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Engineering Properties of Soils Reinforced By Recycled Polyester Fiber

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Abstract: *Environmental authorities are concerned about the growing amount of polyethylene (PET) bottles produced by household sectors. This paper presents results of an investigation into utilization of recycled polyester fiber that produced of polyethylene (PET) bottles in order to improve engineering properties of cohesive soils. This research in order to study effect of adding recycled polyester fiber on soil engineering properties, especially shear strength and California Bearing Ratio (CBR) used clay soil with low liquid limit (CL) and atterberg limits used high liquid limit (CH). Clay soil with recycled polyester fibers are mixed with soil in three different percentages 0.1%, 0.3% & 0.5% (the portion of stabilizer matters to soil net weight). Shear strength, CBR, atterberg limits of stabilizer samples were measured by direct shear test and CBR test and atterberg limits test. Experiments results show this fact that using of recycled polyester leads to increasing shear strength and CBR and reduction, plasticity index. It is remarkable that according to economic problems, the most optimum quantity of recycled polyester is 0.5%.*

Keywords: *Recycled polyester fiber, Soil reinforced, Shear strength, CBR, Atterberg limits*

I. Introduction

The main reason behind this trend is the excessive production of waste like fly ash, plastics, rice husk ash which is not only hazards but also creating deposition problems. Using some of these waste materials in construction practice will reduce the problem in a great extent. One of the main advantages of using randomly distributed fibers is the maintenance of strength isotropy and the absence of potential planes of weakness that can develop in soils with oriented reinforcement [1]. Khattab et al. [2] reported that a more limited reduction in compressive strength was obtained for the samples stabilized with industrial waste lime than those stabilized with lime. Ghazavi and Lavasan [3] studied the interference effect of shallow foundations constructed on sand reinforced with geosynthetics and reported that geogrid lead to increases the bearing capacity and decreases the shear strain transmitted to the soil. Madhavi Latha and Somwanshi [4] studied the effect of reinforcement form on the bearing capacity of square footings on sand and reported that the bearing capacity improvement factor is significantly affected by the form of reinforcement. Maliakal et al. [5] studied the properties of coir fibers-reinforced clay and reported that for a constant fiber length (aspect ratio), major principal stress at failure increased with increase in fiber content. Kumar et al. [6] studied the properties of polypropylene reinforced clay and reported that polypropylene fibers with aspect ratio 100 lead to increase shear peak and residual strength. Estabragh et al. [7] studied the mechanical behavior of a clay soil reinforced with nylon fibers and reported that the inclusion of fiber leads to an increase of the excess pore water pressure in undrained conditions. Mohamed [9] believes that adding dry straw decreases soil dry special weight and also adding straw fibers up to 1.0%, decreases the soil shrinkage limit. Kamei et al. [9] studied the use of recycled bassanite and coal ash to enhance the strength of very soft clay in dry and wet environmental conditions and reported that both the recycled bassanite and coal ash increase strength of very soft clay soils and also the strength of soil decreased with the increase in the number of the wet–dry cycles up to the third cycle. Park [10] reported that the addition of 1% polyvinyl alcohol (PVA) fiber to 4% cemented sand resulted in a two times increase the axial strain at peak strength when compared with the non-fiber-reinforced specimen. Jiang et al. [11], by direct shear test, estimated shear strength of polypropylene fibers-reinforced clay soil and reported that soil shear strength of soil had increased and this strength increasing was because of increasing cohesive and internal friction angle of soil respect to natural soil. Maheshwari [12] by model footing tests and determining the bearing capacity of soil reinforced by Polyester fibers understood that the bearing capacity of polyester fibers- reinforced soil with depth equaled to 25% of width foundation was 3.53 times of natural soil. A number of factors such as the fiber characteristics (fiber type, fiber content, fiber length, thickness, aspect ratio, orientation etc.) and the soil characteristics influence the behavior of the clay–fiber composite [13, 14]. The main objective of this study is to examine the effect of recycled polyester fiber on strength parameters of clay soil and presentation a method practical for stabilization of soil and reduction environmental pollution caused by polyethylene bottles. Recycled polyester fibers can be used in the design and construction of geotechnical structures such as retaining walls, foundations, embankments, pavements, etc.

II. Materials And Test Methods

2.1 Properties of soil and reinforcement

The selection of the soils was based on the difference in their atterberg limits. Soils used in the investigation were classified as CL and CH according to Unified Soil Classification System. Table 1 presents data for the properties of A soil and B soil. Picture of recycled polyester fiber is shown in Figure 1. Surface of fibers are wrinkle. The properties of recycled polyester fiber are presented in Table 2.

