Geotechnical properties of soil reinforced with Shredded Plastic Bottle

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Abstract— *The rate at which plastic waste is generated yearly is alarming and proper disposal poses a serious problem. Particularly, recycling ratio of the plastic wastes in life and industry is low and many of them have been reclaimed for the reason of unsuitable ones for incineration. It is necessary to utilize the wastes effectively with technical development in each field.*

This study presents a simple way of recycling plastic waste in the field of civil engineering as reinforcing material. Reinforcing of soil in construction is an efficient and reliable technique for improving the strength and stability of soils. The technique is used in a variety of applications, ranging from retaining structures and embankments to subgrade stabilization beneath footings and pavements.

This research experimentally studied the influence of shredded plastic waste on two types of soil (clayey soil and sandy soil) at different mixing ratios (0, 5, 10 & 15)% by weight respectively. For the two types of soils, a series of compaction tests were performed on soil samples mixed with different percentages of waste pieces to determine the maximum dry density (MDD) and optimum moisture content (OMC). In addition, the reinforced samples were investigated by the CBR test to determine it strength, the CBR values at (0, 5, 10 and 15)% were (2.07, 3.08, 3.90 and 5.13)% for clay soil and (32.7, 41.4, 53.94 and 59.88)% for sandy soil respectively.

It was found that, there is significant improvement in the strength of soils due to increase in the percentage of the plastic waste. The percentage of increase in the strength for sandy soil is slightly more than that in clayey soil. Also, it was concluded that the plastic pieces decreases the maximum dry density of the soil due to their low specific gravity and decreases the optimum moisture content.

It can therefore be concluded that plastic waste is a promising soil reinforcement.

Keywords— *soil reinforcement, plastic waste, compaction, CBR.*

I. INTRODUCTION

The Properties of a soil are very uncertain when it is subjected to variable moisture. It shows huge volumetric change when exposed to dry and wet conditions. These changes create challenges for civil and geotechnical engineers doing work on site specially while constructing foundations either for structural or pavement designs. There are many available methods used to improve the volumetric changes, bearing capacity and reduce the settlement of such soils. One of these methods is using reinforcement. Reinforced soil is a construction material that consists of soil fill strengthened by a variety of tensile inclusions ranging from low-modulus, polymeric materials to relatively stiff, high-strength metallic inclusions. These tensile inclusions come in many forms ranging from strips and grids to discrete fibers and woven and non-woven fabrics. The soil and reinforcing element will interact by means of frictional resistance. Appropriate selection of the type and location of the reinforcement material is necessary in order to achieve optimum improvement.(Maha HatemNsaif, 2013)

Synthetic fibres are made from synthesized polymers of small molecules. The compounds that are used to make these fibers come from raw materials such as petroleum based chemicals or petrochemicals. These materials are polymerized into a long, linear chemical that bond two adjacent carbon atoms. Differing chemical compounds will be used to produce different types of synthetic fibers.

Plastic waste classification

Plastics waste is of two types:

- Pre-use plastic (production scrap)

• Post-use plastic

pre-use plastic

That plastic which does not fulfil the desired requirement during casting and assembly i.e. material that has the mismatching colour, undesirable hardness, or wrong processing characteristics are called Pre-use plastic waste. This material is easy to use for other applications and has the property to get recycled. Pre-use plastic waste is the ultimate source of plastics which are suitable for reprocessing from manufacturers of plastic products. Processing of Pre-used plastic is less as compared to post-use hence Pre-use is more valuable then Post-use plastic.

post-use plastic

Post-use plastic waste suitable for recycling generally falls into one of five main categories:

• Plastic bottles, pots, tubs and trays

• Plastic film

• Rigid plastics, such as crates, pipes and moldings

• Plastic foams, such as expanded polystyrene (EPS)

Flexible plastics, such as strapping and cable sheathing

II.   LITERATURE REVIEW

Dr. A.I. Dhatrak et al in 2015 after reviewing performance of plastic waste mixed soil as a geotechnical material observed that for construction of flexible pavement to improve the sub grade soil of pavement using waste plastic bottles chips is an alternative method. In his paper a series of experiments are done on soil mixed with different percentage of plastic (0.5%, 1%, 1.5%, 2 % & 2.5%) to calculate CBR. on the basis of experiments that he concluded using plastic waste strips will improve the soil strength and can be used as sub grade . It is economical and eco-friendly method to dispose waste plastic because there is scarcity of good quality soil for embankments and fills.

