowed to dry by returning it to the sample on the plate and spreading out thinly. After sufficient time the sample was mixed together again and the handle at the rate of two rotations per second was turned. The cup was lifted and dropped until the two parts of the soil along the bottom of the groove touched. The number of blows at which this occurs was recorded and a little portion of the sample for moisture content was determined. The moisture content corresponds to each number of blows was read off as a Liquid limit.

To determine the Plastic Limit test for lateritic soil sample of about 15g weights was sieved through a No.36 B.S sieve. The soil was thoroughly mixed on the glass plate and sufficient Nano chemicals (Terrasil and Zycobond) as additive in 5, 10, 15 and 20%, respectively were added to make it plastic enough to be shaped into a small ball. The ball was then rolled between the hand and on the glass plate with enough pressure to form into a thread, the diameter of the thread was decreased and the crumbled threads were then gathered into a container its moisture content was determined as the plastic limit.

### Compaction Test

The apparatus used is :-BS mold, displaced disk, base plate, a rammer, weighing balance, Scraper, moisture cylinder, Head pan. An air dried sample of the soil was pre-treated and passed through the 20mm BS sieve and the particle passing was collected for the compaction. The empty weight of the mold was taken using a balance readable to 1g and recorded. A quantity of the collected soil was weighed and with a measured volume of water and was mixed with Nano chemicals (Terrasil and Zycobond) as additive in 5, 10, 15 and 20% respectively. The soil mixing was done manually using a scoop and trowel and five layers of the soil were introduced into the mold whose base plate was already covered with filter paper to prevent adherence.

The quantity of the soil for each layer was such that five of it filled the mold. 62 blows of 4.5kg metal rammer were applied to each layer. After compacting the five layers, the collar was removed and excess soil was scrapped with a straight edge. The mold and compacted soil were weighed to determine the wet bulk density. A sample of the soil was collected for moisture content determination from both the top and bottom of the mould. This procedure was repeated, maximum dry density and Optimum moisture content were determined. A compaction curve was obtained by plotting dry density against moisture content for each of the samples.

**California Bearing Ratio (CBR) (Soaked and Unsoaked) Test:** This method covers the *in situ* of the dry density and optimum moisture content. This test was conducted based on the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) of the soil obtained from the dynamic compaction method. The apparatus used is :- CBR equipment consisting of 152 mm diameter ×178 mm height, CBR compaction mold with collar and spacer disk 151mm diameter ×61.4 mm height, compaction rammer, expansion measuring apparatus with dial gauge reading to 0.01mm, compression machine equipped with CBR penetration piston. The desired amount of water was added, mixed with Nano chemicals (Terrasil and Zycobond) as an additive at 5, 10, 15 and 20% respectively. The mold was then assembled and compaction of the specimen was done. A sufficient number of test specimens were compacted over a range of moisture content to establish the optimum water content and maximum dry density.

After the specimen has been compacted, the collar was removed from the mold and the compacted soil was carefully trimmed even, with the top of the cylinder by means of the straight edge. The perforated base plate and spacer disc were then removed, and the weight of the mold and compacted soil was recorded. A disc of coarse filter paper was placed on the perforated base plate, the mold and compacted soil inverted and the perforated base plate was clamped to the mold with the compacted soil in contact with the filter paper. The mould was placed in the loading frame of the C.B.R machine and the plunger was adjusted appropriately by lowering to within 1.5mm of the mold. The surcharge rings were placed, the machine switch on and both the penetration and load gauge readings noted and recorded. The mold is inverted and the loadings and penetrations are again noted also for the bottom just as for the top side. Portions of the sample from the top and bottom sides of the mould were taken for Moisture Content Determination.

## **RESULTS AND DISCUSSIONS**

### **Sieve Analysis**

Sieve analysis shows the distribution in percentages of various particle sizes present in the soil sample. The experiment carried out on the sample of lateritic soil shows that the proportion of fines to coarse particles is large. The percentage passing sieve No 200 for Sample A and B are 76.6% and 66.5% respectively. Using the AASHTO classification system, the soils fall into A-5, A-6 and A-7 soils because both Samples had more than 35% passing No. 200 according to road and Bridges Specification Revised Edition of Federal Ministry of Works (1997), These categories are suitable for subgrade and may be stabilized before its usage as either sub base or base course. Table 2 shows the Engineering properties of the weak laterite soil. The percentage passing through various diameters is shown in Table 3.

