Effect of Polypropylene Fiber on Shear Parameter of Expansive Soil

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Abstract— **The main objective of this study is to investigate the use of waste fiber materials in geotechnical applications and to evaluate the effects of waste polypropylene fibers on shear strength of unsaturated soil by carrying out direct shear tests and unconfined compression tests on two different soil samples. The results obtained are compared for the two samples and inferences are drawn towards the usability and effectiveness of fiber reinforcement as a replacement for deep foundation or raft foundation, as a cost effective approach. All the Direct Shear Tests were conducted at different mix compositions of polypropylene fiber with two different soil sample silty clay and clay. Based on direct shear test on soil sample- 1 and soil sample-2, with fiber reinforcement of 0.05%, 0.15% and 0.25% it was observed there was increase in shear parameters cohesion and internal friction angle. On the basis of the experiments performed, it is determined that there was not that much on shear parameter cohesion and angle of internal friction of silty clay when used with polypropylene fiber is not effective but shear parameter cohesion and angle of internal friction of clay has considerably.**

Index Terms— **Polypropylene Fiber, Direct Shear Test, Fiber Reinforcement, Shear Parameters, Clayey Soil**

I. INTRODUCTION

The improvement in the shear strength parameters has been stressed upon and comparative studies have been carried out using different methods of shear resistance measurement.

In general, higher clay contents in a soil cause higher plasticity, greater shrinkage and swell potential, higher compressibility and lower shear strength. Most mechanical properties of clays depend on the type and content of clay minerals, the interactions between the clay mineral particles and pore water, as well as on the sedimentary and consolidation history. The soil mechanical behavior of some problematic clays like expansive or swelling soils, quick clays and black shales is described in detail.

The amount of wastes has increased year by year in the form of polyethylene (PE) and the disposal becomes a serious problem. India, produces a waste of plastic in order of 39 million ton per year up to the year 2000. Plastic waste management institute reported about 55% of waste plastic are effectively being utilized in energy recovery and feed stock recycling. Most of these wastes are non-degradable and destined for landfill. The use of polyethylene for improving the engineering properties of the clay soil and Bentonite is the goal of this present study.

Over the years, the use of geotextiles and other polymeric reinforcements such as Geogrids has increased drastically in geotechnical engineering. However; in certain cases; especially for low cost embankment or road construction, their cost becomes a prohibitive factor for their wide spread use. In comparison with systematically reinforced soil, randomly distributed fiber reinforced soils exhibit some advantages. Preparation of randomly distributed fiber reinforced soils mimics' soil stabilization by admixture. Discrete fibers are simply added and mixed with soils, much like cement, lime or other additives. Randomly distributed fibers offer strength isotropy and limit potential planes of weakness that can develop parallel to oriented reinforcement.

The attempt has been made to demonstrate the potential of reclaimed plastic wastes as soil reinforcement for improving the sub grade soils. The study will describe series of tests carried out to initially understand the types of soil and its properties. Then a number of laboratory tests were carried out with varying percentage of plastic strips mixed uniformly with the clay. The scope of the study entails mixing shredded square LDPE strips of size 5 mm x 5 mm at different percentages of 0.05%, 0.075%, 0.25%, 0.50%, 0.75%, and 1.0% by the weight of the clay, assessing the geotechnical properties necessary for recommending reuse of the clay-plastic waste mix.

II. LITERATURE REVIEW

Many researchers have conducted investigations using different types of reinforcement and materials like plastic waste, fibers, ceramic tile waste and lime- gypsum.

The techniques of soil reinforcement are broadly categorized into macro- reinforcement and micro- reinforcement (Gregory and Chill, 1998; Morel and Gourc, 1997). Woven and nonwoven polymeric materials referred to as geosynthetics widely used in the construction industry today are considered as macro-reinforcement material and their reinforcement mechanism is well established in literature (John, 1987; Koerner, 1999; Richardson and Koerner, 1990; Sarsby 2007). Micro-reinforcement, on the other hand, involves randomly incorporating small reinforcing elements into the soil mass with uniform distribution to produce a three-dimensional reinforcement system (Al-Refeai, 1991; Falorca and Pinto, 2011; Gray and Maher 1989; Ibraim and Fourmont, 2006,).