Akshat Malhotra and Hadi Ghasemain et al in 2014 studied the effect of HDPE plastic waste on the UCS of soil. In a proportion of 1.5%, 3%, 4.5% and 6% of the weight of dry soil, HDPE plastic (40 micron) waste was added. They concluded that the UCS of black cotton soil increased on addition of plastic waste. When 4.5 % plastic waste mixed with soil strength obtained was 287.32kN/m^2 which is maximum because for natural soil it was 71.35kN/m^2.

III.   MATERIALS AND METHODS

3.1   Soil sample

1. **Expansive (clay) soil (sample A)**: 35kg of representative soil sample was collected from a borrow pit at Fasola – Apapa Road, Moniya, Oyo State, Nigeria; with sample depth of above 1m; Sample was collected and carefully labeled for easy identification. The soil sample employed in this work was a disturbed sample due to mechanical actions.

2. **Loose (sandy) soil (sample B)**: 35kg of soil was collected from at The Polytechnic Ibadan (South Campus), Oyo State, Nigeria; with sample depth of above 0.2m; Sample was collected and carefully labeled for easy identification. The soil sample employed in this work was a disturbed sample due to mechanical actions

3.2   Plastic waste material

3. Plastic waste bottles were collected within The Polytechnic, Ibadan vicinity and were shredded to smaller sizes for the purpose of this project.

3.3   Laboratory Tests

Preliminary/ Classification Test

The tests carried out includes:

Natural water content determination: Naturally occurring soils usually contain water as part of their structure. The water content in such soil is refer to as moisture content, moisture content of a soil is assumed to be the amount/quantity of water within the pore space between the soil grains that is removable by oven drying at 105º– 110ºC, expressed as a percentage of the mass of dry soil. Measurement of moisture content, both in natural state and under certain defined test conditions, can provide an extremely useful method of classifying cohesive soils and of assessing their engineering properties. The results are referred to as the index properties, or consistency limits.

Grain Size Analysis: This was done to analyse the soil particles according to their aggregate. Soil sample was poured into the Riffle box with the intention of getting an appreciable sample that would contain all particles present in the soil (a small sample that would contain different sizes of particles present in the soil. A handful of sample was collected into the crucible and kept in the oven at a temperature of 105ºC for 24 hours so as to remove moisture content in the soil sample. The sample was weighed with the aid of weighing balance (weight of sample before sieving). Consequently, wet sieving was carried out on the sample. The sample was poured/soaked in a tray filled with water and was stirred, washed, sieved with sieve No.200 (75µm) under tap until water became

clean. This was done to remove clay/silt particles finer than sieve No.200. The particles retained in the sieve were collected into the crucible and oven dried for 24 hours to expel moisture present in the sample in preparatory for dry sieving. Dry sieving was accomplished by passing/pouring the particles through assemblage of sieves of various sizes. These sieves were shaken for some time so that each sieve could retain particles not finer than the sieve and the weight of particles retained in each sieve is determined, from where percentage retained and percentage passing were deduced.

