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Investigation of Glass Fiber Potential in Soil Stabilization

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Abstract*: The use of natural fibers to reinforce soil is an old and ancient idea. Traditional geosynthetics such as geotextile, geogrid etc. have proved to be efficient, and are increasingly used in geotechnical engineering. In contrast, the use of glass fibers in soil needs further investigation. Soil samples were obtained from borrow pits at Ajibode and Chapel both located in the University of Ibadan, Ibadan, Nigeria and stabilized with procured glass fiber at proportions of 0.4%. 0.8%, 1.2%, 1.6%, 2.0%, 2.5% and 3.0% by weight. Tests such as particle size analysis, compaction and California bearing ratio (CBR) were carried out on the unstabilized (control) soil samples. Thereafter, the compaction and CBR tests were carried out on stabilized soil samples. The results showed an improvement in the two soils' maximum dry density and CBR on addition of the glass fibers. The glass fibers had optimum effect on the soils between 1.2% and 1.6% of soil samples. Therefore, incorporating glass fiber into the soils in the required quantity will enhance soils' CBR and density.

***Index Terms*: Glass Fiber, Soil Stabilization, California Bearing Ratio, Maximum Dry Density, Reinforcement.**

I. INTRODUCTION

Engineering properties of soils play vital role in civil engineering construction works in road work, foundations, embankments and dams to mention but a few. Therefore, it is imperative to carry out tests on soil upon which foundation or superstructure is to be erected prior to construction. Invariably, the outcome will determine soil suitability as construction material. On the other hand, laterite is a highly weathered material rich in oxides of iron, aluminum or both. Nearly all laterites are of rusty-red coloration because of high iron oxide content [1]. Lateritic soil generally exhibits erratic engineering properties and tends to have low shear strength that reduces further upon increasing its consistence. Problematic soils, such as fine-grained soils are subjected to improvement to attain the best mechanical conditions. Site feasibility study is of far most beneficial before a project can take off. Site survey usually takes place before the design process begins in order to understand the characteristics of subsoil upon which the decision on location of the project can be made.

The following geotechnical design criteria have to be considered during site selection: design load and function of the structure, type of foundation to be adopted, and bearing capacity of subsoil. In the past, once the bearing capacity of soil was found to be very low, the following would be adopted change the design to suit site condition, remove and replace the in-situ soil, and abandon the site.

Abandoned sites due to undesirable soil bearing capacities drastically increased resulting to scarcity of land and increasing demand for natural resources. Affected areas include those which were susceptible to liquefaction and those covered with soft clay and organic soils. Other areas were landslide areas and contaminated land [2]. However, in most geotechnical projects, it is not possible to obtain a construction site that will meet the design requirements without ground improvement. The current practice is to modify the engineering properties of the soil at the site to meet the design specifications. Therefore, soils such as soft clays and organic soils can be improved upon to meet the civil engineering requirements.

Soil stabilization is the process of improving the geotechnical properties of soils to satisfy the engineering requirements. Numerous kinds of stabilizers are being used as soil additives to improve soil engineering properties such as lime, cement and fly ash, depending on their chemical reactions with the soil elements in the presence of moisture. Soil stabilization improves soil strength and increases its resistance to softening by water by bonding the soil particles together, water proofing the particles or combination of the two effects [3]. The simplest stabilization processes are compaction and drainage (if water drains out of wet soil it becomes stronger) termed mechanical stabilization. The process of improving gradation of particle size by adding binders to the weak soils [4] is termed chemical stabilization.