Studies into the polypropylene fibers for micro-reinforcement have reported increases in peak shear strengths and reductions of post peak losses in soils (Consoli et al, 2007; Zornberg, 2002,).

.Bauer and Oancea (1996), based on their triaxial test results, and indicated that the secant modulus as an indicator of the stiffness within the initial vertical strain of 2% decreased with increasing polypropylene fiber contents up to 0.5%. They also reported that beyond this vertical strain the secant modulus remained fairly constant. Consoli et al. (1998), conducting triaxial compression tests, showed that fiber reinforcement decreased the stiffness. Gray and Ohashi (1983), based on direct shear test results, indicated that fiber reinforcement increased the peak shear strength and limited post-peak reductions in shear resistance. However, no increase in stiffness of the fiber-sand composite was observed. Freitag (1986) reported that randomly distributed fibers in a compacted fine-grained soil could result in greater stiffness.

III. MATERIALS

Soil sample-1: Silty clay
Location: Shankhwas Road, HI Area Phase II, Basni, Jodhpur
Soil sample-2: Clay
Location: Deepawas, Raipur, Pali Reinforcement: Short PP (polypropylene) fiber

Table 1: Index and Strength parameters of PP Fiber

Behavior Parameters	Values
Fiber Type	Single Fiber
Unit Weight	091g/cm^3
Average Diameter	0.034 mm
Average Length	12mm
Breaking tensile strength	350MPa
Modulus of Elasticity	3500Mpa
Fusion Point	165^{0}C
Burning Point	590^{0}C
Acid and Alkali Resistance	Very Good
Dispersibility	Excellent

Figure 1: Short PP (polypropylene) fiber

IV. PREPARATION OF SAMPLES

Following steps are carried out while mixing the fiber to the soil-
All the soil samples are compacted at their respective maximum dry density (MDD) and optimum moisture content (OMC), corresponding to the standard proctor compaction tests
Content of fiber in the soils is herein decided by the following equation:

$$\rho_f = \frac{W_f}{W}$$

Where, ρ_f= Ratio of Fiber Content
W_f = Weight of the Fiber
W = Weight of the Air-Dried Soil

The different values adopted in the present study for the percentage of fiber reinforcement are 0, 0.05, 0.15, and 0.25.

In the preparation of samples, if fiber is not used then, the air-dried soil was mixed with an amount of water that depends on the OMC of the soil.

If fiber reinforcement was used, the adopted content of fibers was first mixed into the air-dried soil in small increments by hand, making sure that all the fibers were mixed thoroughly, so that a fairly homogenous mixture is obtained, and then the required water was added.

Figure 2: PP Fiber Mixed With Soil Sample

V. BRIEF STEPS INVOLVED IN THE EXPERIMENTS

5.1 Specific Gravity of the Soil

The specific gravity of soil is the ratio between the weight of the soil solids and weight of equal volume of water. It is measured by the help of a Pycnometer in a very simple experimental setup where the volume of the soil is found out and its weight is divided by the weight of equal volume of water.

5.2 Liquid limit

The Casagrande tool cuts a groove of size 2mm wide at the bottom and 11 mm wide at the top and 8 mm high. The number of blows used for the two soil samples to come in contact is noted down. Graph is plotted taking number of blows on a logarithmic scale on the abscissa and water content on the ordinate. Liquid limit corresponds to 25 blows from the graph.

5.3 Plastic limit

This is determined by rolling out soil till its diameter reaches approximately 3 mm and measuring water content for the soil which crumbles on reaching this diameter. Plasticity index (IP) was also calculated with the help of liquid limit and plastic limit.

5.4 Particle Size Distribution

The results from sieve analysis of the soil when plotted on a semi-log graph with particle diameter or the sieve size as the abscissa with logarithmic axis and the percentage passing as the ordinate gives a clear idea about the particle size distribution. From the help of this curve, D10 and D60 are determined. This D10 is the diameter of the soil below which 10% of the soil particles lie. The ratio of, D10 and D60 gives the uniformity coefficient (Cu) which in turn is a measure of the particle size range.