Atterberg's limit: This was done to determine the liquid limit, plastic limit, Plastic Index and Shrinkage limit of soil. An appreciable sample of clay soil was poured in a mortal and was grinded with a rubber-headed pestle and also sieved using sieve No.36 (425μm) to separate the pebbles from the fines (pulverization process). Water was added to the fines on a wide glass, mixed thoroughly with the aid of spatula to obtain a paste that was subsequently wrapped with/in polythene nylon, and kept in a crucible for 24 hours so as to allow the paste to swell to its maximum capacity. Consequent upon this, water was added to the paste and mixed thoroughly with spatula. The paste was now placed in a brass cup on the Liquid limit device and levelled to a maximum depth. A long narrow cut (groove) was made along symmetrical axis on the cup. The cup was made to fall on a hard rubber base by turning the handle on the device. The number of blows that closed the groove was first noted between the ranges of 40 – 50 blows. At this point, a small sample or paste was collected along the symmetrical axis on the cup and kept in a can from where weights of wet sample and dry sample were known to determine the moisture content. More water was added and the number of blows that closed the groove was noted at ranges of 30 – 40 blows, 25 – 30 blows, 15 – 25 blows and 10 – 15 blows respectively, and samples were collected to determine their moisture contents. The more the volume of water added, the lesser the number of blows that would close the groove. The sample for shrinkage limit was collected when 18 – 22 blows closed the groove. The sample was used to fill shrinkage limit mould of 12.7cm long and kept in the oven for 24 hours so as to determine linear shrinkage in percentage.

$$\text{Linear shrinkage} = \frac{(P – P')\ 100}{P'}$$

Where P = Original length of mould

P' = New length of sample after oven drying.

The remaining 1/4 of the original soil sample mixed was used for the plastic limit test. The soil sample was further mixed with distilled water until a consistency was reached whereby the soil can be rolled without sticking to the hands. The soil was formed into an ellipsoidal mass, and then rolled between the palm/fingers and the glass plate.

Sufficient pressure was applied to the soil sample to roll the mass into a thread of uniform diameter by using about 90 strokes per minute. (A stroke is one complete motion of the hand forward and back to the starting position.) The thread formed by rolling the soil sample becomes deformed so that its diameter reaches 3.2 mm (1/8 in.). The portions of the crumbled thread were then gathered together and placed into moisture cans, then weighed before they were placed in the oven and allowed to dry for at least twenty (24) hours. The water content from each of the plastic limit moisture cans was calculated. The average of the water contents was used to determine the plastic limit, PL.

Engineering Test

Engineering tests carried out on the samples includes;

Compaction Test: The compaction test used for this research was carried out in accordance with the Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort. This was carried out to determine the Optimum Moisture Content (OMC) and Maximum Dry Density (MDD). Weights of cylindrical moulds were determined using weighing balance. The soil samples was divided into four different portions of about 6kg each. 100ml of water was added to the first portion and mixed thoroughly. Some parts of it were kept in two separate cans to determine weight of wet sample and weight of dry sample after spending 24 hours in the oven in order to know its moisture content. The first layer of a 3- layer cylindrical mould was filled with the sample and rammed 27 times with the aid of 4.5kg rammer. The same was done on the rest layers and rammed 27 times each. The weight of compacted wet sample was determined using weighing balance and wet density calculated thereof as shown in below. The same procedures were followed for remaining four portions but with increment of 100ml of water on each portion from the first100ml. That is, 200ml, 300ml, 400ml and 500ml of water respectively.

$$\% \text{ MOISTURE} = \frac{\text{WEIGHT OF MOISTURE} * 100}{\text{WEIGHT OF DRY SAMPLE}}$$

$$\text{DRY DENSITY} = \frac{\text{WET DENSITY} * 100}{\% \text{ MOISTURE CONTENT} + 100}$$

California bearing ratio (CBR): This was carried out to estimate the bearing capacity of the soil using the California Bearing Ratio (CBR) Machine. The dry soil mixed with the shredded plastic waste, water was added based on the OMC and then placed into the mould and compacted in 3- layers with the 4.5kg rammer of 27 blows. The compacted sample was placed on the California Bearing Ratio (CBR) machine. The proofing ring gauge and plunger

penetration gauge were set at zero. Immediately the plunger penetration made a contact with the soil, the gauges started working simultaneously and, the readings were taken on the proofing ring gauge at every 25 division on the plunger penetration gauge. The first 10 readings were referred to as first pointer and the 10th reading being the correct reading was adopted and multiplied with a multiplication factor of 0.18 while the last 10 readings were referred to as second pointer, and so also, the 20th reading was adopted and multiplied with a multiplication factor of 0.12. The test was done on both

top and bottom of the compacted wet soil. The higher of the two values was chosen as actual CBR. The average of the top and bottom was however the actual final CBR value.

