Influence of XL-bond nanochemical on strength indices of weak lateritic soil
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Abstract
Lateritic soil is among the major construction materials in road pavement. However, obtaining lateritic soil with sufficient strength is difficult and stabilization with cement is expensive. Stabilization with cement and lime has been well reported but there is paucity of information on stabilization with XL-Bond nanochemicals. In this study, the strength characteristics of stabilized lateritic soil with XL-Bond nanochemical were investigated. Lateritic soil samples were taken from Bariga and Mushin, Lagos State, Nigeria borrowpits (A: Latitude 6.5391º, longitude 3.3849 º) and (B: Latitude 6.5273º, longitude 3.3414 º), respectively. The geotechnical properties which include Moisture Content (MC), Particle Size Analysis (percentage passing sieve no 200), Plastic Index (PI), Optimum Moisture Content (OMC), Maximum Dry Density (MDD), Unconfined Compressive Strength (UCS) and California Bearing Ratio [CBR] (soaked) of lateritic soils were determined at natural state. The lateritic soils were stabilized at 2, 4, 6, and 8% of XL-Bond nanochemical by dry unit weight of the soil samples. The PI, MDD, CBR (soaked and unsoaked) and UCS of stabilized laterite soil samples were determined in line with standard methods.

The MC, percentage passing sieve no 200, PI, OMC, MDD, UCS and CBR (soaked and unsoaked) of soil samples A, B were (45.6%, 38.98%, 5.0%, 10.5%, 2420 g/m 3, 59kPa, 12.0% and 10.0% ); (41.1%, 54.52%, 2.0%, 12.50%, 1960g/m 3, 72kPa, 4.0% and 20.0%), respectively. The PI, MDD, CBR (soaked and unsoaked) and UCS of stabilized soil with XL-Bond varied from (3-7%; 2.30-2.35g/cm 3,12-23%, 23-50% and 64-83 kPa) and (3-6%; 1.44-1.50g/cm 3,6-20%, 21-40% and 79-8 kPa), respectively. There is significant effect of varying percentage of XL-Bond on CBR of stabilized samples (P = 0.1004>0.05). In conclusion, stabilization of Laterite soil with XL-Bond nanochemical enhanced its compressive strength. The stabilized lateritic soil can be used as subgrade materials in highway construction.
Keywords: Stabilization, nano-chemical, XL-Bond, lateritic soil, subgrade materials, highway construction

1 Introduction

XL-Bond nanochemicals are emerging nanomaterials that enhance the strength of soil. Nanochemical (XL-Bond) can be added to soils to enhance its workability and load bearing capacity [1]. The nanochemical can significantly improve soil properties such as stability, impermeability and load bearing capacity of soil. Application of Nano chemical (XL-Bond) to subgrades can provide significant improved engineering properties [1]. XL-Bond is water soluble and can be easily applied on the field. It is characterized as heat stable reactive soil stabilizer with excellent waterproof property. It reduces capillary rise and permeability from top of the soil. It also minimizes water permeability of soil bases and expansive properties of soil minerals. XL-Bond is acrylic co-polymer in nature which enhances bonding of soil particles. It is mostly sprayed on compacted soils and in turns reduces drastically the permeability and therefore increases the soil bearing capacity [1]. According to Olaniyan et al. [2], the nanochemical converts silanol group (Si–O–H) which makes surface hydrophobic to Alkyl siloxane surface. This implies that it convert water loving to water repellent property of soil.

