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Improvement of lateritic soil using shredded plastic bottles for road construction in Jos-South, Plateau State of Nigeria

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Abstract

Some geotechnical properties of lateritic soil treated with plastic shred were assessed. The test method employed involves treating lateritic soil with Plastic shreds in the percentages of 0%, 0.5%, 1.0%, 1.5%, and 2.0% by dry weight of soil. Test carried out include preliminary test, compaction test using British Standard light (BSL) and Unconfined compressive strength (UCS) test and shear strength test. One-way analysis of variance (ANOVA) and Regression Analysis was carried out using Microsoft Office Excel software. Percentage passing BS No 200 sieve (%) was 19.34. The MDD initially increased from its natural value of 1.70Mg/m^3 to 1.77Mg/m^3 at 0.5% PS content, while OMC increased with increase in PS. The UCS increased from 51 kN/m^2 for the natural soil to 72 kN/m^2 at 0.5% shredded plastic content and thereafter, a decrease in UCS was observed with further increase in the percentage of shredded plastic (1%, 1.5%, and 2%). The angle of internal friction increased by about 11% and the cohesion coefficient increased by 12%; bearing capacity increased generally with an increase in PS from 147 kN/m^2 natural to 215 kN/m^2 at 2%. ANOVA analysis shows that shredded plastic has a significant effect on the treated lateritic soil. Based on the result obtained, an optimal 2% of PS content improved the index and strength characteristics of the treated soil and is recommended for geotechnical engineering application based on regulatory standards.

Keywords: Shredded plastic; Lateritic soil; Road construction; Improvement; Bearing capacity

1. Introduction

Laterites are formed from the leaching of parent sedimentary rocks, metamorphic rocks and igneous rocks which leaves the more insoluble ions of mainly iron and aluminum [1]. It has been stated by [2] that lateritic soil is a residual of rock decay that is yellowish, reddish-brown, and red with or without nodules or concretion and has a high content of oxides of iron and hydroxides of aluminum and a low proportion of silica. Lateritic soils depending on the number of halloysites and montmorillonites are known to be expansive with the varying decree of expansivity. When lateritic soil contains a large number of clay materials, its strength and stability cannot be guaranteed under load especially in the presence of moisture. The improvement in the strength and durability of lateritic soil in recent times has become imperative which has geared up researchers towards using stabilizing materials that can be sourced locally at a very low cost. These local materials can be classified as either agricultural or industrial wastes. The ability to blend the naturally occurring lateritic soil with some chemical additives to give it better engineering properties in both strength and waterproofing is very essential. Technically, soil can be improved either by modification or stabilization, or both. Soil modification is the addition of a modifier (cement, lime, etc.) to a soil to change its index properties and improve its workability, while soil stabilization is the treatment of soils to improve their strength and durability such that they become totally suitable for construction beyond their original classification [3]. Soil stabilization is the alteration of soil to enhance their properties. Stabilization can increase the shear strength of soil and/or control the shrink-swell properties of soil, thus improving

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the load bearing capacity of lateritic soil to support foundations. Soil may be stabilized by the addition of binders such as cement and lime [4]. Soil stabilization is a process of achieving desired soil properties when they are low or unsuitable for the intended use [5] Primeval nations of the Chinese, Romans, and Incas used various approaches to increase soil strength, etc., some of these methods were so effective that their buildings and roads still exist today [6]. In recent times, cement and lime are used to improve soil properties [5]. In more recent times, engineers are looking to use wastes from agricultural products such as Rice Husk [7]; and industrial wastes such as disposable plastics [8]. The use of cement as a stabilizing agent is common. But with increasing awareness of environmental (mostly climate) derogation caused by the production process of cement; Cement is no longer a sustainable product [9] Hence, alternative binders are required. Binders from agricultural and industrial waste are viable [10].

Also, it has become a challenge to find eco-friendly methods to dispose of plastic waste from water and drink bottles, disposable cups, food packaging, plastic plates, etc. About 1.2 million bottles are being bought and indiscriminately dumped worldwide every year. [11]. From 1950 to 2018, about a billion tons of plastic waste have been produced worldwide, 9-12% of which have been incinerated or recycled [12]. These numbers are only increasing with time and increase in the human population and are expected to balloon in the years to come. As a way to dispose of the plastic waste, it has been assessed as an alternative soil stabilizer to cement. [13].