IV.   RESULTS AND DISCUSSION

4.1 Natural Moisture Content

Sample A retains more water than sample B given by the values 26% and 6% respectively. This shows that sample A contains more silty clay than sample B.

4.2 Particle Size Analysis

The particle size distribution analysis shows not only the range of particle sizes present in a soil but also the type of distribution of various size particles.

According to clause 6201 of Federal Ministry of Works and Housing (F.M.W & H) Specification Requirement, for a sample to be used as both subgrade/fill and base, the percentage by weight passing the No.200 sieve (75µm) shall be less than but not greater than 35%.

Sequel to the above, the sample Ais not a good sample because percentages by weight passing sieve No. 200 exceed 35% requirement, while sample B is good sample because it does not exceed 35% requirement.
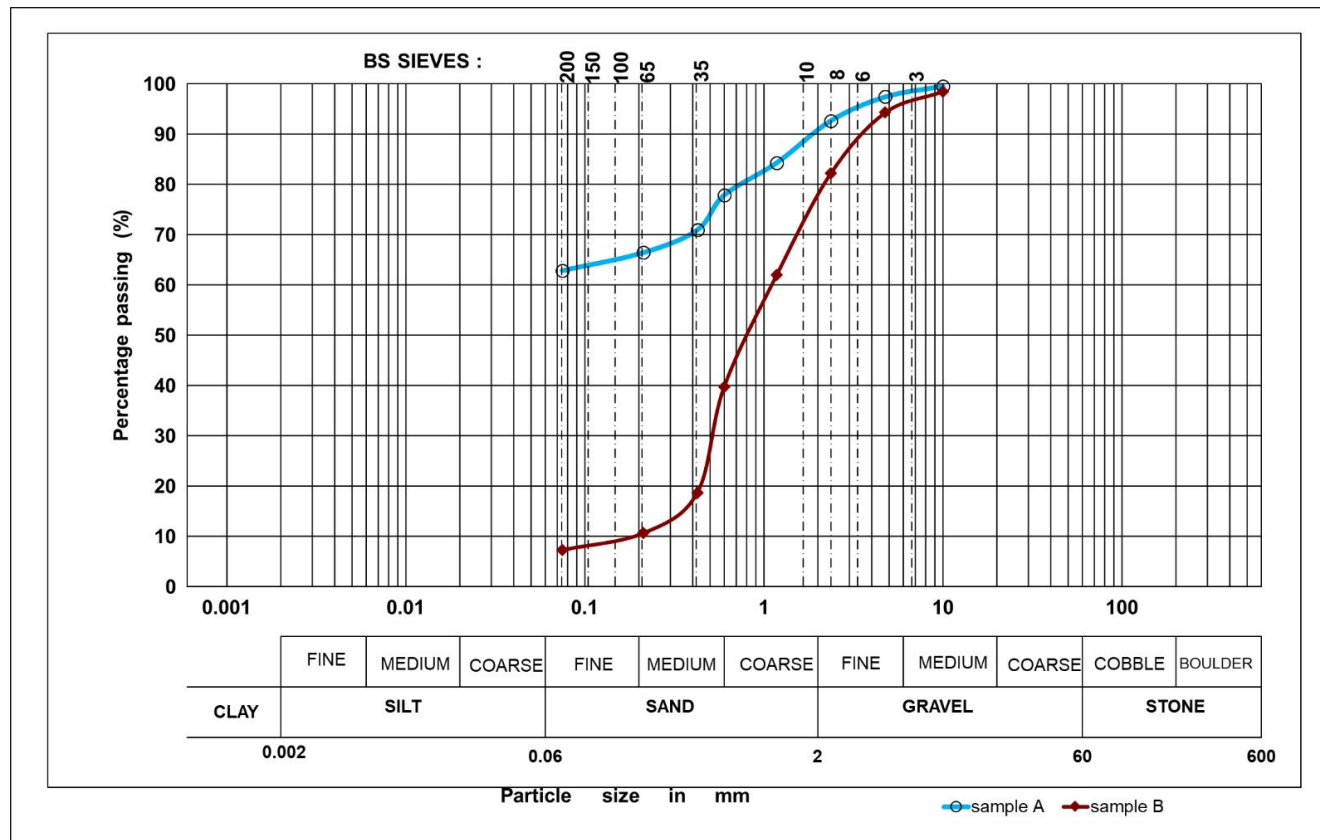

