

A Study on Use of Polyethylene Terephthalate (PET) Fiber for Stabilization of Subgrade Soil of Road Pavement

Brajesh Mishra

M. Tech., Assistant Engineer, Department of Cane Development, Lucknow, India

ABSTRACT: Stabilization of subgrade soil is prime concern in any highway project. In the present scenario the environmentalists are very much concerned about the growing use of polyethylene terephthalate (PET) bottles by people in their daily life. This paper is aimed on studying the effect on engineering properties of soil by addition of recycled polyethylene terephthalate (PET) fibers. The engineering properties especially to be studied are shear strength, California Bearing Ratio (CBR) and Atterberg limit using clay soil. The recycled PET fiber was added in the clayey soil in the proportion ranging from 0% to 0.8% by weight of soil with an increment of 0.2%. The various laboratory tests were performed. Experimental investigations show that there was an improvement in shear strength and CBR value and decrease in plasticity index. Optimum quantity of recycled PET fiber which showed favorable strength was found to be 0.6% .

KEYWORDS: Recycled polyethylene terephthalate (PET) fiber, soil stabilization, shear strength, CBR value, Atterberg limits.

I. INTRODUCTION

It has become a common practice in present scenario to stabilize the soil all over the world by using various waste materials. The basic reason behind this is the enormous generation of wastes like fly ash, plastic, various types of slag, foundry sands which are threat to environment and creating a problem for disposal of the same. The reuse of these materials in construction projects will solve the problem of its safe disposal to great extent. Various researchers have tried different materials and fibers to achieve different results in recent past years in stabilization of soil. Limited reduction in compressive strength of soil samples were observed by Khattab et al. by using industrial waste lime in place of convention lime for stabilizing soil. Studies also reveal that there was an improvement in CBR value and unconfined compression index by stabilizing the natural soil by mixing rice husk and fly ash. Kumar et al. showed that there was an improvement in shear resistance of natural soil by reinforcing the soil with polypropylene fibers. It was also observed that there was also a marked improvement in CBR value of soil. The effect of addition of waste carpet fiber in clayey soil was studied by Mirzababaei et al., they reported that by virtue of increase in optimum moisture content and reduction in soil dry weight the swelling pressure can be decreased. Studies also reveal that sand with 2% cement and 1% fiber was responsible to increase its unconfined compression resistance by 3.5 times that of unreinforced soil. There was an improvement in shear strength with adding polypropylene fibers as reported by Hamidi et al. The study on different fiber reinforced soils was carried out by Freitag and Mesbah et al. and they concluded that indexes like length, quantity and aspect ratio have their own effect on reinforced soil behavior. Jiang et al. had carried several direct shear tests on clayey soil reinforced with 0.4% polypropylene fibers by weight of soil and reported that cohesion and internal friction angle of fiber reinforced soil was greater than those of the natural soil. With increase in percentage of nylon fiber shear strength and friction angle of modified soil was increased as observed by Estabargh et al. The effective stresses was also increased with increase in fiber content. The main objective of this study is to examine the effect of recycled PET fiber on resistance parameters of clay soil and find a method practical for stabilization of soil and to check the environmental pollution caused by polyethylene containers.

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II. MATERIALS AND METHODS

2.1. Materials: The soil that has been used in this research was collected from around the Lucknow city, located in Uttar Pradesh, a state of India. Soil was pulverized and sieved through 4.75 mm size sieve. Recycled PET fibers were used as reinforcement and were added in specified proportion to the soil.

2.1.1. Properties of Soil: The selection of the soils was based on the difference in their Atterberg limits. Table 1 presents data for the properties of soil X and soil Y.

Table-1 Properties of soils X and Y

Properties	Values	
	Soil X	Soil Y
Specific gravity	2.75	2.68
Sand (%)	32	22.3
Fine- grained(%)	66	77.5
USCS Classification	CL	CH
Liquid Limit(%)	28.4	53.8
Plastic Limit(%)	21.3	33.8
Shrinkage Limit (%)	19	28.5
Optimum Moisture Content (OMC) %	14	20
Maximum Dry Density(g/cm^3)	1.74	1.70

Various properties of soil sample X and Y like specific gravity, liquid limit, plastic limit, shrinkage limit, optimum moisture content(OMC), maximum dry density (MDD) and content of fines are shown in Table -1.

2.1.2. Properties of PET Fiber: Picture of recycled PET fiber is shown in Fig.1. Surface of fibers are crinkle. The PET fiber is colorless. The length of fiber taken varies from 30 to 40 mm and diameter from 20 to 30 mm.



