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Unconfined Compressive Strength of Compacted Lateritic Soil Treated with Selected Admixtures for Geotechnical Applications

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ABSTRACT

The unconfined compressive strength (UCS) of treated lateritic soil was assessed using correlation and reliability analysis. The soil was admixed with groundnut shell ash (GSA) and sisal fibre (SF) included in varying percentage of 0 up to 8% of GSA and 0 up to 1% of SF by dry weight of soil. The SF was treated with Sodium Borohydride ($NaBH_4$) (1%wt./vol.) to remove the cellulose present. Laboratory tests performed on the specimens included index properties, compaction test using British Standard Light and UCS test. Laboratory results were used to compute reliability indices using a FORTRAN based first order reliability program. The maximum dry density (MDD) decreased from 1.85Mg/m^3 for the natural soil to 1.73 Mg/m^3 at 0% GSA/1% SF content. Optimum moisture content (OMC) increased with GSA and SF addition. Correlation and reliability indices of the laboratory-based model shows that the independent parameters (GSA, SF, MDD and OMC) affect UCS with MDD and OMC having more effect. UCS increased from 101 kN/m^2 for natural soil to optimum value of 696.41 kN/m^2 at 0.75% SF/6%GSA content which met the minimum regulatory value for sub-base material and is recommended for use as sub-base material for rural roads.

1. INTRODUCTION

Design, construction, maintenance and management of buildings and other civil engineering structures on low bearing capacity soils could pose a threat to life and properties. Poor geotechnical properties of soils have been constantly linked to one of the causes of building and road failures (Akinyemi et al., 2016; Afolayan and Olalekan 2017). It was reported that some soils with low bearing strength are susceptible to swelling and shrinkage with moisture changes within the soil matrix (Amadi, 2010; Moses et al., 2019; Etim et al., 2019). The resultant effect of this behaviour often times lead to differential settlements, high compressibility, poor drainage condition and ultimately low bearing strength (Sakr et al., 2009). Laterite gravels are conventionally good for gravel roads alongside pisoliths, which are predominantly available in tropical countries such as Nigeria (Osinubi and Bajeh, 1994). There are exceptional cases where lateritic soils may contain a large proportion of clay minerals which has consequential effect on its engineering properties under loads. This type of lateritic soil is prevalent in various tropical zone, where in most circumstances sourcing other soils may well be uneconomical. Based on this, construction engineers are rather left with the option of modifying the existing soil properties to meet their minimum expected bench mark for civil engineering construction (Osinubi et al., 2006; Etim et al., 2019). Reinforced earth technique has proven to be an efficient ground improvement method because of its cost and easy adaptability (Okechukwu et al., 2016). Also, some studies have recorded some degree of achievement in strength (unconfined compressive strength) of deficient soil when treated with chemicals and or industrial waste stabilizers (Osinubi et al., 2015; Etim et al., 2017; Sani et al., 2019). Some lateritic soils are good for pavement applications in their natural form due to their very compatible engineering properties which makes them suitable for slope stability and various constructions. However, others need to be improved to achieve their desired suitability for pavement applications. Industrial or agricultural wastes admixed in cement or lime stabilization of deficient soil was reported to improve the soil behaviour for construction purpose (Osinubi, 2000, 2009; Amadi, 2011, 2014; Etim et al., 2014; Amadi and Osu 2016; Etim et al., 2017). This is much desired as it did not only help in enhancing the engineering properties of the soil at low cost but also contribute to disposal of these products which are subsequently neglected, occupying large expanse of land space, generating disposal difficulties and causing pollution to the environment.

Groundnut shell (an agricultural waste) constitutes an environmental problem and its effective disposal is important to the manufacturers of groundnut oil and other products. Groundnut shell is an agricultural waste from milling of groundnut, while groundnut shell ash (GSA) is obtained by burning the groundnut shell. Groundnut farms occupying up to 20,000,000 hectares of land are cultivated per year in many parts of the world (Madhusudhana, 2013). Nigeria is one of the largest producers of groundnut in the world and contributes about 7 percent of world groundnut production (Alabi et al., 2013; Edeh et al., 2013). In 2002, about 2,699,000 metric tons of groundnut were recorded to have been produced in about 2,783,000 hectares of land (Oriola and Moses, 2010). The World Bank's spending on research and development has been on the increase aimed at advancing the use of industrial and agricultural waste products for engineering and other applications (Harshwardhan and Upadhyay, 2017).