Fig 1: Particle size curve for sample A and B

4.3 Atterberg's limit

It is obvious from the results that sample A absorbs more water and swells on drying which is evident in the result of Linear Shrinkage and Plastic index. It can be said to be more clayey/plastic than subgrade samples.

According to Federal Ministry of Works and Housing (F.M.W & H) Specification Requirement in clauses 6201 and 6252,material passing the 425μm sieve shall have a liquid limit of not more than 35% and a Plastic Index (P.I) of not more than12% as determined by American Society for Testing Materials Method.

In view of the above, subgrade samples are fit to be used in road construction since both their Liquid limits and

PlasticIndex values do not exceed the stipulated values of 35% and 12% respectively. The base sample is not suitable for thepurpose for which it was used, since it shows Liquid Limit and Plastic Index of 48% and 25% which do not fall within thestipulated values of 35% and 12% for Liquid Limit and Plastic Index respectively.

4.4 Compaction Test

The table and the figure below shows the result of the compaction test carried out in this project. The compact test helps in determining the Optimum Moisture Content (OMC) and the Maximum Dry Density (MDD).

Table 1: Compaction result for both soil samples

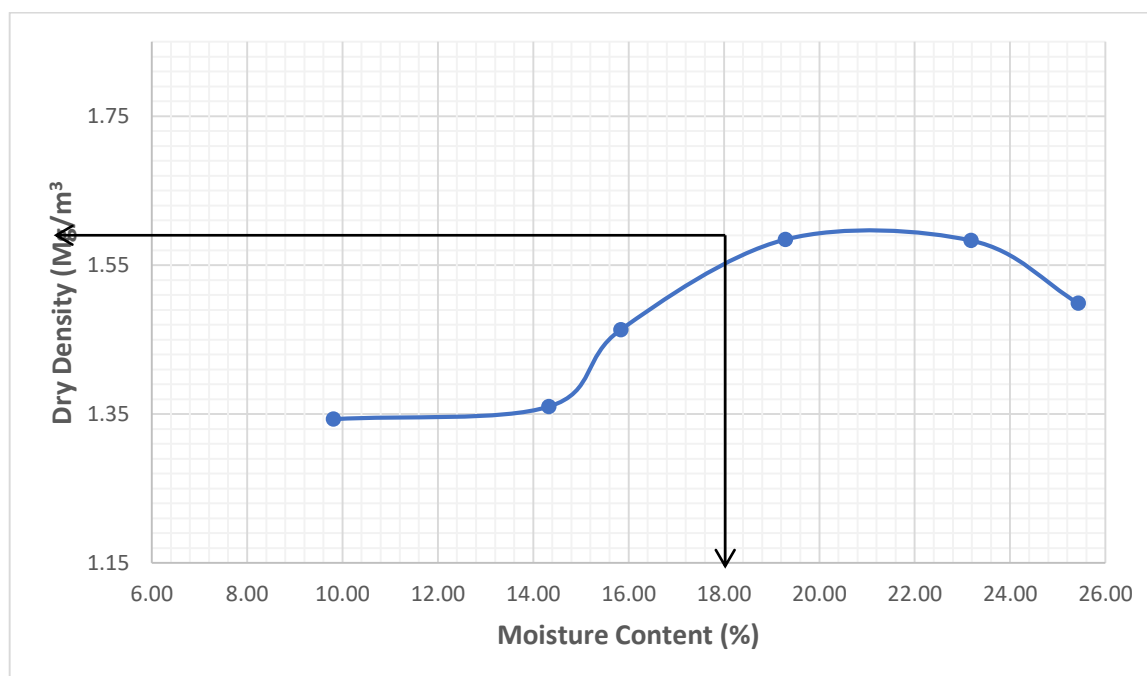|	1	2	3	4	5	6
CLAY SAMPLE						
Average moisture content %	9.81	14.33	15.83	19.28	23.18	25.43
Dry density (Mg/m^3)	1.34	1.36	1.46	1.58	1.58	1.50
SANDY SAMPLE						
Average moisture content %	6.57	10.40	13.22	16.36	19.84	22.36
Dry density (Mg/m^3)	1.75	1.79	1.83	1.85	1.83	1.76