Table 1 properties of A soil and B soil

Properties	Result	
	Soil A	Soil B
Specific gravity	2.8	2.7
Sand (%)	33	21.5
Fine-grained (%)	67	78.5
USCS classification	CL	CH
Liquid limit (%)	29.6	54.6
Plastic limit (%)	21.5	34.2
Shrinkage limit (%)	18	29.5
Optimum moisture content (%)	15	21
Maximum dry density (kN/m3)	17.68	17.34

Figure1 Picture of recycled polyester fibers

Table 2 Properties of recycled polyester fiber

Properties	Result
Type	Recycled polyester
Specific Gravity	1.22
Moisture content (%)	0.4
Tensile Strength (N/mm^2)	200-400
Length (mm)	30-40
Diameter (μm)	20-30
Color	Colourless

2.2 Test methods

In this paper effect of the recycled polyester fibers on the strength properties of cohesive soils has been evaluated. In order to evaluation shear strength parameters of soil by direct shear test were used three normal stresses: 100, 200 & 300 kPa. Direct shear tests CBR test were done with different percentages of the recycled polyester (0.1, 0.3 & 0.5 percent of soil dry weight). Atterberg limits test was used to determine liquid limit, plastic limit and shrinkage limit. Atterberg limits test were done with different percentages of the recycled polyester (0.5, 1.0 & 1.5 percent of soil dry weight).

2.2.1 Sample preparation

First all the soil was crashed by a hammer. In order to prepare recycled polyester fibers - reinforcement specimens for Atterberg limits test, at first, the B soil was mixed at 0.5, 1.0 & 1.5% with fibers. Then, the mixture of soil with fibers was mixed with different water content and stir it 10 min until a homogenous mixture reached. This composite was used to estimate the liquid limit, the plastic limit and the shrinkage limit of recycled polyester fibers reinforced soil. Also in order to prepare recycled polyester fibers - reinforcement specimens for direct shear test and CBR test, at first, the soil A was mixed at 0.1, 0.3 & 0.5% (fiber weight to soil net weight) with fibers. Using more than 0.5% recycled polyester fibers caused sticked fibers to form lumps and nonuniform distribution in soil; consequently, the density of soil decreased. Then, the mixture of soil with fibers was mixed with 15% water which was the optimum water due to standard proctor compaction test and stir it 15min until a homogenous mixture reached. This composite was used to estimate the strength properties of recycled polyester fibers reinforced soil in direct shear test and CBR test.

2.2.2 Testing procedure for Atterberg limits test

The liquid limit test is performed according to standard ASTM D 4318-85. Casagrande device is used to determine liquid limit of natural and stabilized specimen with recycled polyester fibers. To perform the liquid limit test, the mixture was filled in a Casagrande cup. Then a groove is created at the center of the soil with the standard grooving tool. By the use of the crank-operated cam, the cup is lifted and dropped from a height of 10 mm. The moisture content, in percent, required to close a distance of 12.7 mm along the bottom of the groove after 25 blows is defined as the liquid limit. It is difficult to adjust the moisture content in the mixture to meet the required 12.7 mm closure of the groove in the soil pat at 25 blows. Hence, at least four tests for the same soil are conducted at varying moisture contents. In total, 16 liquid limit tests were conducted by varying recycled polyester fibers content. The plastic limit tests are performed under fixed conditions and according to standard ASTM D 424. The plastic limit test is performed by repeated rollings of an ellipsoidal-sized soil mass by hand on a ground glass plate. The shrinkage limit test is performed under fixed conditions and according to standard ASTM D 427-83. This test is performed in the laboratory with a porcelain dish about 44 mm in diameter and about 12.7 mm high. The inside of the dish was coated with petroleum jelly and was then filled completely with mixture. Excess soil standing above the edge of the dish was struck off with a straightedge. The mass of the mixture inside the dish was recorded. The mixture was the dish was then oven-dried. The volume of the oven-dried mixture was determined by the displacement of mercury.