Each length of sisal fibre (SF) is normally added to the soil at different percentages to improve the engineering performance of soil (Prabakar and Sridhar, 2002). The notion of soil reinforcement using fibres was discovered over 5000 years ago (Abtahi et al., 2009). For instance, the popular Chinese world was reinforced with branches as tensile elements; woven mats were used to reinforce the Ziggurats of Babylon and so on. The habit of using high tensile fibres have become a widespread method in earthwork construction (Santhi and Sayida, 2009). Natural fibres include fibres of plant leaves, branches or roots, palm, sisal, abaca, straw, flax, etc. Synthetic fibres on the other hand include polypropylene fibres, polyester fibres, polyethylene fibers, polyvinyl fibres, glass fibres, steel fibres and the geosynthetic family (Roy, 1999; Prabakar and Sridhar, 2002; Santhi and Sayida, 2009; Sayyed et al., 2012).

The aim of this study was to explore the effect of GSA admixed with treated SF on the geotechnical properties of lateritic soil.

2. MATERIALS AND METHODS

2.1. Materials

The soil sample was sourced from a borrow pit in Zaria, Nigeria, (latitude 11° 15' N and longitude 7° 45' E), by disturbed sampling method. Groundnut shell ash was obtained from the burning of groundnut shell under normal temperature until the shell turned into ash. SF was sourced from Kaduna, Nigeria. According to the report of Tanko et al. (2018), SF contains cellulose which made it bio-degradable and thus could degrade with time. In other to overcome this challenge, the sisal fibre was treated with Sodium Borohydride ($NaBH_4$) (1% wt./vol.) based on recommendation of Moraes et al. (2011). The choice of 3.5 cm length of SF is based on the recommendation made by Tanko et al. (2018) who reported the highest strength attained for soil modified with SF was at fibre length of 3.5 cm.

2.2. Methods

2.2.1. Index properties

Index tests were carried out on the untreated (natural) soil in accordance with British Standard 1377 (1990).

2.2.2. Compaction test

Compaction test was done as described in British Standard 1377 (1990a) and British Standard 1924 (1990b) for both untreated and treated soils. For this test, about 3 kg of the soil/soil-admixtures were mixed thoroughly with 8% of water and repeated for each of the compaction. The sample was then compacted into the 1000 cm^3 of mass (M_1); in three layers each receiving 27 blows of 2.5 kg rammer falling through the rammer height of 300 mm. The bulk density (ρ_b) in Mg/m^3 was computed using Equation 1:

$$\rho_b = \frac{(M_2 - M_1)}{1000} \tag{1}$$

The dry density ρ_d in Mg/m^3 was also calculated using Equation 2:

$$\rho_d = \frac{\rho_b}{1 + w} \tag{2}$$

Where: M_1 is the mass of mould, M_2 is mass of mould plus soil and w is the moisture content of each compacted layer.

2.2.3. Unconfined compressive strength (UCS) test

The determination of UCS of both treated and untreated was done as described in British Standard 1377 (1990a) and British Standard 1924 (1990b) compacted using British Standard light (BSL) energy. The natural soil sample/treated soil samples were compacted in 1000 cm^3 mould at their respective OMCs. The compacted samples were then removed from the cylindrical mould and trimmed to 38.1 mm diameter and 76.2 mm length. Soil specimens extruded from the cylindrical mould were carefully wrapped using polythene materials and cured for the duration of 7 days. At the end of 7 days of curing, the soil specimens were subjected to a compression testing machine and a compressive force was applied on the specimen with a constant strain control. Record was taken simultaneously of the axial deformation and the axial force at regular interval until failure of the sample occurred. Equation 3 showed how the UCS was determined.

$$\text{Compressive strength} = \frac{\text{Failure load}}{\text{Surface area of specimen}} \qquad (3)$$

2.2.4. Statistical and sensitivity analysis procedures

Laboratory investigations were conducted to produce data that was used for sensitivity analysis. A regression equation was established by means of statistics software, Minitab R15 from results of laboratory investigations. The regression equation was then used as a limit state function in a FORTRAN program to produce reliability index values (in the range of 10-100% coefficient of variation). XLSTART 2017 software was used to carry out correlation studies while two-way analysis of variance (ANOVA) on the obtained results was examined using Microsoft excel.

3. RESULTS AND DISCUSSION

3.1. Material Characterization

The natural soil has 20.43 % moisture at natural state before air-drying, a free swell value of 20.76 %, and linear shrinkage of 7.87 % and specific gravity of 2.73. The reddish-brown soil was classified as A-7-6(10) according to American Association of State Highway and Transportation Officials classification (AASHTO, 1986) and CL based on the Unified standard classification system USCS (ASTM, 1992). Summary of the characteristics of natural soil is displayed in Table 1. Typical chemical composition of oxides of lateritic soil and groundnut shell ash is displayed in Table 2. The characteristics of the natural sisal fibre (SF) used in this study is presented in Table 3. The results show that the tensile strength of SF increased with number of strands. This indicates that multiple strands reinforced in soil might provide a better strength behaviour. Amongst other properties, the average diameter of SF was 0.13 mm.