Lateritic soils are abundant and among the most useable construction materials. The soils are sourced from tropical environment characterized with intense chemical weathering and leached soluble minerals. Lateritic soils are reddish brown, well graded and often located within depth of several tens of metres. They are mostly found in tropics with and useful in most construction work. This makes the study of the soil characteristic important in the areas of consistency limit, grain size distribution, permeability compaction, consolidation and shear strength [2, 3]. The origin of expansive soil is related to a complex combination of condition and processes that bring about formation of clay mineral materials characterized with expansive properties when in contact with water. The expansive soils can be hard and later lose their strength completely when wet [4]. Road pavement constructed on weak subgrades shows distresses of different kinds, which leads to road failure. The poor subgrade will need to be stabilized to enhance its strength if getting a good subgrade materials from borrow pit is unrealistic.
Most of the asphalt-aggregate based pavement fails as a result of moisture related distress. Failed asphaltic mixture due to moisture ingress is a major problem for State and Federal highway agencies in Nigeria for many years, as is evidenced by increasing budget needs for maintenance and rehabilitation. Water reduces the cohesive strength of the mastic and weakens the pavement’s ability to resist damage due to pore pressure and premature cracking. Moisture is an arch enemy of road, which can be tackled by improving design, construction and road maintenance. The aim of the study is to assess the influence of XL-Bond nanochemical on strength indices of weak lateritic soil.

2 Methodology
The geotechnical properties of lateritic soil used were determined from these tests: sieve analysis, Atterberg limit (Liquid Limit, Plastic Limit), Compaction Test, California Bearing Ratio (CBR) and Unconfined compressive strength. The technical specification of the XL-Bond nanochemical used is presented in Table 1.

| Property         | Description                                      |
|------------------|--------------------------------------------------|
| Appearance       | Pale clear to light honey color in concentrate form.|
| Viscosity at 25 ºC | 500-800 CPS                                    |
| Specific gravity | 1.05 at 25 ºC                                    |
| Solubility       | Mixable with Water, Soluble in Methanol          |
| Flash Point      | 100 ºC (212 F) / non-flammable                   |
| XL-Bond          | 1 kg : 200 liters of water                       |
| Penetration      | 3-7 mm                                           |

2.1 Laboratory Test
(i) Sieve Analysis
The equipment used for include: set of sieves, mortar and pestle, weighing balance, wash bottle, mechanical sieve shaker, measuring can and porcelain dish. The analysis was done in accordance with the provision of BS1377: Part 2, 1990 [5]. Five hundred (500) g of air-dry representative
soil sample were placed on the sieve No. 200 and washed through the sieve using distilled water until the water passing through the sieve were clear. Then the dish and the remaining soil-water suspension were dried in oven for at 110 °C. The stack sieves were placed in electrical shaker and the weighed test soil were poured into the topmost sieve. The stacked sieves were clipped into the shaker and shaken for 15 min electronically. The sieves were removed and carefully separated. The particles retained on each sieve were weighed, expressed in gram and percentage weight of the sample. Equations 1, 2 and 3 were used for the calculation.

\[
\text{Weight passing a sieve} = \text{Weight of Dry Sample} - \text{Weight Retained on the Sieve}
\]

\[
\% \text{ Weight Retained} = \left( \frac{\text{Weight Retained}}{\text{Total dry weight of sample}} \right) \times 100\% \tag{1}
\]

\[
\% \text{ Weight Passing} = 100\% - \% \text{Percentage Retained} \tag{2}
\]

\[
\text{Cumulative \% Weight Retained} = \left( \frac{\text{Cumulative Weight}}{\text{Total dry weight of sample}} \right) \times 100\% \tag{3}
\]

(ii) Consistency Limit Test

The apparatus used for this test are Liquid- limit device with grooving tool, moisture cans, plastic limit plate, weighing balance, sieve and its pan. The test was done in accordance with the provision of BS1377 (No. 40: BS sieve (0.425). The concentration of XL-Bond nanochemical used was 2.5 g/l.

To determine the Liquid limit test of lateritic soil, 120 g of the lateritic soil were weighed and placed upon the glass plate. The soil was thoroughly mixed using spatula with XL–Bond nanochemical as additive at 2, 4, 6 and 8% of the soil weight, until the consistency of a thick paste was achieved. The apparatus cups were half-filled with the wet soil and levelled. The soil was spread out on the plate to dry. The soil sample was later mixed again, groove was made and the cup was turned at two rotations per second. The cups were dropped until the two parts of the soil along the groove touched. The number of blows at which the closure of groove occurred were recorded and the moisture content was of the soil was determined. The moisture content corresponding to each number of blows represents the Liquid limit.