2.2.3 Testing procedure for direct shear test

This test is performed under fixed conditions and according to standard ASTM D3080-90. The mixture was filled in 101.4 mm diameter × 116.5 mm high cylindrical mould in three equal layers and each layer was compacted using a tamping device to attain the maximum dry unit weight determined using the standard Proctor test. Then the shear ring of 60 × 60 mm in plan and 25 mm in depth by hydraulic jack were pushed into the soil mixture. Then the samples were extruded into shear box. In order to prepare the consolidated and saturated samples, the samples were kept under normal stress for about 24 hours into the shear box bowl filled with water. The normal stresses in the present study were 100, 200 and 300 kPa, while drainage was allowed from the top and bottom of the shear box. Since under undrained condition fiber has least effective in increasing in soil resistance, tests were conducted under undrained condition. Because of the fact that the rate of imposing horizontal displacement was 1.25mm/min, the sample was sheared under undrained condition by applying the shear stress. Three specimens were tested for each combination of mixture and the average is obtained. Shear stresses were recorded as a function of horizontal displacement up to a total displacement of 13 mm. The relation stress-displacement is plotted.

2.2.4 Testing procedure for CBR test

The CBR test was performed under fixed conditions and according to standard ASTM D 1883-94. The mixture was filled in 150 mm diameter × 180 mm high cylindrical mould in five equal layers and each layer was compacted using a tamping device. The velocity of test was 1.25mm/min. For each combination of mixture, three samples were prepared and the average value of test data was obtained. In total, 12 groups of CBR tests were conducted by varying contents of recycled polyester fibers. In this paper the load-penetration curves were plotted and the CBR values were computed.

III. Results And Discussions

3.1 Effect of recycled polyester fibers on the liquid limit of clay

The liquid limit of soil reinforced with varying fiber content, is presented in Figure 2. Observation of this Table indicates that with increase in fiber content the liquid limit of reinforced soil increase. With inclusion of fibers, the liquid limit is increase by factors 1.04, 1.13, 1.19 respectively for fiber content of 0.5, 1.0 and 1.5%. The observed changes are attributed to the replacement of soil grains by fibres. The soil reinforced is more continuity then the soil non- reinforced; consequently, the liquid limit of soil reinforced increase. This result contrasts with the result' Kinjal et al. [15] in regard to behavior of soil.

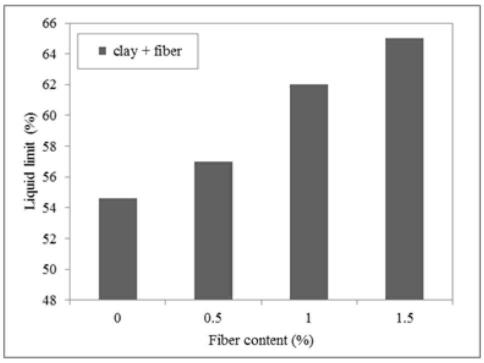

Figure 2 Variation of liquid limit with recycled polyester fibers content

3.2 Effect of recycled polyester fibers on the plastic limit of clay

The plastic limit of soil reinforced with varying fiber content, is presented in Figure 3. Observation of this Table indicates that the increase in fiber content be responsible for increase in the plastic limit of reinforced soil. With inclusion of fibers, the plastic limit is increased by factors 1.29, 1.42, 1.44 respectively for fiber content of 0.5, 1.0 and 1.5%. With compare of Table 3 and Table 4, it can be observed that increase in recycled polyester fiber content lead to decrease in the plasticity index (PI) of soil. With inclusion of fibers, the plasticity index (PI) is decreased by factors 0.65, 0.7, 0.8 respectively for fiber content of 0.5, 1.0 and 1.5%. This result somewhat similar to results' Fauzi et al. [16] that studied the atterberg limits of high density polyethylene reinforced clay and reported that, with inclusion of (HDPE), the plasticity index (PI) is decreased by factors 0.93, 0.81, 0.79 respectively for (HDPE) content of 1, 4 and 8%.

3.3 Effect of recycled polyester fibers on the shrinkage limit of clay

Shrinkage limit, one of the Atterberg limits, is pertaining with plasticity-based soil behaviors. The shrinkage limit of soil reinforced with varying fiber content is presented in Figure 5. Observation of this Table indicates that increase in fiber content be the reason for increase in the shrinkage limit of reinforced soil. With inclusion of fibers, the shrinkage limit is increased by factors 1.36, 1.41, 1.45 respectively for fiber content of 0.5, 1.0 and 1.5%. Therefore, it can be concluded that random fiber inclusion seems to be a practical and effective method of increasing tensile strength of the clayey soils to resist volumetric changes.