Table 1: Characteristics of natural soil

Property	Quantity
Percentage passing BS No 200 sieve, (%)	57.5
Natural moisture content, (%)	20.43
Liquid limit, (%)	48.00
Plastic limit, (%)	27.27
Plasticity index, (%)	20.73
Linear shrinkage, (%)	7.87
Free swell, (%)	20.76
Specific gravity	2.73
AASHTO classification	A-7-6(10)
USCS	CL
Maximum dry density, (Mg/m^3)	1.85
Optimum moisture content, (%)	18.0
Unconfined compressive strength, (kN/m^2)	100
Colour	Reddish brown

Table 2: Oxide compositions of lateritic soil and groundnut shell ash

Oxide	Concentration (%)	
	Lateritic soil*	Groundnut shell ash**
SiO_2	41.82	33.36
Al_2O_3	25.12	6.73
CaO	0.061	10.91
K_2O	0.05	25.38
TiO_2	0.578	-
V_2O_5	0.013	-
Cr_2O_3	0.011	-
Fe_2O_3	17.52	2.16
MnO	0.015	-
MgO	0.83	4.72
ZnO	0.001	-
Na_2O	0.08	-
LOI	10.30	10.25

(*Etim et al., 2019; **Moses et al., 2019)

Table 3: Characteristics of the natural sisal fibre

Property	Quantity
Natural humidity, (%)	14.48
Average diameter, (mm)	0.13
Water absorption, (%)	340
Specific gravity, (g/cm^3)	0.22
Tensile Strength, (N/mm^2)	
One strand	10.60
Two strands	24.45
Three strands	30.60
Elongation at break, (mm)	5.58
Colour	Shiny white

3.2. Tensile Strength

The deviations of tensile strength (using 3 strands sisal fibre) of natural and treated sisal fibre carried out, after been buried in the lateritic soil to monitor its tensile strength for 90 days is shown in Figure 1. It was observed that the tensile strengths of untreated sisal fibre are higher than the treated sisal fibre, although beyond 30 days, the difference is marginal. The probable reason could be due to the exclusion of the cellulose present in the sisal fibre by the Sodium Borohydride. The tensile strength for the untreated sisal fibre decreased from its natural value of 30.60 N/mm^2 to 15.57 N/mm^2 after 7 days and after 90 days it decreased to a value of 5.03 N/mm^2. The tensile strength for the untreated sisal fibre decreased from its natural value of 30.60 N/mm^2 (Table 3) to 15.57 N/mm^2 after 7 days and after 90 days it further decreased to a value of 5.03 N/mm^2 (Figure 1). The tensile strength for the treated sisal fibre on the other hand declined from 27.31 N/mm^2 to 13.25 N/mm^2 after 7 day and maintain a uniform strength for the next 60 days before decreased to a value of 3.15 N/mm^2. This result indicates that the sisal fibre retains a constant strength for a longer time after been treated with Sodium Borohydride. The findings observed in this study mirror those of the previous studies that have examined the effect of rice husk ash admixed with treated sisal fibre on properties of lateritic soil (Sani et al., 2018).

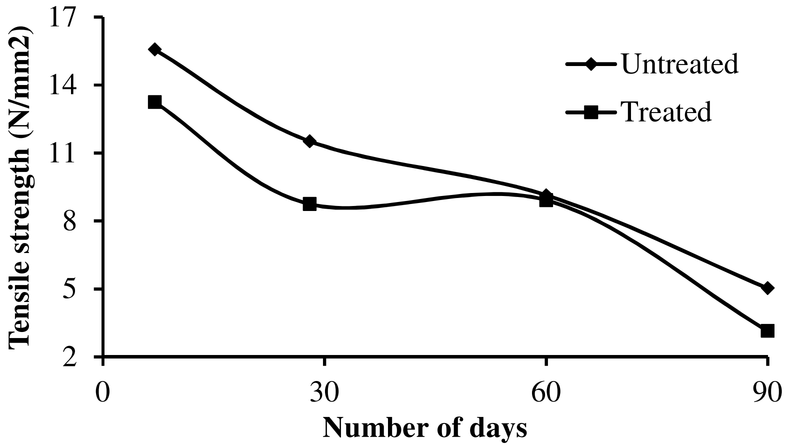

Figure 1: Tensile strength for natural and treated sisal fibre with number of days

3.3. Elongation/Extension

The change in elongation/extension of sisal fibre with number of days is shown in Figure 2. The result shows that the ability of the treated sisal fibre to elongate or extend beyond its elastic limit increased which suggest its ability to withstand axial load. The values obtain for the treated sisal fibre are higher than that of the untreated sisal fibre beyond 28 days of burying in the lateritic soil. Although there was an initial sharp decrease of the elongation value up to 28 days but beyond 28 days there was an increase i.e. from 3.02 mm to 4.45 mm for untreated sisal fibre and from 2.28 mm to 6.19 mm for the treated sisal fibre (Sani et al., 2018).