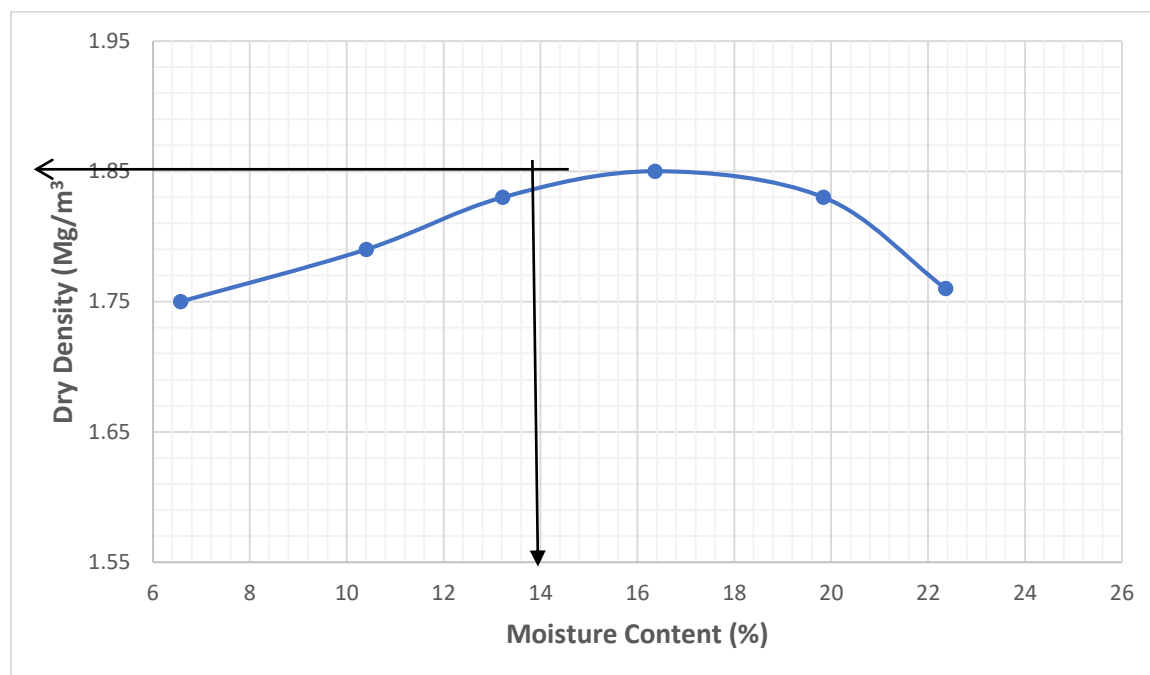*Fig.2: Graph of Dry density against Moisture Content for clayey Sample*

Fig.3: Graph of Dry density against Moisture Content for Sandy Sample

3.5 California bearing ratio (CBR)

According to clause 6201 of Federal Ministry of Works and Housing (F.M.W & H) Specification Requirement, the minimum strength of subgrade and sub-base material shall not be less than 20% and 50% un-soaked C.B.R respectively.

In light of the above, clay sample is a very poor subgrade material because it exhibits un-soaked CBR of 2.07% as control and (3.03, 3.90 and 5.13)% with the inclusion of shredded plastic waste at (5, 10 and 15)% which is less than the stipulated 20%. The sandy sample is a very good subgrade and sub-base material because it exhibit un-soaked CBR value of 32.7% as control and (41.4%, 53.94 %,and 59.88%) with the inclusion of shredded plastic waste at (5, 10 and 15)% which is close to what is stipulated in the specification. Based on this, sandy sample is better than the clay sample as a subgrade and sub-base material for the construction of the road which is evident in their CBR values.