**Table 2: Engineering Properties of the Weak Laterite Soil**

S/No	Property	Result
1	Grain size distribution (%)	05
	Gravel size	25
	Sand size	53
	Silt size	17
	Clay size	66
2	Consistency limits (%)	67
	Liquid Limit (LL)	31
	Plastic Limit (PL)	36
	Plasticity Index (PI)	
3	Engineering Properties	
	1. AASHTO Compaction	
	a) MDD (g/cc)	2.34
	b) OMC %	10.8
	2. CBR Value	
	a) Un-soaked condition	25
b) Soaked condition	17	

**Table 3: Particle Size Analysis Results for Sample A and B**

Sieve Diameter (mm)	Percentage Passing (Sample A)	Percentage Passing (Sample B)
20.0	99.37	98.8
8.0	97.01	97.3
4.0	93.91	92.0
2.0	89.91	85.7
1.0	87.71	78.2
0.425	85.79	76.6
0.250	83.44	73.7
0.125	81.34	69.7
0.075	76.64	66.5

### Atterberg Results

The results of liquid limit, plastic limit and plasticity index of lateritic sample stabilized with Terrasil and Zycobond at 0.5, 10, 15 and 20%. Increase in Liquid Limit indicates that the soil is becoming more clayish (containing more fine particles). The affinity for water decreases and this automatically improves its strength and its Optimum Moisture (OMC).

It was observed that Liquid Limit ranges between (36 – 52)%, Plastic Limit ranges between (20 - 28)% and plasticity index was between (8 - 32)% of the sample A using Terrasil as additives. For sample B, the liquid limit ranges from (36 - 58)%, Plastic limit ranges from (19-41) % and the plasticity index ranges from (15-34)%. With the application of Zycobond for Sample A the liquid limit ranges from (45-50)%, plastic limit ranges from (20-31) % and the plasticity index ranges from (14-30)%. For sample B, the liquid limit ranges from (37-56)%, plastic limit ranges from (18-29) % and the plasticity index ranges from (11-38)%.

Federal Ministry of Works and Housing (1997) for roadworks recommended Liquid Limit less than 30% and plasticity index of less than 12% for sub base and base materials.

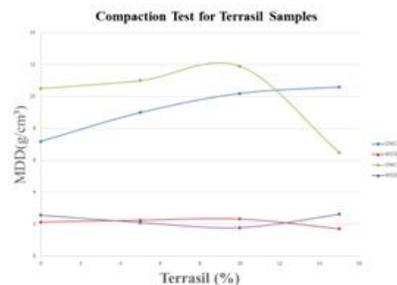
According to Whitlow (1995), Liquid Limit less than 35% indicates low plasticity, between (35 – 50)% indicates intermediate plasticity, between (50 – 70)% indicates high plasticity. Hence, the addition of Nano chemicals (Terrasil and Zycobond) to the soil causes the liquid limit to fall above 50% and thereby makes the soil to have high plasticity.

## Compaction Characteristics of the Soil

### Maximum Dry Density

The Maximum Dry Density (MDD) for AASHTO ranges from  $(1.73 - 2.34)g/cm^3$  and  $(1.8 - 2.63)g/cm^3$  for Terrasil Stabilization for sample A and B. The maximum dry density (MDD) for Zycobond ranges between  $(2.21 - 1.92)g/cm^3$  and  $(1.79 - 2.09)g/cm^3$  for Sample A and B. The decrease in density according to Lees *et al.*, (2000) is as a result of the flocculated and agglomerated clay particles occupying larger spaces leading to a corresponding decrease in dry density, which is in agreement with Osinubi (1995).

It was observed that between 0-10% partial replacement of Terrasil solution, there was an increase in the value of MDD for sample A while for sample B, there was a decrease in MDD. It was also observed that with the use of Zycobond brought a drastic decrease in MDD for the samples. It was observed that between 0-5% Stabilization, it decreased and later increased. Reduction in MDD shows that the soil is loosely packed and as a result, there will be more voids. In such situation, when loads come on soil mass there will be depression and this may lead to different improvement in strength of road pavement.



**Figure 1**

### Optimum Moisture Content (OMC)

For AASHTO Compaction, the OMC increased from  $(7.20 - 10.8)\%$  and from  $(10.5 - 14.0)\%$  for Terrasil Stabilized samples. The increased in the trend of OMC agreed with findings of Osinubi (1999), Akinmade (2008). The explanation presented in this trend is that there was increasing demand for water by various cations and the clay mineral particles to undergo hydration.

It was observed that the OMC increased from  $(11.5 - 24.0)\%$  and from  $(9.6 - 12.4)\%$  of Zycobond Stabilized samples. The OMC increased as a result of an increase in surface area caused by the high amount of Nano chemicals. This implies that apart from water needed for hydration to take place.

The advantage of the increase in the OMC with higher stabilizer content and the corresponding decrease in MDD of the soil is that it allowed compaction to be easily achieved with wet soil. Thus, there is less need for the soil to be dried to lower moisture content prior to compaction in the field.