[14] investigated the impact of recycled plastic fibre on the geotechnical properties of soft Iraqi soil. In this research, plastic fibre was used as the stabilizer for the soft clayey soils of Baghdad, using different percentage concentrations of 1, 2 and 4% (the proportion of stabilizing matter to soil net weight) of the dried soil. Geotechnical properties for stabilized and non-stabilized clayey soil where determined. The geotechnical properties studied were Particle size distribution (PSD), Atterberg limits, unconfined compressive strength (UCS), compressibility, and California bearing ratio (CBR). Results show that plastic fibre content has a remarkable effect on the liquid content, plastic behaviors, and plasticity index. The liquid limits decrease as the percentage of plastic fibre increases while the plastic limit increases, which caused a great reduction in plasticity index. This decrement approached 50% with the addition of 4% plastic fibre to the clayey soil. Addition of different percentages of plastic fibre led to noticeable decreases in maximum dry unit weight up to approximately 11% by adding 4% plastic fibre, while the optimum moisture content reduction approached 7.5%. The effect of plastic fibre was also clearly shown on the unconfined compressive strength of soils; the increase in the unconfined compressive strength approached 180% with the addition of 4% plastic fibre. The ratio of compression index (cc) to recompression index (cr) reduced as the percentage of plastic fibre increased up to 2%, although it increased after this point. Finally, the California Bearing Ratio (CBR) increased as the plastic fibre content increased, with this increment approaching 210 % when adding 4% plastic fibre.

[2], from his study tilted stabilized lateritic soil by use of extensible fibre reinforcement. Both natural and synthetic fibres were used. Direct shear test was performed on lateritic soil with different types of fibre. Results indicate that fibre reinforced lateritic soil has increased peak strength and modified the stress-deformation. Shear strength increase was greatest with placement of 0-60 with respect to shear surface while 120 angle indicated the least of laterite. The research also revealed that inextensible earth reinforcement (high modulus metals) give lower shear strength. Shear strength was shown to be highest at 50% reinforcement.

[15] studied the uses and benefits of natural and synthetic fibers, and their main conclusion was that natural and synthetic fibers can be used in six geotechnical engineering fields: pavement layers, earthquakes, soil foundations, protection of slopes, retaining walls, and railway embankments. This research investigates the suitability of plastic shreds as a stabilizer for compacted lateritic soil in improving its UCS and bearing capacity.

2. Material and methods

2.1. Lateritic Soil

Lateritic soil was obtained from a borrow pit in Kwang ($9°50'24.6''N$ $8°55'14.1''E$), Jos-South Local Government Area of Plateau State at a depth of approximately 1m below the surface. Below is the location map.