5.5 Proctor compaction test

This experiment gives a clear relationship between the dry density of the soil and the moisture content of the soil. The experimental setup consists of (i) cylindrical metal mould (internal diameter-10.15 cm and internal height-11.7 cm), (ii) detachable base plate, (iii) collar (5 cm effective height), (iv) rammer (2.5 kg). Compaction process helps in increasing the bulk density by driving out the air from the voids. The theory used in the experiment is that for any compactive effort, the dry density depends upon the moisture content in the soil. The maximum dry density (MDD) is achieved when the soil is compacted at relatively high moisture content and almost all the air is driven out, this moisture content is called optimum moisture content (OMC). After plotting the data from the experiment with water content as the abscissa and dry density as the ordinate, we can obtain the OMC and MDD.

5.6 Direct shear test

Direct shear test was performed on Silty clay and sand clay a strain controlled shear apparatus at a rate of strain of 1.25 mm per min. in accordance with IS 2720 (Part XIII). The direct shear testing apparatus used in the study. Direct shear test have been carried out for air dried samples of all types of mix for determining c- φ values. Test results have been tabulated and discussed in next chapter. The specimen tested for the test is shown in figure 5.6 in which the randomly distributed Short PP (polypropylene) fiber are visible.

Figure 3: Direct Shear Test Apparatus

Figure 4: Direct Shear Box with Reinforced Specimen

VI. RESULTS AND DISCUSSIONS

6.1 Different types of engineering properties of soil sample 1 and soil sample2 were find out as shown in table 2

Table 2- Engineering properties of soil sample 1 and soil sample 2

S.NO.	PROPERTIES OF SOIL	SOIL SAMPLE 1	SOIL SAMPLE2
1.	Uniformity Coefficient	1.362	1.362
2.	Specific gravity	2.71	2.76
3.	Liquid Limit	28.90	43.491
4.	Plastic Limit	25.73	21.76
5.	Plasticity Index	6.32	24.35
6.	Optimum Moisture Content (OMC)	13.7%	19.02%
7.	Maximum Dry Density (MDD)	1.71 g/cc	1.85 g/cc

6.2 Direct Shear Test

A constant normal load (ς) is applied to obtain one value of c and φ. Horizontal load (shearing load) is increased at a constant rate and is applied till the failure point is reached. This load when divided with the area gives the shear strength 'τ' for that particular normal load. The equation goes as follows:

$$\tau = c + \sigma * \tan(\varphi)$$

After repeating the experiment for different normal loads (ς) we obtain a plot which is a straight line with slope equal to angle of internal friction (φ) and intercept equal to the cohesion (c). Direct shear test is the easiest and the quickest way to determine the shear strength parameters of a soil sample Following Values of cohesion C and internal friction angle φ .The Shear stress values according to Direct shear test results for Soil 1 at MDD 1.71 g/cc with 0% reinforcement 0.59 Kg/cm^2, 0.91 Kg/cm^2,1.14 Kg/cm^2, 1.27 Kg/cm^2 and at 0.25% reinforcement 0.86 Kg/cm^2, 1.34 Kg/cm^2, Kg/cm^2, 2.29 Kg/cm^2. The shear stress for soil 2 at MDD 1.85g/cc with 0% reinforcement 0.58 Kg/cm^2,0.82 Kg/cm^2,1.05 Kg/cm^2,1.28 Kg/cc.

- **Soil sample 1**

Table 3: Shear Parameters of Soil Sample 1

MIX NO.	MIX COMPOSITION	SYMBOL	COHESION (C) kg/cm^2	Angle of Internal Friction (φ)
1.	Unreinforced soil	DS 1	0.325	47.72^0
2.	Reinforcement 0.05% + SOIL 1	DS2	0.3575	48.101^0
3.	Reinforcement 0.15% + SOIL 1	DS3	0.3747	48.254^0
4.	Reinforcement 0.25% + SOIL 1	DS4	0.3887	48.483^0