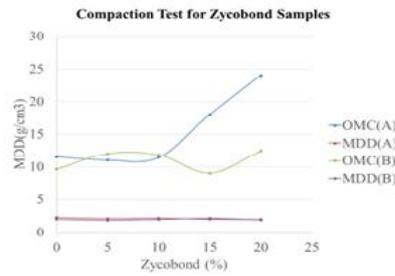


Figure 2

**Strength Characteristics of the Soil**

The Strength Characteristics of the stabilized soil comprises of California Bearing ratio (CBR).The CBR is used to quantify the behavioral characteristics of the soil, trying to resist deformation when an applied load is put on it **Results of California Bearing Ratio (CBR) Test**

The California bearing ratio test was carried out for 0, 5, 10, 15 and 20% of Nano chemicals (Terrasil and Zycobond) as a stabilizing agent as presented by AASHTO compaction energy for both soaked and unsoaked samples with a compactive volume of 2305cm<sup>3</sup> and 4.5kg rammer.

The CBR (Soaked and Unsoaked) values obtained gradually increases the CBR of the laterite soil, which shows that the higher the Nano chemical, the higher the CBR value. The maximum value of CBR obtained at 15% Nano chemical (Terrasil and Zycobond)addition. It was observed that the California Bearing Ratio (CBR) values ranging from (5-6)% and (13-17)% of both Soaked samples A and B for Terrasil Solution.

The CBR (Unsoaked samples) ranges from (4-6) % and (20- 25)% of Terrasil solution while for Zycobond solution, California Bearing Ratio (CBR) values ranges from (5-7)%. The values of soaking samples were from (20-29)%. The Unsoaked samples increases from (3 – 14)% and (22 – 55)%. This indicates an increment in CBR values with an increase in Nano Chemical. The CBR values of the samples increased from (0-15)% considerably with the additive

Terrasil stabilized samples have CBR value of 25% lesser than 30% of FMW specification which says that CBR lesser than 30% is suitable for subgrade. Zycobond stabilized samples have a CBR value of 55% higher than 30% of FMW specification which says that CBR greater than 30% is suitable for subbase.

According to Federal Ministry of Works specification Road Works, CBR of Terrasil is suitable for subgrade and Zycobond suitable for Subbase.

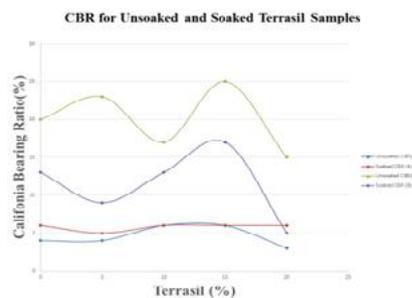
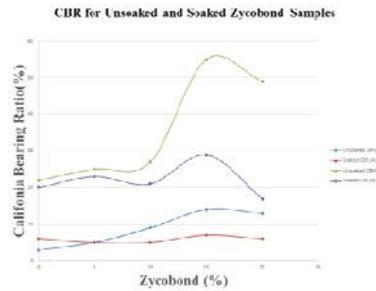


Figure 3



**Figure 4**

## CONCLUSIONS

From this Study, the Following Conclusions Can be Deduced

- The Geotechnical properties of the lateritic soil show that the percentage passing sieve No 200 for Sample A and B are 76.6% and 66.5% respectively, the soil falls into A-5, A-6 and A-7 Soils. The LL, PI, MDD and OMC for Terrasil Stabilized Samples A and B are (36 -52)%, (8-32)%, (1.73 -2.34)g/cm<sup>3</sup>, (7.20- 10.8)% and (36 -58)%, (15-34)%, (1.8 -2.63)g/cm<sup>3</sup>, (10.5- 14.0)%. Zycobond Stabilized samples gave (45 -50)%, (14-30)%, (2.21 -1.92)g/cm<sup>3</sup>, (11.5- 24.0)% and (37 -56)%, (11-38)%, (1.79 -2.09)g/cm<sup>3</sup>, (9.6- 12.4)%.
- To stabilized different samples of the lateritic soil with 5, 10, 15 and 20% of Nano chemicals (Terrasil and Zycobond) show an increase in Liquid Limit, Plastic Limit which indicates that the soil was more clayish. Reduction in MDD shows that the soil was loosely packed. OMC increased as a result of an increase in surface area caused by the high amount of Nano chemicals. The CBR value of the samples increased considerably with the Nano chemicals.
- The CBR (Soaked and Unsoaked) for Terrasil Stabilized samples ranges from (5-6)%, (13-17)% and (4-6)%, ( 20-25)%. For Zycobond Stabilized samples ranges from (5-7)%, ( 20-29)% and (3-14)%, ( 22-55)%. The UCS value for Terrasil Stabilized samples varies from (43-105)KN/m<sup>2</sup> and (64-125)KN/m<sup>2</sup> while Zycobond Stabilized samples varies from (59-74)KN/m<sup>2</sup> and (72-83)KN/m<sup>2</sup>.
- The results show that 15% Nano chemicals (Terrasil and Zycobond) gives maximum strength for California Bearing Ratio (CBR)

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