Table 2: CBR Value for both samples

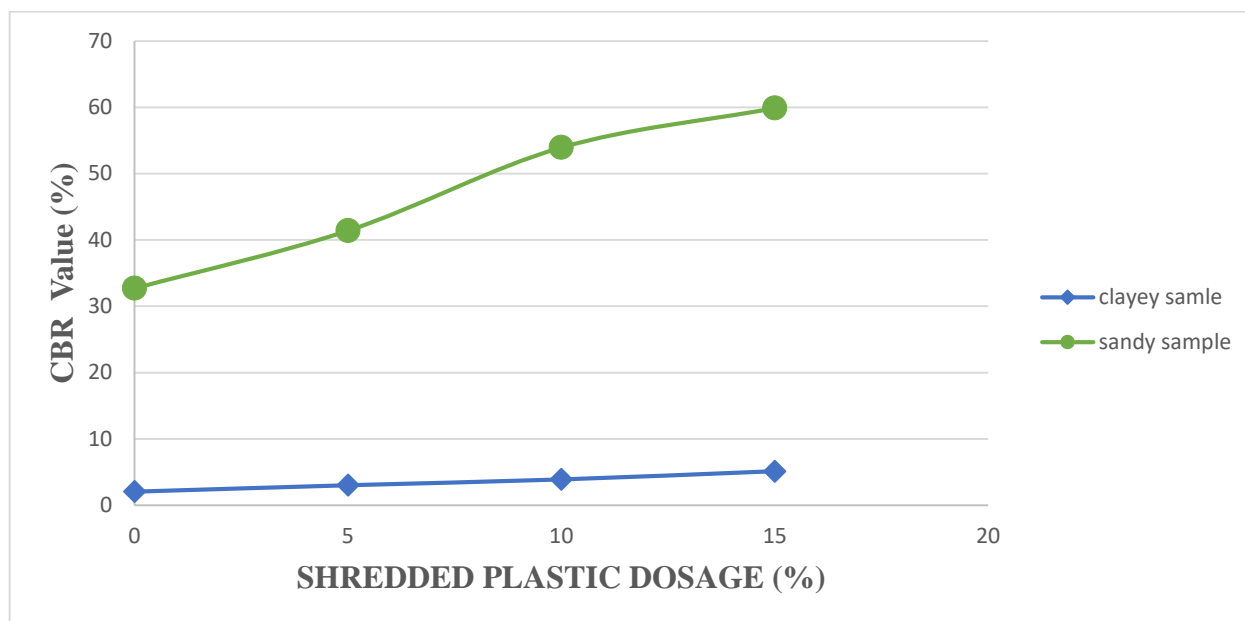| Dosage of shredded plastic bottle (%)	clayey sample (%)	sandy sample (%)
0	2.07	32.7
5	3.03	41.4
10	3.90	53.94
15	5.13	59.88

Fig.3: CBR Value against Shredded plastic Dosage for both sample

V. CONCLUSION

This research work examined the geotechnical properties of clayey and sandy soil reinforced with synthetic fibre {shredded plastic bottle}. The following were observed during the course of the practical aspect of the project:

1. The effect of plastic waste pieces on soil is influenced by various factors such as soil type and plastic waste content.
2. The addition of plastic pieces to the two types of soilincreased the CBR valves of both soil. However, significant increase was observed in CBR values of sandy soil.
3. The increment for clayey soil does not make it relevant in Engineering and Geotechnical world i.e for construction purpose based on the research result.
4. The plastic pieces decrease the maximum dry unit weight of the soil and optimum moisture content. The variation of optimum water content and maximum dry unit weight with plastic pieces content is linear.

VI. RECOMMENDATION

Based on the investigations of the study, the following recommendations are proffered;

1. It is recommended that shredded plastic material is a potential soil reinforcing material.
2. There is need to investigate more on the effect of higher percentage of plastic material on the soil sample to determine optimum yield/performance.

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