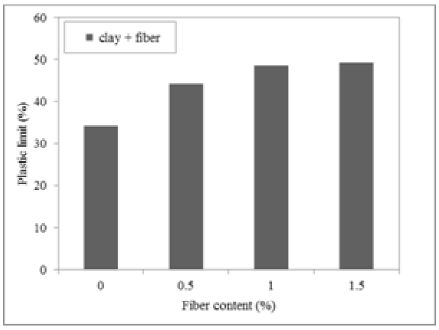

Figure 3 Variation of plastic limit with recycled polyester fibers content

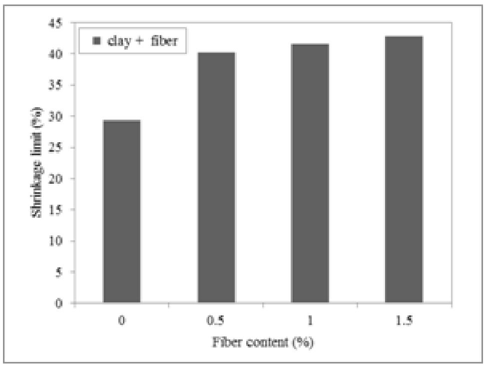

Figure 4 Variation of shrinkage limit with recycled polyester fibers content

3.4 Effect of recycled polyester fibers on the shear parameters of clay

The stress-displacement behaviour of soil reinforced with varying fiber content, obtained from direct shear tests is presented in Figure 5. From this Fig, it can be observed that the peak strength of fiber-reinforced soil occured at higher horizontal displacement in majority of specimens investigated compared to the unreinforced soil. Observation of this Figure indicates that with increase in normal stress and fiber content contribute to increase in the peak strength of reinforced soil. With inclusion of recycled polyester fibers in the soil, the maximum increase in the peak strength is observed at normal stress 300 kPa. With inclusion of fibers, in normal stress 300 kPa, the peak shear stress is increased by factors 1.36, 1.63, 1.83 respectively for fiber content of 0.1, 0.3 and 0.5%. The shear parameters presented in Table 3. From this Table, it is observed that recycled polyester fibers are responsible for increase the angle of internal friction and the cohesion. The angle of internal friction and the cohesion are increased by factors 1.46, 1.77, 2.01 and 1.20, 1.31, 1.41 respectively for fiber content of 0.1, 0.3 and 0.5%. It increase in the shear parameters may be due to interaction between the soil particles and recycled polyester fibers. With compare of results' the angle of internal friction and results' the cohesion, it can be observed that in increase the shear strength of fiber-reinforced soil the angle of internal friction is more efficiently then the cohesion. The previous research results show that the interaction mechanism between soil and fiber is influenced by many factors. These can be illustrated by the confinement, reinforcement surface roughness, shape. Interlock between soil particles and fiber surface is the reason for improvement the strength of soil. From the sketch drawing of Figure 6 can be observed that the fiber surface is attached by some soil particle and produces bonding and friction between the fiber and soil matrix. Several previous research results show that the fiber sliding resistance is influenced by the fiber surface roughness [17, 18]. The recycled polyester fiber surface roughness contributes to an increase in interfacial interlock force. Consequently, the fibers in the soil are difficult to slide and resisted the relative movement of fibers in the soil. This result and results' Yan et al. [19] have attitudes in common. Interlock between soil particles and fiber surface are the reason for improvement the shear strength. Similar results were obtained by Tang et al. [20].

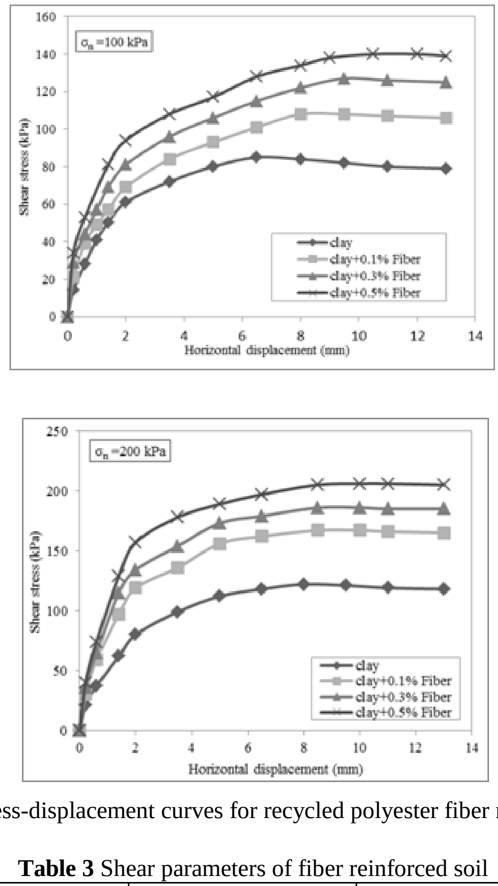

Figure 5 Stress-displacement curves for recycled polyester fiber reinforced soil

Table 3 Shear parameters of fiber reinforced soil

Specimens	Fiber content (%)	Cohesion (c), kPa	Angle of internal friction (Φ), degrees
1	0.0	63	14.3
2	0.1	76	21
3	0.3	83	25.4
4	0.5	89	28.8