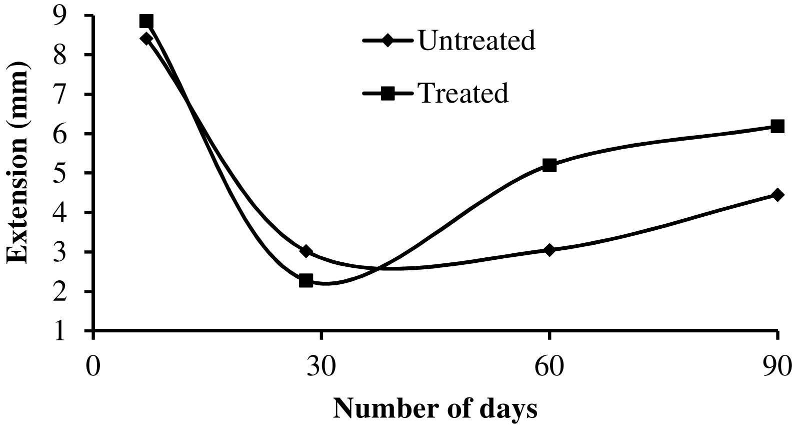

Figure 2: Elongation for natural and treated sisal fibre with number of days

3.4. Compaction Characteristics

3.4.1. Maximum dry density

The variations in MDD of lateritic soil- SF with GSA is shown in Figure 3. Generally, MDD values decreased with higher additive contents due to the presence of SF/GSA content filling the voids within the soil. The rise in fibre content caused a drop in the maximum dry density demonstrating that the values of the MDD generally decreased as the content inclusion increased. The MDD was observed to decreased from 1.85 Mg/m^3 from the natural soil to 1.68 Mg/m^3 at 0% GSA/SF treatment. For the 2, 4, 6 and 8% GSA, the MDD reduced from 1.72 to 1.67 Mg/m^3, 1.63 to 1.59 Mg/m^3, 1.60 to 1.54 Mg/m^3 and 1.55 to 1.48 Mg/m^3 respectively. This reducing trend in MDD can be attributed to the SF having low density as related to the density of the soil and thus reducing the average unit weight of the solids in the mixture (Sani et al., 2018). The fibres now occupying more space that soil was naturally supposed to, thereby creating some voids in the mixture. Results indicate that as the SF rise from 0 to 0.25% by dry weight of soil, a decline in MDD was recorded which further increased as the content increased from 0.25 to 0.5, 0.75 and 1.00 %. This trend recorded was in line with that recorded by (Prabakar and Sridhar, 2002; Santhi and Sayida, 2009; Chegenizadeh and Nikraz, 2011). Statistical examination of the test result by means of two-way analysis of variance (ANOVA) for MDD of lateritic soil-GSA mixtures with SF content show that the influenced of GSA and SF on the MDD were significant (F_{CAL} = 30.42918> F_{CRIT} = 3.006917) for GSA and (F_{CAL} = 4.96406> F_{CRIT} = 3.006917) for SF.

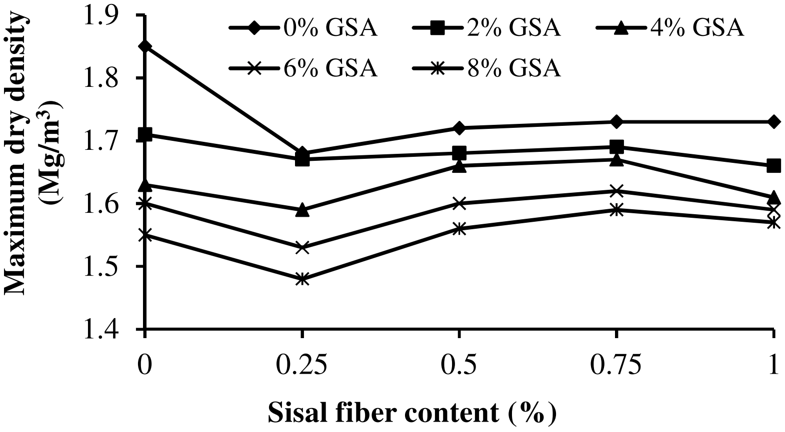

Figure 3: Plot of maximum dry density of soil-sisal fibre- GSA mixtures

3.4.2. Optimum moisture content

The change in OMC with GSA and SF content is shown in Figure 4. The OMC initially increased with rise in both GSA and SF content. Upon further increase in the fibre content, the OMC reduced as fibre content increased. This suggest that the fibre, which naturally had a high water absorption capacity, caused an initial increase in OMC from the plain state of the soil to 0.5 and 0.75% content of the fibre by dry weight of soil and subsequently reduced the OMC with rise in aspect ratio and percentage content. The OMC of the natural soil rise from 18 to 23% at 6 % GSA /0.75% SF. The OMC value later declined to a value of 22% as the SF content rise to 1%. This trend of decline in the OMC is principally associated with the fibre water absorption property of the SF. Similar behaviors were observed by Prabakar and Sridhar, (2002) as well as Santhi and Sayida, (2009) who used laterites soil and black cotton soils correspondingly. Statistical examination using ANOVA demonstrated that the impact of GSA and SF on the OMC were significant (F_{CAL} = 57.08343> F_{CRIT} = 3.006917) for GSA and (F_{CAL} = 9.661645> F_{CRIT} = 3.006917) for SF, with GSA having a more pronounced effect.