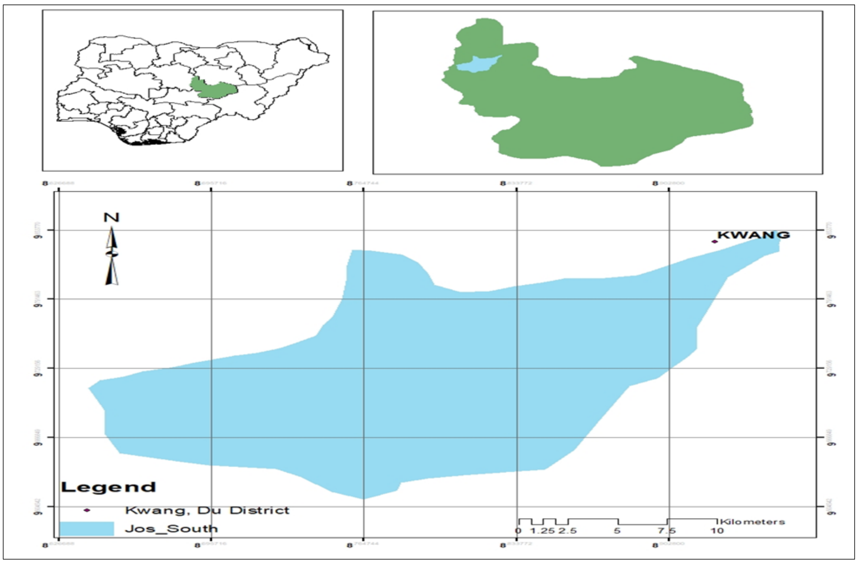

Figure 1 Location map of Kwang

2.2. Plastic Shreds

This was obtained from cutting waste Swan Water Bottles into shreds of average 0.5mm thickness and 10mm length by hand. The "Swan Water Bottles" where obtained from around the areas of University of Jos Permanent Site Campus.

Figure 2 Shredded plastic

2.3. Methods

2.3.1. Index properties

Index property tests were carried out on both the natural and the treated soils in different percentages of Plastic shreds by dry weight of lateritic soil all in accordance with the BS 1377 (1990) part 2 and BS 1924 (1990).

2.3.2. Compaction test

The compaction characteristics of both the natural and the treated soils in different percentages of Plastic shreds by dry weight of soil were carried out all by the BS 1377 (1990) part 2 and BS 1924 (1990). Using the BSL energy.3 kg of the soil/soil-admixtures sample was mixed thoroughly with 8% of water (the water was added at 8% for each of the compaction). Soil samples were compacted in 1000 cm^3 cylindrical mold of mass M_1; in three layers each layer received 27 blows of 2.5 kg rammer falling through a height of 300 mm. The blows were uniformly distributed over the surface of each layer during compaction. The collar was then removed and the compacted sample leveled off at the top of the mold with a straight edge. The mold containing the leveled sample was then weighed as M_2. Two small samples were then taken from the compacted soil for the determination of moisture content. The sample was then removed from the mold, crushed, and water added at (8%), and the same procedure was repeated until a minimum of five sets of samples were taken for moisture content determination. The bulk density ρ in Mg/m^3 was calculated for each compacted layer using Equation 1:

$$\rho = \frac{M_2 - M_1}{1000} \quad \text{......} \quad (1)$$

The dry density ρ_d was calculated using Equation 2:

$$\rho_d = \frac{100\rho}{(100 + w)} \quad \text{......} \quad (2)$$

Where: w is the moisture content of each compacted layer.

The values of the dry densities as obtained from Equation 2, were plotted against their respective moisture contents. The MDD and OMC were deduced from the curve.

2.4. Unconfined Compressive Strength Test

The UCS tests were performed on the soil samples according to BS 1377 (1990), for soils compacted with BSL energy. 3 kg of the natural soil sample/treated soil samples were compacted in 1000 cm^3 cylindrical molds at their respective OMCs.The samples were extruded from the cylindrical molds and trimmed into a cylindrical specimen of 38.1 mm diameter and 76.2 mm length. The three cylindrical specimens from the mold were cured for 7 days. At the elapsed day of curing, the specimens were then placed on the lower platen of a compression testing machine and a compressive force was then applied on the specimen with a strain control at 0.10% mm. The record was taken simultaneously of the axial deformation and the axial force at regular intervals until failure of the sample occurs. The UCS of the sample was determined at the point on the stress-strain curve at which failure occurred. The UCS was calculated using Equation 3.

$$UCS = \frac{Failure\ load}{Surface\ area\ of\ specimen} \quad \text{......} \quad (3)$$

2.4.1. Direct Shear Test

This includes the testing of a square prism of the soil of 3600 × 3600 mm that is laterally restrained and sheared along a mechanically involved horizontal plane while subjected to pressure applied along a plane normal to the shear plane. The shearing resistance was measured at regular intervals using data loggers and tests were carried out with three samples using different normal pressures; 40 KN/m^2 , 80 KN/m^2, and 120 KN/m^2, until the shearing resistance reached the maximum sustained value. The relationship between measured shear stress failure and normally applied stress obtained would enable the effective shear strength parameters and the angle of internal friction to be obtained.