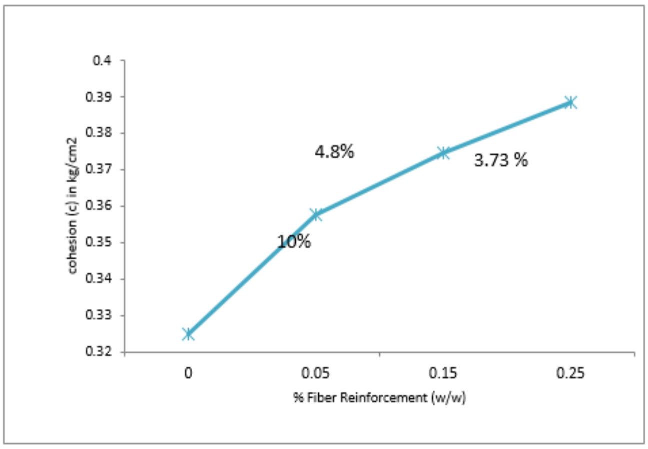

Figure 5: Relationship between cohesion and fiber content for soil sample- 1

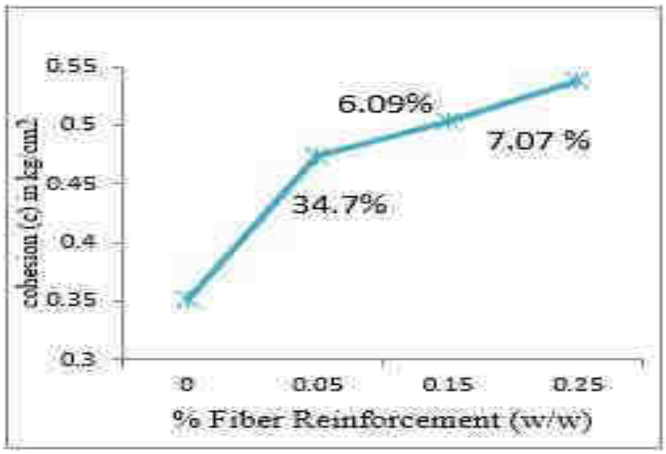

Figure 7: Relationship between cohesion and fiber content for soil sample- 2

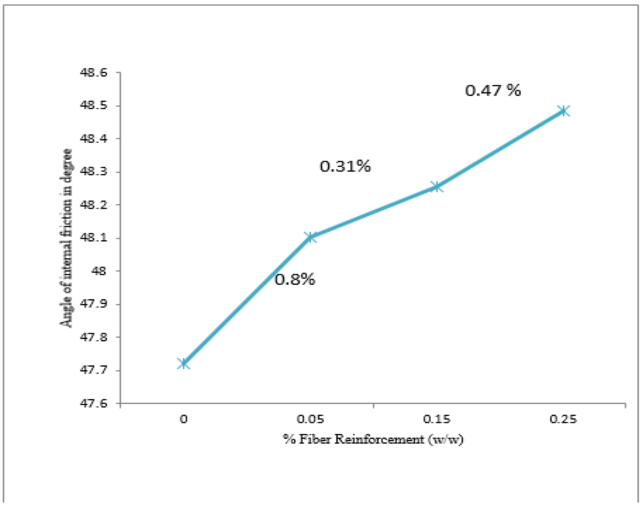

Figure 6: Relationship between angle of internal friction and fiber content for Soil sample-2

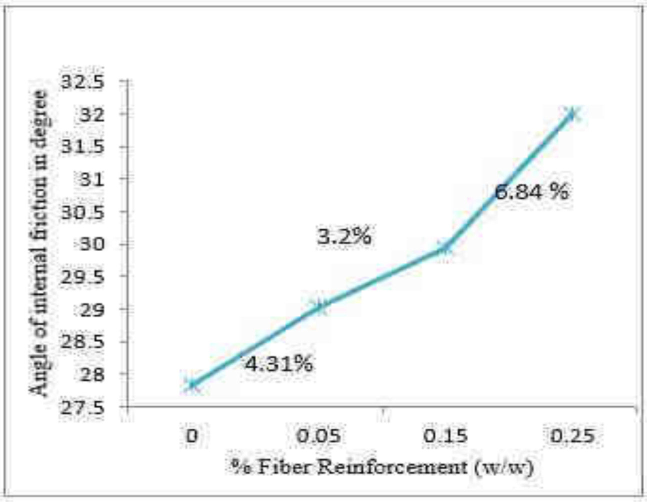

Figure 8: Relationship between angle of internal friction and fiber content for soil sample-2