To determine the Plastic Limit test, 15 g of the lateritic soil were weighed and sieved through a (No. 40: BS sieve (0.425) in accordance to BS1377. The soil were mixed properly on the glass plate and nanochemical XL–Bond as additive in 2, 4, 6 and 8% by weight of soil...
respectively, were added to make it plastic enough to be moulded into small ball. The balls were rolled between the hand and glass plate to form into a thread. As the diameter of the thread decreases, it crumbles and its moisture content was determined as the plastic limit.

(iii) Compaction Test

The apparatus used are BS mould, displaced disk, base plate, a rammer, weighing balance, scraper, moisture cylinder and head pan. The dried lateritic soil samples that passed through the 4.75 mm BS sieve were used in line with the provision of BS1377: Part 2, 1990 [5]. Exactly 800 g of the soil samples were weighed and mixed with a measured volume of water and mixed with XL–Bond as additive in 2, 4, 6 and 8% by weight of the soil sample. The soil mixing was done using scoop and trowel. Five layers of the soil were put into the mould with filter paper covered base plate to remove adhesive force. Thereafter, 62 blows of 4.5 kg metal rammer were applied to each layer, static compaction were employed. After compaction, the excess soils were scrapped with a straight edge. And compacted soil weighed to determine the wet bulk density. A sample of the soil was taken from top and bottom of the compacted soil to determine the moisture content. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) were determined.

(iv) 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 done by using the established OMC and MDD of the soil determined from the static compaction method. The apparatus used include CBR equipment of 152 mm diameter × 178 mm height, compaction mould with collar and spacer disk 151 mm diameter × 61.4 mm height, compaction rammer, expansion measuring apparatus with dial guage reading to 0.01 mm, compression machine equipped with CBR penetration piston. Precisely 800 g of lateritic soil samples that passed through the 4.75 mm BS sieve were used for compaction. The lateritic soils were broken to avoid reduction of the natural size of the individual particles. The, 150 ml of water was added, and mixed with XL-bond as additive at 2, 4, 6 and 8% by weight of the soil. The mould was arranged and the lateritic soil was compacted. Eight test specimens were compacted at varying moisture content to determine OMC and MDD.
After compaction, collars were removed and compacted soil trimmed even using straight edge. The weight of the mould and compacted soil were measured and recorded. The mould was placed in the loading frame of the CBR machine and its plunger adjusted by lowering to 1.5 mm of the mould. The surcharge rings were placed and both penetration and load gauge readings were measured and recorded. The loadings and penetrations were also recorded from the bottom by inverting the mould. Moisture content of soil samples taken at the top and bottom of compacted soil were determined.

(v) Unconfined Strength Test

The apparatus used were compression device, evaporating dish, triple beam balance (sensitive to 0.1g), strain gauge and oven. The natural soil samples and the treated samples were compacted in 1000 cm$^3$ mould at their OMC. The samples were extruded, trimmed and placed centrally on the lower plate of a compression testing machine. A compressive force was applied to the specimen and records of axial deformation and force at regular interval until failure occurred were noted. The unconfined strength of soil sample was determined at the point on the stress strain curve at which failure occurred.

3 Results and Discussion

(a) Grain Size Analysis Test

Particle size analysis of soil determines its engineering properties. The analysis gives the grain size distribution which is used to classify the soil. The sieve analyses of Sample A and B are presented in Tables 2 and 3. Results showed that samples A and B are silty-clay according to AASHTO classification system. The samples are not suitable for subgrade, sub-base and base, because they failed the specific requirement which is, the percentage passing through the sieve No. 200 are greater than 35% and must be stabilized for highway application.

The results of Liquid Limit (LL), Plastic Limit (PL) and Plastic Index (PI) of lateritic samples stabilized with XL-bond at 0, 2, 4, 6 and 8% by weight are presented in Tables 4 and 5. The liquid limit values of the entire samples met the AASHTO classification system requirements which specify material for subgrade course which are greater than 35%. The plastic index of the entire samples collected met the requirement specifies material for subgrade course which is
below 30%. Also, sample A and sample B met the requirement specification for sub-base and base course which is PI must be below 10%.