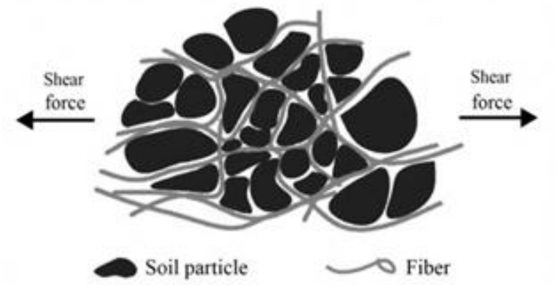

Figure 6 Sketch drawing of interfacial mechanical behavior between soil particles and fiber surface

3.5 CBR test

The results of CBR tests are presented in Figure 7. The results indicate that the inclusion of fiber content contribute to increase in the CBR values. With inclusion of fiber, the CBR values is 6.7, 8.9 and 9.8 MPa respectively for fiber content of 0.1, 0.3 and 0.5% and the CBR value of unreinforced soil is 5.4. Thus with inclusion of recycled polyester fibers, the CBR values is increased by factors 1.24, 1.64 and 1.81 respectively for fiber content of 0.1, 0.3 and 0.5%.From these results one can conclude that the best ratio of recycled polyester fiber addition is about 0.5%. This agrees with the work of Fauzi et al. [16].

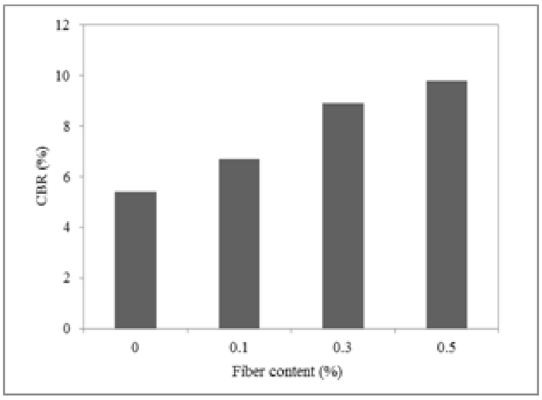

Figure 7 CBR values for fiber reinforced soil at different fiber contents

IV. Conclusion

This study investigated the effect of adding recycled polyester fibers on the strength behavior of clay soil. The effects of fiber reinforcement on clayey soil were studied by using results obtained from a series of, Atterberg limits and direct shear and CBR tests. Based on the results presented in this paper the following conclusions are drawn:

1- Due to the increase in fiber content, the liquid limit of reinforced soil increases, also the plastic limit of reinforced soil increases. With inclusion of fibers, the plasticity index is decreased by factors 0.65 for fiber content of 0.5%.
2- Increase in recycled polyester fiber content contribute to increase the peak shear stress. Better result of the peak shear stress was observed by 0.5% of recycled polyester fiber content that under this condition, the peak shear strength is increased by factors 1.83.
3- The increase in fiber content lead to increase both angle of internal friction and cohesion. With inclusion 0.5% of recycled polyester fibers the angle of internal friction and the cohesion are increased by factors 2.01 and 1.41 respectively.
4- In view of increase in fiber content, the CBR values of reinforced soil increases, in such a way that with inclusion of 0.5% recycled polyester fibers, the CBR of reinforced-soil is increased by factors 1.81.
5- Due to the fact that the recycled polyester fibers covers around soil particles, the interlock force between soil particles increases and bond characteristics improves.

This investigation, it is clearly indicated that the technique of the mixture soil and recycled polyester fibers is a very effective method of ground improvement, which improves the shear strength, the CBR values and the plasticity index of soil and consequently, enhance the stability of infrastructures such as foundation and roadbed. With the development of the construction technology, this improvement technique can be considered as a practical method for improvement of strength behavior of clay in many fields of geotechnical engineering, such as foundation, roadbed and slope engineering.

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