3. Results and discussion

3.1. Soil Index Properties

3.1.1. Particle Size Distribution

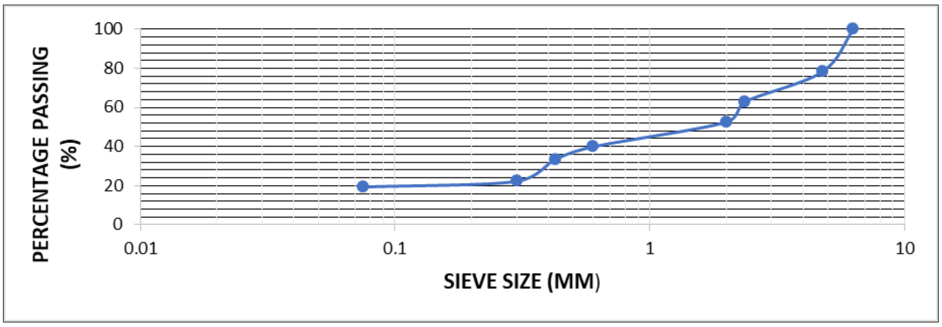

Figure 3 The Particle size distribution curve of natural soil

The soils Particle Size Distribution (PSD) is represented with the PSD curve in Figure 1.

Table 1 Index Properties of Natural Soil

Property	**Quantity**
Percentage passing BS No 200 sieve%	19.34
Natural Moisture Content, %	13.20
Liquid Limit, %	37.60
Plastic Limit, %	29.40
Plasticity Index, %	20.73
Linear Shrinkage, %	8.20
Free Swell, %	20.76
Specific Gravity	2.66
AASHTO Classification	A-1-b(0)
USCS	SC
Maximum Dry Density, Mg/m^3	1.70
Optimum Moisture Content, %	20.20
Unconfined Compressive Strength, kN/m^2	126.83
Cohesion (KN/m^2)	33.98
Angle of Internal Friction (°)	34.18
Direct Shear Test, kN/m^2	215
Colour	Reddish Brown

Table 2 Physiochemical Composition of Lateritic soil

Oxide Composition	**Lateritic Soil**
SiO_2	35.60
Al_2O_3	27.40
Fe_2O_3	24.0
P_2O_5	-
SO_3	0.85
K_2O	-
TiO_2	-
MnO	2.00
Na_2O	-
CuO	-
CaO	0.28
ZnO	0.09
MgO	-
Loss of Ignition	14.6

3.2. Effect of Plastic Shreds on Atterberg Values of Soil

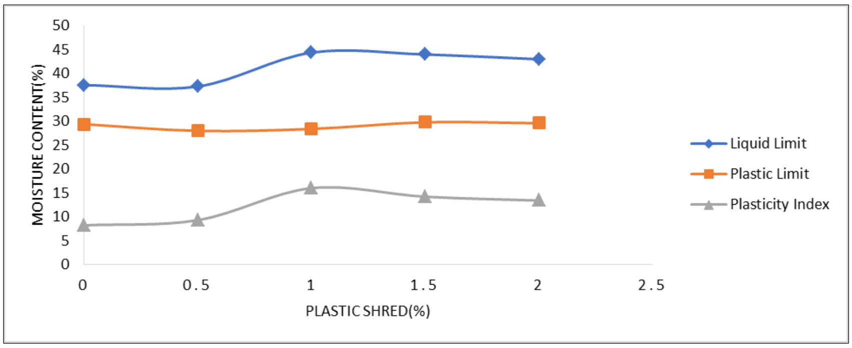

Figure 4 Effect of Plastic shreds on Liquid and Plastic Limit and Plasticity Index

3.3. Effect of Plastic Shred on Density of soil

The Maximum Dry Unit Weight of the soil was seen to decrease with increase in Plastic Shred content. See Figure 5