Table 2. Sieve analysis result of sample A

| Sieve Diameter (mm) | Mass Retained | Percentage Retained (%) | Percentage Passing (%) |
|---------------------|--------------|--------------------------|------------------------|
| 20                  | 0            | 0.00                     | 100.00                 |
| 8                   | 22.4         | 4.48                     | 95.52                  |
| 4                   | 24.4         | 4.88                     | 90.64                  |
| 2                   | 33.8         | 6.76                     | 83.88                  |
| 1                   | 34.9         | 6.98                     | 76.90                  |
| 0.71                | 30.3         | 6.06                     | 70.84                  |
| 0.425               | 38.9         | 7.78                     | 63.06                  |
| 0.355               | 27.4         | 5.48                     | 57.58                  |
| 0.25                | 31.7         | 6.34                     | 51.24                  |
| 0.125               | 36.5         | 7.30                     | 43.94                  |
| 0.075               | 24.8         | 4.96                     | 38.98                  |
| <0.075              | 194.90       | 38.98                    | 0.00                   |
Table 3. Sieve analysis results for sample B

| Sieve Diameter (mm) | Mass Retained (g) | Percentage Retained (%) | Percentage Passing (%) |
|---------------------|-------------------|--------------------------|------------------------|
| 20                  | 0                 | 0.00                     | 100.00                 |
| 8                   | 3.5               | 0.70                     | 99.30                  |
| 4                   | 8.5               | 1.70                     | 97.60                  |
| 2                   | 14.0              | 2.80                     | 94.80                  |
| 1                   | 30.0              | 6.00                     | 88.80                  |
| 0.71                | 20.8              | 4.16                     | 84.64                  |
| 0.425               | 35.7              | 7.14                     | 77.50                  |
| 0.355               | 17.6              | 3.52                     | 73.98                  |
| 0.25                | 28.5              | 5.70                     | 68.28                  |
| 0.125               | 50.9              | 10.18                    | 58.10                  |
| 0.075               | 17.9              | 3.58                     | 54.52                  |
| <0.075              | 272.6             | 54.52                    | 0.00                   |

Table 4. Summary of Atterberg Limit test for 0-8% XL-bond sample A

| Type of Test                  | 0%   | 2%   | 4%   | 6%   | 8%   |
|-------------------------------|------|------|------|------|------|
| Mass of empty can (g)         | 42.8 | 42.8 | 43.0 | 46.8 | 45.2 |
| Mass of can + wet soil (g)    | 51.1 | 47.6 | 47.3 | 55.0 | 50.1 |
| Mass of can + dry soil (g)    | 48.5 | 45.9 | 45.8 | 52.1 | 50.4 |
| Mass of moisture (g)          | 2.6  | 1.7  | 1.5  | 2.9  | 2.5  |
| Mass of dry soil (g)          | 5.7  | 3.1  | 2.8  | 5.3  | 5.2  |
| Moisture content (%)          | 45.6 | 54.8 | 53.6 | 54.7 | 48.1 |
| Number of blows               | 35   | 23   | 21   | 18   | 20   |
| Liquid Limit                  | 40   | 36   | 38   | 44   | 42   |
| Plastic Limit                 | 35   | 30   | 35   | 39   | 35   |
| Plastic Index                 | 5    | 6    | 3    | 5    | 7    |
Table 5. Summary of Atterberg Limit test for 0-8% XL-bond sample B

| Type of Test                  | 0%   | 2%   | 4%   | 6%   | 8%   |
|------------------------------|------|------|------|------|------|
| Mass of empty can (g)        | 42.9 | 47.0 | 46.7 | 43.2 | 42.0 |
| Mass of can + wet soil(g)    | 50.8 | 55.1 | 54.6 | 53.9 | 50.4 |
| Mass of can + dry soil(g)    | 48.5 | 52.6 | 52.1 | 50.3 | 48.0 |
| Mass of moisture(g)          | 2.3  | 2.5  | 2.5  | 3.6  | 3.0  |
| Mass of dry soil(g)          | 5.6  | 5.6  | 5.4  | 7.1  | 6.0  |
| Moisture content (%)         | 41.1 | 44.6 | 46.3 | 50.7 | 50   |
| Number of blows              | 41   | 37   | 28   | 15   | 18   |
| Liquid Limit                 | 40   | 44   | 44   | 42   | 45   |
| Plastic Limit                | 37   | 38   | 39   | 39   | 40   |
| Plastic Index                | 2    | 6    | 5    | 3    | 5    |