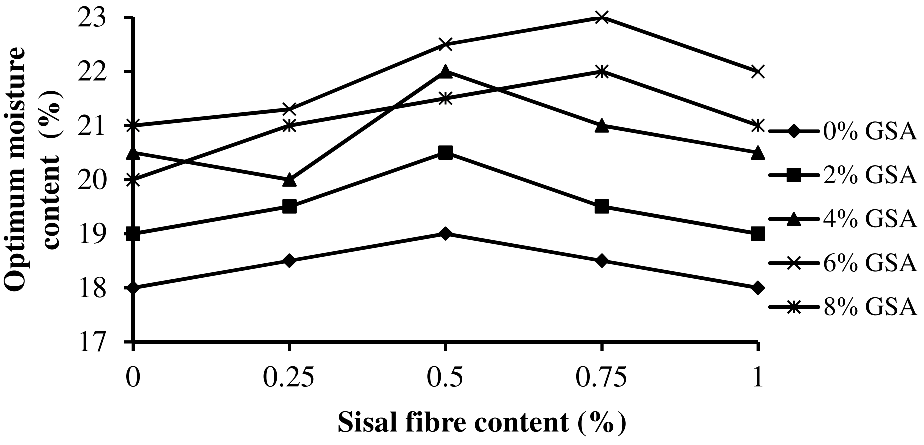

Figure 4: Plot of optimum moisture content soil-sisal fibre-GSA mixtures

3.5. Unconfined Compressive Strength

The UCS test was done to determine the properties of the soil under compressive loads (Singh, 1991) and for subsequently evaluating its suitability for pavement applications (Ola, 1983). The variation of the UCS test results of the soil-SF-GSA mixtures is shown in Figure 5.

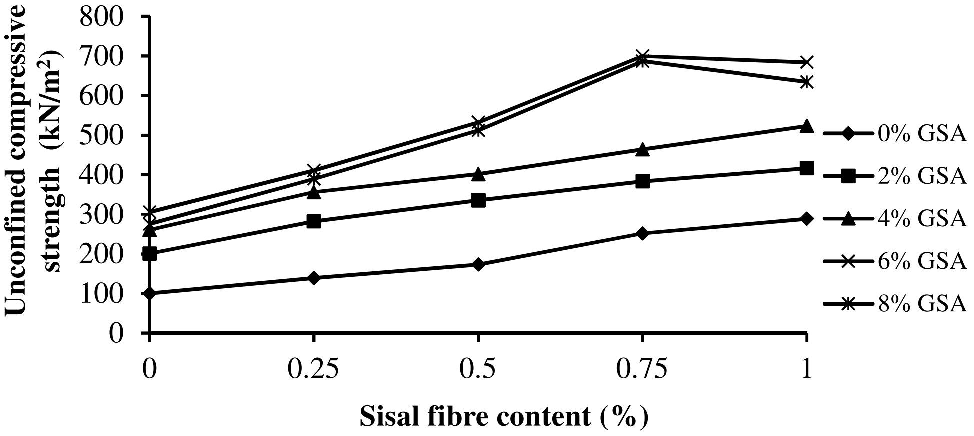

Figure 5: Plot of unconfined compressive strength (7 days curing period) soil-sisal fibre- GSA mixtures

The UCS value increased from 100.57 kN/m^2 for natural soil to 139.38 kN/m^2 at 0 % GSA/0.25 % SF content. This increasing trend continued to 699.41 kN/m^2 at optimum of 0.75% SF/6% GSA. The UCS values of the soil-GSA-SF mixed soil initially increased and thereafter decreased with fibre content. The initial increment with fibre content could be due to increase in friction developed between the soil and the reinforcing material; this led to transfer of the load that is built up in the soil mass to the reinforcement material (Deepjyoti et al., 2016). Further increase in the SF content beyond 0.75 % caused a decrease in the UCS values which may be due to SF occupying a lot of spaces and thereby creating more failure surfaces and the voids render it vulnerable to failure. The UCS values increased with GSA content due to availability of sufficient water which enhanced hydration reaction that has contributed to the reaction between lime liberated from the hydration reaction of GSA to form secondary cementation compounds. Similar statement was reported by (Osinubi and Medubi, 1997). Statistical examination using (ANOVA) for UCS of lateritic soil-GSA mixtures with SF content reveals the influence of GSA and SF on the UCS were highly significant (F_{CAL} = 37.03389> F_{CRIT} = 3.006917) for GSA and (F_{CAL} = 28.33891> F_{CRIT} =3.006917) for SF.