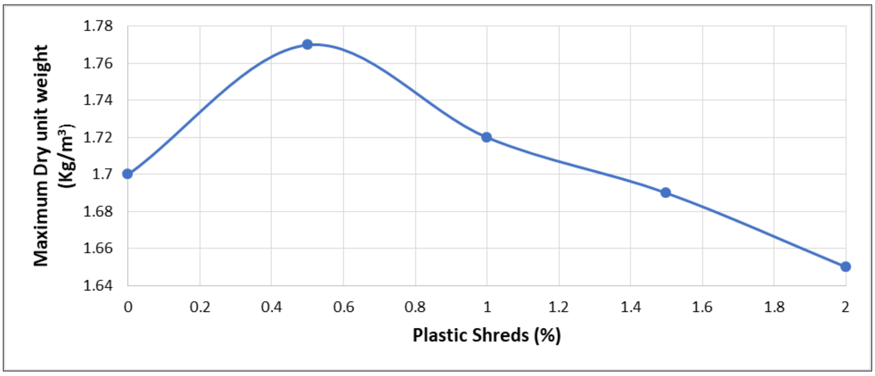

Figure 5 Graph of Unit weight against additive

One – way analysis of variance (ANOVA) test on the OMC results shows that the effects of shredded plastic on lateritic soil was statistically significant (FCAL = 805.2941> FCRIT = 5.32).

3.4. Effect of Plastic Shred on Optimum Moisture Content of Soil

The water required to reach maximum soil strength increases with increase in Plastic Shred content. On average the 0.5 to 1.5% of PS content of the PS stabilized soil was below the OMC of the Natural Optimum Moisture content while 2% was above Natural OMC. See Figure 6

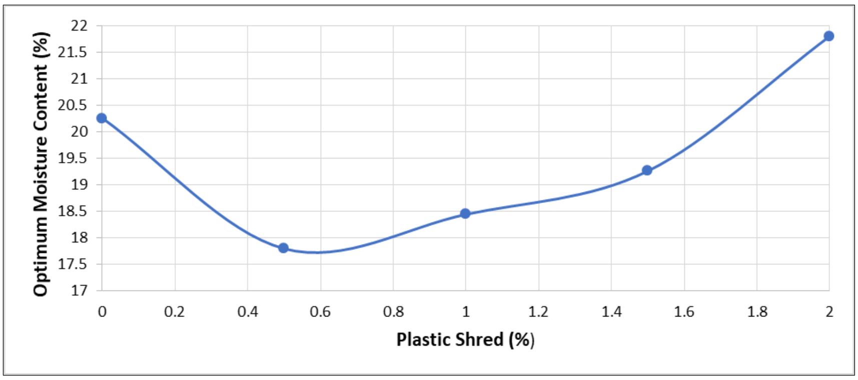

Figure 6 Graph of Optimum Moisture content against additive

3.5. Unconfined Compressive Strength

The unconfined compressive strength (UCS) test was carried out in order to understand how the soil sample will behave under compressive loads and particularly important in establishing the stabilization potential of an additive (Prabakar and Sridhar (2002) and for subsequent evaluation of the material for use as a pavement material (Bahrami et al., 2016). The UCS increased from 51 kN/m^2 for the natural soil to72 kN/m^2 at 0.5% shredded plastic content and thereafter, a decrease in UCS was observed with further increase in the percentage of shredded plastic (1%, 1.5% and 2%) signifying a decrease in the strength of the sample. The maximum value in strength is achieved corresponding to the optimum plastic content i.e 0.5% plastic content.

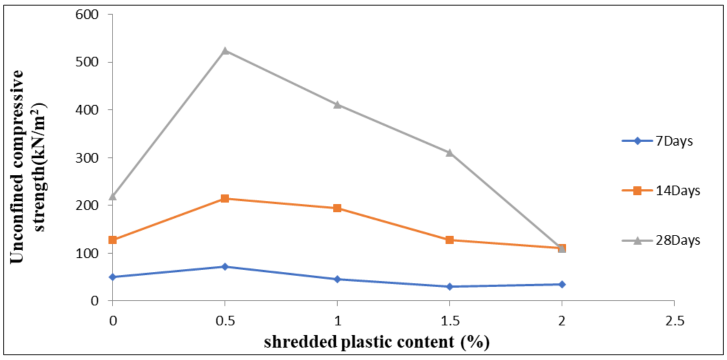

Figure 7 Variation of Unconfined Compressive Strength of lateritic soil – shredded plastic mixtures for 7 Days

One – way analysis of variance (ANOVA) test on the UCS result shows that the effects of PS on lateritic soil were statistically Significant (FCAL =39.12418 > FCRIT = 5.318).