Several researchers have worked on the geotechnical properties of lateritic soils. Historically, engineers have long been aware of the stabilizing effects of various materials in earth works. The first and by far, the most extensive and successful application of soil reinforcement was developed by the French engineer, Henry Vidal, in the late 1950's. Vidal's system was known as 'Reinforced Earth', which consisted of placing steel reinforcing strips at predetermined intervals within the fill mass for the purpose of providing tensile or cohesive strength in a relatively cohesionless material [5]. The [6] reported that lateritic soils had been used successfully as base and sub-base materials in road construction. The [7] worked on lateritic soil in connection with construction of road, highways and airfields. The engineering problems associated with lateritic soil are continuously being evaluated. The [8] reported that the addition of lime to the soil increased its optimum moisture content,

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liquid limit, California bearing ratio (CBR) etc. Meanwhile, [9] studied the engineering properties of some soil samples from Ilorin, Nigeria and discovered that when soils were stabilized by compaction and the samples yielded maximum strength at optimum moisture content (OMC). The [10] evaluated CBR and shear strength of some compacted lateritic soils from Southwestern part of Nigeria. He reported CBR of 27% for un-soaked and 14% for soaked sample of laterite soils derived from amphibolite. Using mica schist, he obtained 10% for unsoaked and 9% for soaked samples. As such, he considered laterite as suitable material for sub base but its linear shrinkage of 10% is greater than the 8% maximum suggested for sub base material. The [10] also studied laterite soil from Ojota area in Lagos, Nigeria and obtained liquid limit of 49.5%, plastic limit of 21.8%, plastic index of 28.4% and linear shrinkage of 6.9%. On the basis of the geotechnical properties, he concluded that the soil was a good engineering construction material. Furthermore, [10] performed CBR and shear strength tests on compacted lateritic soil from Benin in Nigeria and concluded that the compacted soil samples were suitable for sub-base materials in road construction as their CBR fell within the limits specified (7-20%).

Cement is the oldest binder since the invention of soil stabilization technology in 1960's. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required [3], [11]. Cement reaction is not dependent on soil minerals, and the key role is its reaction with water that may be available in any soil [11]. This is the reason why cement is used to stabilize a wide range of soils. Numerous types of cement are available in the market: ordinary Portland cement, blast furnace cement, sulphate resistant cement and high alumina cement. Stabilized soils cannot withstand freeze-thaw cycles. Therefore, in the field, it may be necessary to protect the stabilized soils against frost damage [12], [13]. Shrinkage forces in stabilized soil will depend on the chemical reactions of the binder. Cement stabilized soil are susceptible to frequent dry-wet cycles due to diurnal changes in temperature which may give rise to stresses within a stabilized soil and, therefore, should be protected from such effects [3], [12].

Lime provides an economical way of stabilizing soils. Lime modification can be described as an increase in strength brought by cation exchange capacity action rather than cementing effect brought by pozzolanic reaction [3]. In soil modification, as clay particles flocculate, transformation of natural plate like clays particles into needle like interlocking metalline structures would take place. Clay soils turn drier and less susceptible to water content changes [4]. Lime stabilization refers to pozzolanic reaction in which pozzolanic materials react with lime in presence of water to produce cementitious compounds [3], [11]. Slurry lime also can be used in dry soils where water may be required to achieve effective compaction [14]. Quicklime is the most commonly used lime [4].

There are two main classes of fly ashes; class C and class F [15]. Class C fly ashes are produced from burning sub bituminous coal; they have high cementing properties because of high content of free CaO. While, class C from lignite has the highest CaO (above 30%) resulting in self-cementing characteristics (FM 5-410). Class F fly ashes are produced by burning anthracite and bituminous coal; they have low self-cementing properties due to limited amount of free CaO available for flocculation of clay minerals and thus require addition of activators such as lime or cement. The reduction of swell potential achieved in fly ashes treated soil relates to mechanical bonding rather than ionic exchange with clay minerals [16].

The [17] carried out compaction tests on silty clay soil specimens reinforced with fibers. It was concluded that the presence of fibers decreased the ability of soil to densify. Experiment on sandy gravel showed that increasing the fiber content caused a modest increase in the maximum dry unit weight. The optimum water content was found to decrease with increasing fiber content [18]. The results of compaction test on palm fiber reinforced silty sand showed that the maximum dry density decreased and optimum moisture content increased with increasing fiber content [19]. According to [20], the soil mixture in its untreated form showed a lower dry density and higher optimum moisture content than the treated soil for a given compaction effort. The [21] studied the effect of fiber on the hydraulic conductivity of a kaolinite-fiber composite and showed that its inclusion increased the hydraulic conductivity of the composite which became more pronounced at higher fiber content (up to 4% by weight). Despite the increase, the hydraulic conductivity of the composite was still low enough to be considered for some landfill applications and acceptable to satisfy the requirements for landfill cover design.