In the soil sample 1 from figure 5 and figure 6 it is observed that Cohesion value increases from 0.325 kg/cm^2 to 0.3887 kg/cm^2, a net **19.6%** .The increment graph shows a gradual decline in slope. The angle of internal friction increases from 47.72 to 48.483 degrees, a net **1.59%** the increment in shear strength of soil due to reinforcement is **marginal**.

- **Soil Sample – 2**

Table 3: Shear Parameters of Soil Sample -2

MIX NO.	MIX COMPOSITION	SYMBOL	COHESION (C) kg/cm^2	Angle of Internal Friction (φ)
1.	**Unreinforced soil**	DS 1	0.3513	27.82^0
2.	**Reinforcement 0.05%** + SOIL 2	DS2	0.4732	29.02^0
3.	**Reinforcement 0.15%** + SOIL 2	DS3	0.504	29.95^0
4.	**Reinforcement 0.25%** + SOIL 2	DS4	0.54	32^0

In the soil sample 2 from figure 7 and figure 8 it is observed that Cohesion value increases from 0.3513 kg/cm^2 to 0.5375 kg/cm^2, a net 53.0% .The increment graph for cohesion shows a gradual decline in slope. The angle of internal friction increases from 27.82 to 32 degrees, a net 15.02% .The increment graph for φ shows a variation in slope- alternate rise and fall. The increment in shear strength of soil due to reinforcement is substantial

Conclusions and Suggestions for Further Studies

On the basis of present experimental study, the following conclusions are drawn:

1. Based on direct shear test on soil sample- 1, with fiber reinforcement of 0.05%, 0.15% and 0.25%, the increase in cohesion was found to be 10%, 4.8% and 3.73% respectively (illustrated in Figure 5). The increase in the internal angle of friction (φ) was found to be 0.8%, 0.31% and 0. 47% respectively (illustrated in Figure 6). Since the net increase in the values of c and φ were observed to be 19.6%, from 0.325 kg/cm^2 to 0.3887 kg/cm^2 and 1.59%, from 47.72 to 48.483 degrees respectively, for such a soil, randomly distributed polypropylene fiber reinforcement is not recommended.
2. The shear strength parameters of soil sample- 2 were determined by direct shear test. Figure 7 illustrates

that the increase in the value of cohesion for fiber reinforcement of 0.05%, 0.15% and 0.25% are 34.7%, 6.09% and 7.07% respectively. Figure 8 illustrates that the increase in the internal angle of friction (φ) was found to be 0.8%, 0.31% and 0. 47% respectively. Thus, a net increase in the values of c and φ were observed to be 53%, from 0.3513 kg/cm2 to 0.5375 kg/cm2 and 15.02%, from 27.82 to 32 degrees. Therefore, the use of polypropylene fiber as reinforcement for soils like soil sample- 2 is recommended.

3. Overall it can be concluded that fiber reinforced soil can be considered to be good ground improvement technique specially in engineering projects on weak soils where it can act as a substitute to deep/raft foundations, reducing the cost as well As Energy.

SUGGESTIONS FOR FURTHER STUDIES

The results of this study suggest that Plastic Fiber of Polypropylene may prove useful as soil reinforcement in highway and light- duty geotechnical applications. However, further study is needed to:

1. Optimize the size and shape of the Plastic Fiber.
2. Assess the durability and aging of the strips.
3. Mathematical modeling can be done so that improvement of subgrade of a road structure may be predicted from the properties of soil, and plastic content to be used in subgrade to help the practicing geotechnical engineers.
4. Determine the economic benefits that can be accrued through their use. Larger-scale tests should also be conducted to determine if boundary effects influence the test results.
5. Plastic Fiber can be used in varying sizes too, just like tendons in Pre Stressed concrete.

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