3.6. Effect of Plastic Shred on Shear Parameters of Soil properties

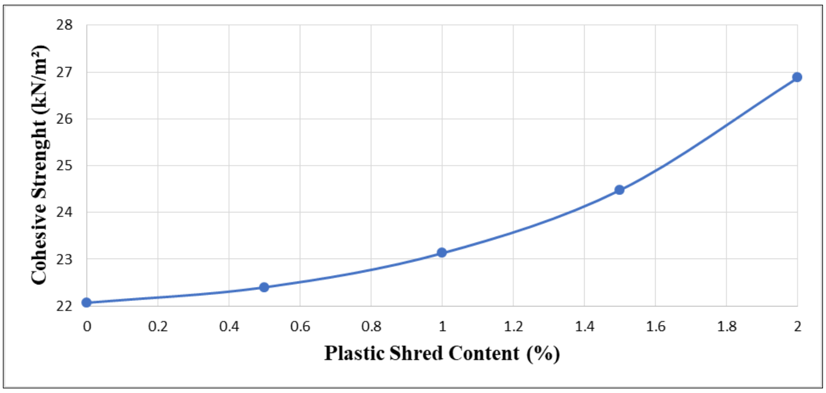

Figure 8 Effect of Plastic Shreds on Cohesive Strength of Soil

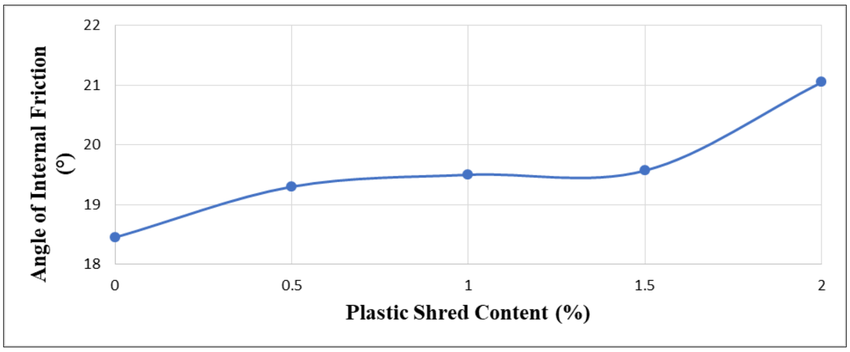

Figure 9 Effect of Plastic Shreds on Angle of Internal Friction of Soil

Increase in PS content caused an increase in the cohesive strength of the soil. See Figure 8. Also, the angle of internal friction (Ø) increased with increase in PS content. See Figure 9.

3.7. Effect of Plastic Shreds on Bearing Capacity

For an assume depth of 900mm, a strip footing of 690mm and Factor of Safety; the bearing capacity increased with increase in PS as indicated in Figure 10.

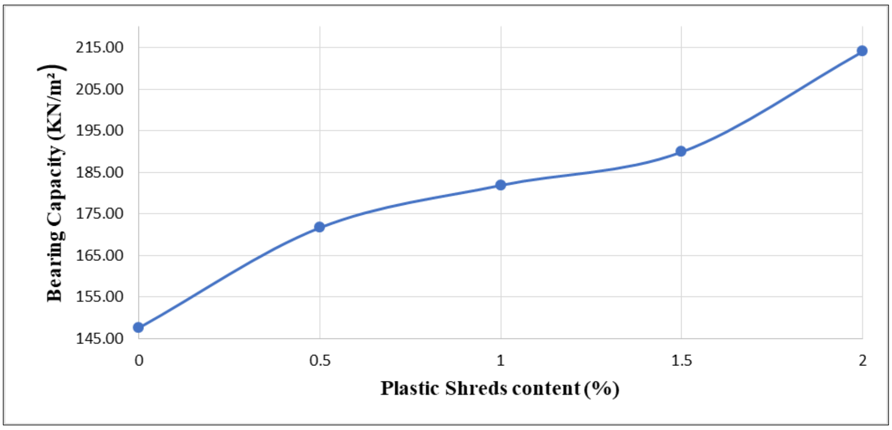

Figure 10 Effect of Plastic Shreds on Bearing Capacity of soil

4. Conclusion

The following were observed from the various tests carried out;