3.6. Correlation Analysis for Unconfined Compressive Strength

The correlation examination for UCS of SF treated lateritic soil using GSA as admixture is shown in Table 4. Parameters assumed to be associated with UCS (MDD; OMC; SF and GSA) shows some levels of relationships. High and Positive correlation exist between UCS and GSA (0.693; $P<0.05$, r=0.48); SF (0.627; $P<0.05$, r=0.394) and OMC (0.807; $P<0.652$, r = 0.652). In the case of UCS and MDD negative correlations was recorded, MDD (-0.568; $P<0.05$, r = 0.322). All the parameters associated with UCS (MDD; OMC; SF and GSA) have substantial influence on the UCS values. Comprehensive results of P-values and coefficient of determination (R^2) are displayed in Tables 6 and 7 respectively. Care should be taken to certify that these parameters are carefully examined during field compactions to achieve a durable pavement or anticipated result in any geotechnical engineering application.

Table 4: Pearson correlation matrix

Variables	UCS	GSA	SF	MDD	OMC
UCS	1				
GSA	0.693	1			
SF	0.627	0.000	1		
MDD	-0.568	-0.875	-0.004	1	
OMC	0.807	0.795	0.156	-0.674	1

Table 5: Table for p values

Variables	UCS	GSA	SF	MDD	OMC
UCS	0				
GSA	0.000	0			
SF	0.001	1.000	0		
MDD	0.003	0.000	0.986	0	
OMC	0.000	0.000	0.457	0.000	0

Table 6: Pearson coefficient of determination, R^2

Variables	UCS	GSA	SF	MDD	OMC
UCS	1				
GSA	0.480	1			
SF	0.394	0.000	1		
MDD	0.322	0.766	0.000	1	
OMC	0.652	0.632	0.024	0.454	1

3.7. Reliability Assessment

The regression equation (Equation 4) was used as a limit state function in a FORTRAN program to produce reliability index values (in the range of 10-100% coefficient of variation). The lists of variables used are contained in Table 7.

$$\mathrm{UCS} = -1419 + 26.5\mathrm{GSA} + 264\mathrm{SF} + 284\mathrm{MDD} + 54.2\mathrm{OMC} \tag{4}$$

$$R^2 = 94.1\%$$

Basically, graphical contribution of each of the parameters was displayed with the aid of a bar graph as shown in Figure 6.

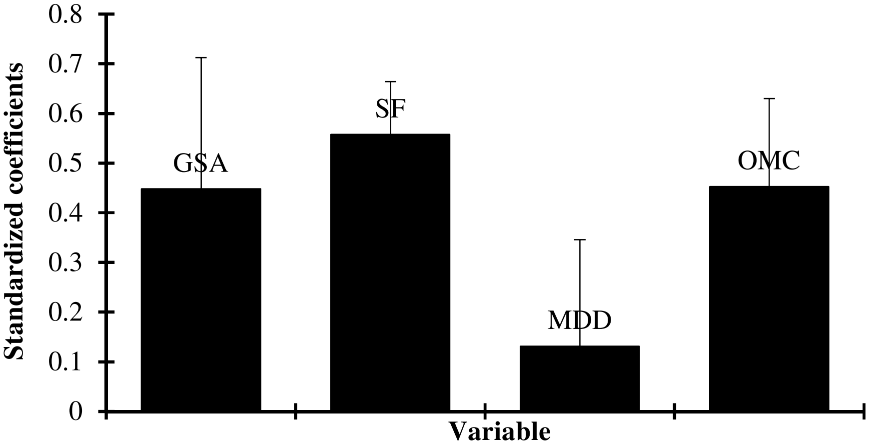

Figure 6: Plot of standardized coefficients of the variables at 5 % level of significance and 95 % confidence

Table 7: Laboratory measured input parameters for reliability-based design using FORM 5

S/N	Variables	Distribution type	Mean	SD	COV (%)
1	Unconfined compressive strength	Lognormal	388.3	170.9	44.01
2	Maximum dry density (MDD)	Lognormal	1.6388	0.0788	4.81
3	Optimum moisture content (OMC)	Lognormal	20.352	1.427	7.01
4	Sisal fibre (SF)	Normal	0.5000	0.3608	72.16
5	Groundnut shell ash (GSA)	Normal	4.000	2.887	72.18

UCS Unconfined compressive strength, SD Standard deviation, COV Coefficient of variation

3.7.1. Influence of unconfined compressive strength

The variation of reliability index for UCS of SF treated lateritic soil using GSA as admixture with coefficient of variation is shown in Figure 7. Results show a decline in the reliability indices with rise in the coefficient of variation. The reliability index lessened linearly with coefficient of variation from 10 to 100%. Reliability index changed significantly which indicate variability of UCS has drastic effect on the reliability index for road pavement sub-base materials. As coefficient of variation varied from 10 to 100%, reliability index varied between –0.368 to 0.0123. When computed with unconfined compressive strength value of 101 kN/m^2 for the untreated soil (natural soil), reliability indices changed from -2.02 to -1.78 (see Figure 8). The extensive variation in the reliability indices with coefficient of variation shows that GSA and SF significantly affect the UCS of the modified soil. The development in UCS with additives is justified with the marked escalation in reliability indices of the treated soil when compared to the untreated soil. End result demonstrate that GSA and SF improved the geotechnical properties of the soil indicated by the deviations in their reliability indices values and should be judiciously examined during field application.