(b) Compaction Characteristics of the Soil:

The compaction characteristics, CBR and UCS results of natural and stabilized Samples A and B are presented in Tables 6, 7 and 8. The MDD decreases as percentage of stabilizer (XL-bond) increases. This in agreement with earlier findings [2, 6] which showed decreasing trends of MDD with an increasing OMC and stabilizing agents. For the soaked samples, it falls within the range of 10-25% CBR values specified for subgrade soils by the AASHTO standard and the Nigerian Highway Design Manual Federal Ministry of Works and Housing. The unsoaked CBR ranges from 10-50% for sample A and 20-40% for sample B which met the specification for Federal Ministry of Works and Housing for subgrade, sub base and base materials are <10, <30 and <80%, respectively. However, it was noticed that an increase in the nanochemical additives causes a tremendous increased in compressive strength. The optimum percentage of XL-bond chemical was 6% which produced the highest values of corresponding compressive strength. In order words, the more the addition of XL-Bond, the more the strength gained.
4 Conclusion and Recommendations

From this study, the following conclusions were deduced: The geotechnical properties of the lateritic soil shows that the percentage passing sieve No 200 for Sample A and B are 38.98 and 54.52%, respectively. The soil falls into A-5 and 6 Soils. The liquid limit values of the entire samples meet the AASHTO classification system requirements, which specify material for subgrade course must be greater than 35%. The MDD decreases with an increase in stabilizer (XL-Bond). The MDD of lateritic soil decreases with an increasing OMC and stabilizing agents. The inclusion of XL-bond increases the strength indices of the weak lateritic soil.

Based on the obtained result from this study, the following recommendations are suggested:
(i) Further research works should be embarked upon in stabilization using other types of nanochemicals such as Zycoprim, Elastobar and Zycosil.
(ii) The Nigeria General Specification [7] did not specify CBR requirement for nanochemical in soil stabilization, hence results from this study can serve as a baseline formulation for the specifications.

Acknowledgement

The authors acknowledge the academic and technical staff of Department of Civil Engineering, LAUTECH, Ogbomoso for creating enabling environment for research.
Table 6. Compaction test for stabilized laterite samples

| XL - Bond Solution (%) | Sample A | Sample B |
|------------------------|----------|----------|
|                        | OMC (%)  | MDD      | OMC (%)  | MDD (g/cm³) |
| 0                      | 10.50    | 2.42     | 12.50    | 1.96        |
| 2                      | 13.40    | 2.35     | 14.00    | 1.50        |
| 4                      | 13.60    | 2.34     | 14.20    | 1.50        |
| 6                      | 13.80    | 2.32     | 14.40    | 1.46        |
| 8                      | 14.0     | 2.30     | 14.40    | 1.44        |

Table 7. CBR results of soil samples

| XL - Bond Solution (%) | Sample A | Sample B |
|------------------------|----------|----------|
|                        | Unsoaked CBR (%) | Soaked CBR (%) | Unsoaked CBR (%) | Soaked CBR (%) |
| 0                      | 10       | 12       | 20       | 4          |
| 2                      | 23       | 18       | 21       | 6          |
| 4                      | 30       | 20       | 26       | 9          |
| 6                      | 38       | 20       | 35       | 14         |
| 8                      | 50       | 23       | 40       | 20         |
Table 8. Results of unconfined compressive strength for soil samples

| XL-Bond Sample (%) | UCS (kPa) Sample A | UCS (kPa) Sample B |
|--------------------|-------------------|-------------------|
| 0                  | 59                | 72                |
| 2                  | 64                | 79                |
| 4                  | 70                | 85                |
| 6                  | 75                | 90                |
| 8                  | 63                | 88                |

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