- The lateritic soil gotten from Kwang is classified as SC under the USCS classification.
- The unconfined compressive strength of the soil was found to increase maximally at 0.5% shredded plastic of all the curing periods and it was also observed that the strength of each of these samples increases with increase in the number of curing days.
- Further increase in the percentage of shredded plastic beyond 0.5% showed decrease in the MDD and the Unconfined Compressive Strength of the soil. This could be explained by the composition and shape of particles found in the plastic.
- The Angle of Internal Friction (Ø) is increased to approximately 11.3% by adding 2% of PS and the Cohesive Strength is increased by 12% by adding 2% of Plastic Shreds.
- The Bearing Capacity was also observed to increase by 45% adding 2% Plastic Shreds which is signifying an increase in strength.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

Authors declare no conflict of interest.

References

[1] Norton. Understanding Pottery Techniques. New York Studio Vista Publisher. 2000; 102-115.

[2] Ola SA. Stabilization of lateritic soil by extensive fibre reinforcement. Engineering Geology. 1989; 26(11): 125-140.

[3] Alhassan M. Potential of rice husk ash for soil stabilization. AUJT. 2008; 71(4): 246-250.

[4] Yao K, Yao Z, Song X, Zhang X, Hu J, Pan X. Settlement evaluation of soft ground reinforced by deep mixed columns. International Journal of Pavement Research Technology. 2016; 9(6): 460-465.

[5] Salahudeen AB, Ijimdiya TS, Eberemu AO, Osinubi KJ. Geotechnical properties and strength characterization of Nigerian soils, Umudike Journal of Engineering and Technology (UJET), Michael Okpara University of Agriculture, Nigeria. 2019; 5(1): 85 - 96.

[6] Satyam T, Nisheet T. Soil Stabilization Using Waste Fiber Materials. International Journal of Innovative Technology and Research. 2016; 4(3): 2927 – 2930.

[7] Mohammad AR, Mohammad S. Soil stabilization with non-conventional eco-friendly agricultural waste materials: experimental study. Transportation Geotechnics. 2018; 14: 52-60.

[8] Megnath N, Ugyen, Kezang W, Sherub T. Stabilization of Soil using Plastic Waste. Internal Journal of Emerging trends in Engineering and Development. 2012; 2(2): 461-466.

[9] Potgieter JH. An overview of cement production: How “green” and sustainable is industry? Environmental and Sustainable Development Journal. 2012; 1(2): 14-32.

[10] Babatunde JO, Opeyemi J, Hassan IO, Muhammad OE. Exploratory study on Agro-waste ashes combination with industrial binders in concrete. NBRRI 2017 International Conference at Abuja, Nigeria. 2017.

[11] Marçal R, Lodi PC, Correia NS, Giacheti HL, Rodrigues RA, McCartney Js. Reinforcing Effect of Polypropylene Waste Strips on Compacted Lateritic Soils. Sustainability. 1(12):9572 DOI: 10.3390/su12229572, 2020.

[12] Alabi OA, Ologbonjaye K, Awosolu O, Alalade OE. “Public and environmental health effect of plastic waste disposal” A Review, DOI: 10.23937/2572-4061.1510021, 2019.

[13] Ashraf A, Dhanya J, Joseph M, Sunil A. Soil stabilization using raw plastic bottles” Conference: Indian Geotechnical Conference. At Kochi, 2011.

[14] Salim N, Al-Soudany KY, Ahmed AA. The Impact of Using Recycled Plastic Fibres on the Geotechnical Properties of Soft Iraqi Soils. IOP Conference Series: Materials Science and Engineering, 433 012017, 2018.

[15] Hejazi SM, Sheikhzadeh M, Abtahi SM, Zadhoush A. A simple review of soil reinforcement by using natural and synthetic fibers Constr. Build. Mater. 2012; 30: 10016

[16] B.S.1377-2. Methods of testing soil for civil engineering purposes. British standards institute, London, 1990.

[17] B.S.1924-1. Stabilized materials for civil engineering purposes: 1990.