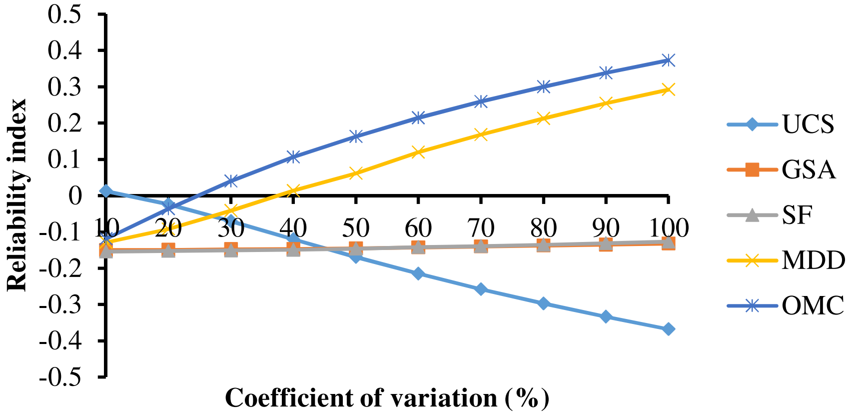

Figure 7: Plot of reliability index against coefficient of variation for treated soil

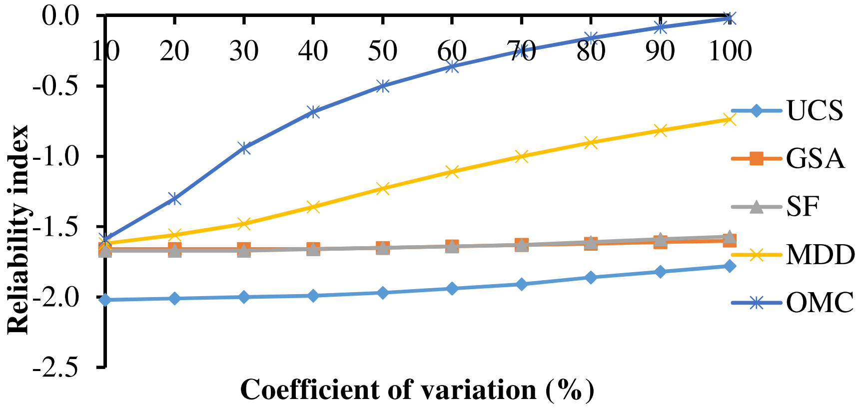

Figure 8: Plot of reliability index against coefficient of variation for untreated soil

3.7.2. Influence of groundnut shell ash content

The influence of GSA content on SF treated lateritic soil using GSA as admixture with coefficient of variation is shown in Figure 7. GSA content produced a linear increasing correlation with coefficient of variation within the range 10 -100 %. A marginal variation was observed with increase in the coefficient of variation which buttresses the fact that variability of GSA content has minor effect on the reliability index for use as road sub-base pavement structures. As coefficient of variation increased from 10 -100 %, reliability index values decreased from -0.15 to -0.132. When computed with unconfined compressive strength value of 101 kN/m^2 for the untreated soil (natural soil) reliability index varied from -1.66 to -1.6 (see Figure 8).

3.7.3. Influence of sisal fibre content

Results of variation of SF content on reliability index as the coefficient of variation changed from 10 – 100 % is shown in Figure 7. SF content produced an increasing association with coefficient of variation in the range 10 – 100 %. A marginal difference was noticed in the reliability index with increase in the coefficient of variation, this is an indication that variability of SF content has little or no effect on the reliability index.

As coefficient of variation increased from 10 to 100%, reliability indices varied from -0.154 to -0.127. When computed with UCS value of 101 kN/m^2 for the untreated soil (natural soil) reliability index varied from -1.67 to -1.57 (see Figure 8). Product of this analysis revealed that treated soil created higher reliability indices over the untreated soil (natural soil) which designates development on the UCS of the soil with GSA and SF content (see Figure 8).