Various soil stabilization techniques including fiber reinforcement have been in use for a while and the results obtained in some of them have been quite satisfactory. Reinforcing soils using tension resisting elements is an attractive means of improving the performance of soil in a cost-effective manner. Practicing engineers are employing this technique for the stabilization of thin layers of soil, repairing failed slopes, soil strengthening around footings and earth retaining structures. However, more research is needed to further understand the potential benefits and limitations and to allow its application to more complex geotechnical structures. Direct shear tests, unconfined compression tests and conventional triaxial compression tests have demonstrated that shear strength was increased and post-peak strength loss was reduced when discrete fibers were mixed with soil [21], [22]. However, its use is still in an infant stage. Factors identified to affect the efficiency of reinforcement were such as the fiber properties (length, density, aspect ratio, extendibility, and degradability of fiber), soil properties (gradation, particle size, shape, and density), and effective confinement and strain levels [23], [24], [25].

Significant improvement in soil strength parameters of glass fiber reinforced-soil in various soil media happened. This is shown clearly by the increasing in cohesion values and internal friction angles. The lightweight, ready availability and non-biodegradable characteristics of the fiber is an advantage and can be used for long term soil improvement [26].

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Glass fiber is one such fiber having a durable, inert nature possessing high tensile and compressive strength. It is extremely strong, and robust material. Glass fibers are among the most versatile industrial materials known today.

The aim of the research was to ascertain glass fiber performance as a stabilizer by measuring its effects on lateritic soil (through a comparison of the properties of the soil with and without the addition of the glass fiber) and determine appropriate quantities of the glass fiber required for adequate stabilization of the lateritic soil. The glass fibers used in the study was locally sourced. The disposal of glass fiber produced from industries has become a great challenge. These materials pose a threat to the environment because they can result in pollution in the nearby locality since they are majorly non-biodegradable. Therefore, finding alternative use for it will be a positive development in the study area.

II. MATERIALS AND METHODS

Two lateritic soil samples were obtained from borrow pits. Sample one (AJ) was obtained from Ajibode while sample two (CH) was obtained from the Chapel. University of Ibadan. The borrow pits were situated in Ibadan, Nigeria. Enough quantities of subsoil samples were excavated from the two borrow pits and transported to the laboratory. During sample collection, at each location, the topsoil was removed manually to a depth of about 1.5m before subsoil samples were collected. At the laboratory, the subsoil samples were air-dried, stock pilled separately and covered with polythene materials to prevent moisture ingression. The soil samples were labelled for identification purpose. Glass fiber was sourced locally as shown in Fig. 1. An appropriate quantity of glass fiber was obtained, transported to the laboratory and cut into pieces of lengths not longer than 25mm manually.

Each soil sample was subdivided into eight portions. A portion served as control while the remaining seven received single dosage of glass fiber proportions 0.4%, 0.8%, 1.2%, 1.6%, 2.0%, 2.5% and 3.0% by weight. The mixing was carried out in dried state. The fiber and soil were mixed together to produced homogeneous mixture. The following geotechnical properties such as particle size analysis, Atterberg's limits (liquid limits and plastic limits), compaction test and California bearing ratio (CBR) of control samples were determined in the laboratory. In addition, stabilized soil samples' compaction characteristic and CBR were determined. All the geotechnical properties were carried out as detailed in [27].