3.7.4. Influence of maximum dry density

The impact of reliability index for MDD is shown in Figure 7. Generally, the reliability index increased linearly with coefficient of variation. Reliability index changed extensively which is a suggestion that variation in MDD has significant impact on the reliability index for road pavement sub-base material. As coefficient of variation increased from 10 to 100 %, reliability indices increased from -0.129 to 0.292. When computed with UCS value of 101 kN/m^2 for the unmodified soil (natural soil), reliability index changed from -1.62 to -0.738 (see Figure 8). Treated soil produced higher reliability indices than the unmodified soil (natural soil) which indicates improvement on the UCS of the soil with additives content.

3.7.5. Influence of optimum moisture content

The effect of reliability index for OMC of lateritic soil – GSA –SF mixtures with coefficient of variation is shown in Figure 7. The reliability index significantly increased with coefficient of variation. As coefficient of variation increased from 10 to 100 %, reliability indices increased from -0.119 to 0.373. It is evident that changes in the OMC influenced unconfined compressive strength significantly as clearly shown in the changes in reliability index. Similar statement was made by (Sani et al., 2017) which suggest that OMC is a factor which must be carefully controlled during field compaction, specification and control for road pavement or any geotechnical engineering application where lateritic soil – GSA – SF mixtures are used. When computed with unconfined compressive strength value of 101 kN/m^2 for the untreated soil (natural soil) reliability index changes from -1.59 to -0.0196 (see Figure 8).

3.8. Comparative Sensitivity Analysis of the Reliability Indices of the Soil Variables

Sensitivity investigation of the reliability indices of the laboratory-based model used was compared with the changes in the independent soil parameters considered (GSA, SF, MDD and OMC) to evaluate their effect on UCS. It was largely noticed that reliability indices diverse for all the variables considered with MDD and OMC having more effect on the UCS. GSA and SF content have marginal effect on the UCS of the treated soil. From Figure 7 it was observed that changes in reliability indices was more for MDD and OMC which are also related to the UCS of the soil evaluated. In the case of reliability indices for the untreated soil (see Figure 8), low values of reliability indices were record for all the soil variables considered. Higher reliability indices recorded for the treated soil portray development on the UCS of the soil. For this cause, a good degree of quality control of these variables is of importance during field compaction requirement and control when used as road pavement sub-base materials; in order to accomplish good flexible pavement materials with statistically significant reliability index values.

3.9. Model Evaluation for Range of Acceptable Safety Indices

Results of reliability index obtained for UCS of the soil are shown in Table 8. NKB-Report, (1978) specified a safety index value of 1.0 as the lowest value for serviceability limit state design of structural components. The results could imply that the factor of safety (safety index value of 1.0) for serviceability limit state of structural component which was adopted to evaluate the effect of GSA, SF, MDD and OMC on UCS of lateritic soil treated with GS-SF admixtures was not achieved (i.e. were far less than 1.0). This could also mean that, the improved geotechnical properties did not meet the requirement of structural component, thus may not meet certain engineering behaviour in service if correlated as structural component.

Table 8: Model evaluation for range of acceptable safety indices

S/N	Variables factors	Beta value	Acceptable range of COV (%)
1	Unconfined Compressive Strength	-0.368 to 0.0123	NIL
2	Groundnut shell Ash Content	-0.15 to -0.132	NIL
3	Sisal Fibre Content	-0.154 to -0.127	NIL
4	Maximum Dry Density	-0.129 to 0.292	NIL
5	Optimum Moisture Content	-0.119 to 0.373	NIL

4. CONCLUSION

The study conducted on the lateritic soil indicates that it falls under A-7-6 (10) according to AASHTO classification and CL according to USCS. The natural soil has moisture content of 20.43 %, liquid limit of 48 %, plastic limit of 27.27 % and plasticity index of 20.73 %. The linear shrinkage was 7.87 %, free swell of 20.76 % with specific gravity of 2.73. The MDD decreased from 1.85 Mg/m^3 for the natural soil to 1.67 Mg/m^3 at 0 % GSA/0.25 SF content before rising to 1.72 Mg/m^3 at 0 % GSA/0.5 % SF content. The OMC increased from 18 % for the natural soil to a peak value of 23 % at 6 % GSA /0.75 % SF content. There was an increase in the UCS values (cured for 7 days) of soil – SF - GSA mixtures from 101 kN/m² for the natural soil to a peak value of 686.63 kN/m² at 6 % GSA/0.75% SF content before dropping to 610.0 kN/m² at 6 % GSA/1 % SF content. Correlation and sensitivity analysis on the reliability indices of the laboratory-based model shows that the independent soil parameters considered (GSA, SF, MDD and OMC) generally have effect on the UCS with MDD and OMC having more effect. Therefore, it is suggested that these variables should be monitored as they are vital factors that controls the overall performance of the road pavement with statistically significant reliability index values. Based on the results obtained, an optimum blend of 6 % GSA/0.75 % SF treatment of lateritic soil is recommended for used as sub-based material for rural roads compacted using BSL compaction energy.

5. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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