Fig. 1. Glass Fiber

III. RESULTS AND DISCUSSION

The results of the preliminary tests (grain size analysis, natural moisture contents, specific gravity, and Atterberg's limits test) as well as the engineering tests (compaction, California bearing ratio and triaxial test) carried out on both unstabilized and stabilized soils are presented below. The liquid limit and plastic limit of the control soils CH and AJ were 45.5, 27.8% and 37.5, 29.79%, respectively. The results of the particle size analysis of the soils were displayed in Figs. 2 and 3. The two samples were classified as well graded sand and A-2-6 (AASHTO). According to Unified Soil Classification System (USCS) soil sample AJ was lean clay with low plasticity (CL) while soil sample CH was silt of low plasticity (ML). Ajibode soil compaction test results indicated a maximum dry density (MDD) of 1.62g/cm3 with corresponding optimum moisture content (OMC) of 21.28% for the control. The summary of the compaction test results for stabilized soil sample AJ was displayed in Table 1 and Fig. 4. The control sample CH MDD and OMC were 1.58g/cm3 and 19.8% respectively. These values for stabilized soil samples CH were in Table 2. The CBR values for all the soil samples were in Table 3. The two soils MDD values increased as the percentage of glass fiber increased and reached the peak values at 1.6% glass fiber addition. Further increase in the glass fiber content led to decline in the MDD. The glass fiber has great affinity for water and excess fiber swell up leading to volume increase and reduction in density. The OMC of stabilized soils followed irregular pattern which is complex to interpret. The CBR value of soil sample AJ without the addition of glass fiber was 51.0%. A gradual nonlinear increment in the CBR with its peak value at 1.2% glass fiber content of value 68% was observed when the soil AJ was stabilized with glass fiber. This value is higher than the control value by 40%. Similar trend was observed when soil CH was stabilized with glass fiber. The control soil CBR was 48.12% and the peak CBR value at 1.6% stabilization was 61.2% equivalent to 27.1% increment. The improvement in the CBR value is as a result of the fact that glass fiber is strong in tension which enhances the bond strength among soil particles. The bond created hinder smooth passage of CBR machine plunger and therefore, required additional force for the required penetration to be reached. The presence of fibers provides mechanical interlocking among soil particles. When optimum value of glass fiber was exceeded, the excess formed spongy spot in the soil matrices that constituted a weak portion and hence the decrease in CBR obtained.

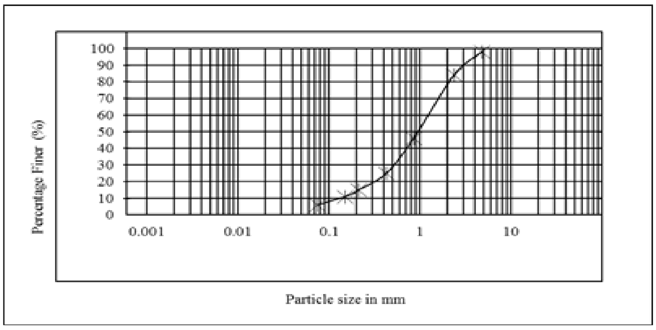

Fig. 2. Grading Curve for Ajibode Soil Sample

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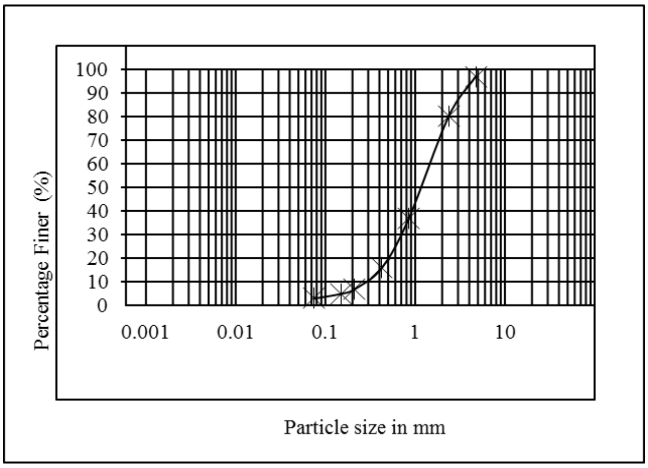

Fig. 3. Grading curve for Chapel soil sample

Table 1. Compaction Test Results for Stabilized Soil Sample AJ

Stabilization percentage	Maximum Dry Density MDD (g/cm3)	Optimum Moisture Density OMC (%)
Control	1.62	21.28
0.4	1.62	21.05
0.8	1.65	19.90
1.2	1.68	20.30
1.6	1.68	19.81
2.0	1.59	26.38
2.5	1.43	24.38
3.0	1.40	28.50

Table 2. Compaction Test Results for Stabilized Soil Sample CH

Stabilization percentage	Maximum Dry Density MDD (g/cm3)	Optimum Moisture Density OMC (%)
Control	1.58	19.80
0.4	1.63	19.29
0.8	1.76	18.14
1.2	1.77	18.22
1.6	1.85	15.75
2.0	1.68	21.36
2.5	1.66	18.00
3.0	1.68	20.37

Table 3. CBR Test Results for Soil Samples AJ and CH

Stabilization percentage	Soil sample AJ (%)	Soil sample CH (%)
Control	51.00	48.12
0.4	53.87	51.65
0.8	63.81	52.83
1.2	68.00	53.83
1.6	63.08	61.20
2.0	63.03	41.32
2.5	43.41	32.43
3.0	31.12	20.90

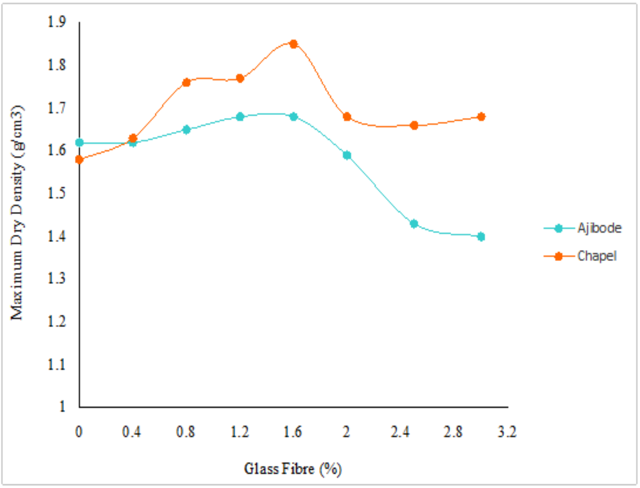

Fig. 4. Maximum Dry Density of Stabilized Soils at Different Percentages of Glass Fiber

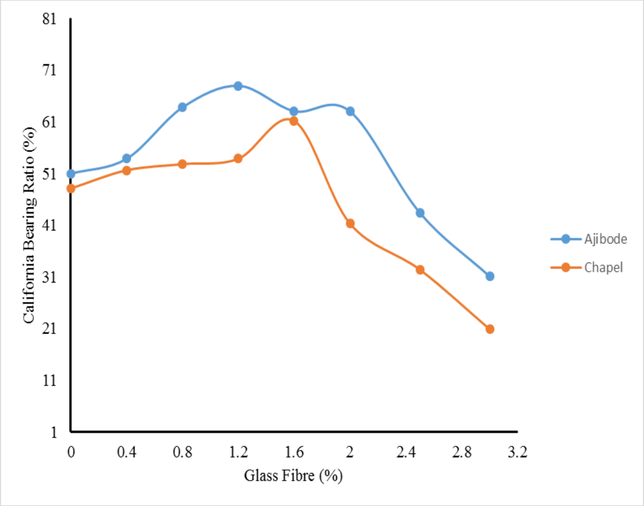

Fig. 5. California Bearing Ratio at Different Percentages of Glass Fiber

IV. CONCLUSION

The study revealed that addition of glass fiber into the two lateritic soils led to increase in soil California bearing ratio and maximum dry density with the peak influence recorded between 1.2 and 1.6% glass fiber. The glass fiber helped to hold the soil particle together and hence improved the bonding forces among the soil particles.

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