Fig. 1. Recycled PET fibers

The various properties like specific gravity, moisture content and tensile strength of Recycled PET fiber are presented in Table 2 below. The specific gravity of PET fiber is 1.22, tensile strength varies from 200 to 400 N/mm² and moisture content is 0.4%.

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Table-2 Properties of Recycled PET Fiber

Properties	Values
Specific gravity	1.22
Moisture Content %	0.4
Tensile Strength (N/mm ²)	200-400
Length (mm)	30-40
Diameter (mm)	20-30
Color	Colorless

2.2. Tests Performed: Various tests were performed to study the effect of addition of the recycled PET fibers on the strength properties of cohesive soil. To evaluate shear strength parameters of soil by direct shear test three normal stresses: 9.72 N/cm², 12.50 N/cm² & 16.67 N/cm² were selected. Direct shear tests and CBR test were performed with different percentages of the recycled PET fibers (0.2, 0.4, 0.6 and 0.8% by weight of soil). Atterberg limits test carried out to determine liquid limit, plastic limit and shrinkage limit. Atterberg limits test were performed with different percentages of the recycled PET fibers (0.4, 0.8 & 1.2% by weight of soil).

III. EXPERIMENTAL RESULTS AND DISCUSSIONS

In this study various tests were conducted on soil without reinforcement and with randomly distributed discrete PET fiber-reinforcement. The effects of recycled PET fibers on stress-displacement behavior, shear parameters, CBR strength and Atterberg limits were also studied. The outcome of study are presented below-

3.1. Effect of recycled PET fibers on the liquid limit of clay: The data of liquid limit variation with introduction of varying percentages of PET fibers are plotted in figure-2. It was observed that with increase in fiber content the liquid limit of reinforced soil increases. With introduction of PET fiber content in percentages of 0.4%, 0.8% and 1.2% the liquid limit increases by factors 1.04, 1.12 and 1.19 respectively for fiber content of 0.4%, 0.8% and 1.2%. The observed changes are attributed to the replacement of soil grains by fibers also recycled PET fibers do not absorb moisture.

3.2. Effect of recycled PET fibers on the plastic limit of clay: The data of plastic limit of soil reinforced with varying fiber content are plotted in figure-2. The data indicates that with increase in fiber content the plastic limit of reinforced soil increases. With addition of fibers, the plastic limit increases by factors 1.30, 1.40 and 1.44 respectively for fiber contents of 0.4%, 0.8% and 1.2%. It was observed that with increase in fiber content the plasticity index of reinforced soil decreases. With introduction of PET fibers, the plasticity index (PI) decreases by factors 0.63, 0.68 and 0.77 respectively for fiber content of 0.4%, 0.8% and 1.2%.

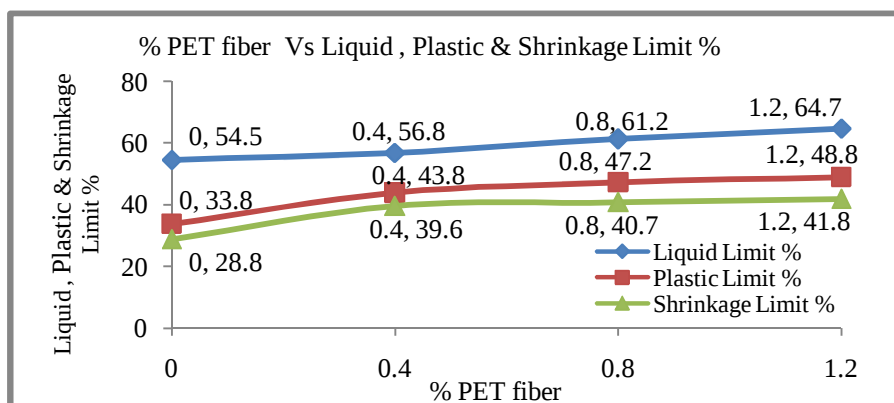


Fig. 2. Variation of Liquid, Plastic and Shrinkage Limit with recycled PET fiber content

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3.3. Effect of recycled PET fibers on the shrinkage limit of clay: The shrinkage limit of soil reinforced with varying fiber content is presented in Fig. 2. It can be observed that with increase in fiber content the shrinkage limit of reinforced soil increase. With inclusion of fibers, the shrinkage limit is increased by factors 1.38, 1.41, 1.45 respectively for fiber content of 0.4, 0.8 and 1.2%. 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.

3.4. Effect of recycled PET fibers on the shear parameters of clay: The stress-displacement behavior of soil reinforced with varying fiber content, obtained from direct shear tests are plotted in Fig. 3 to 5.

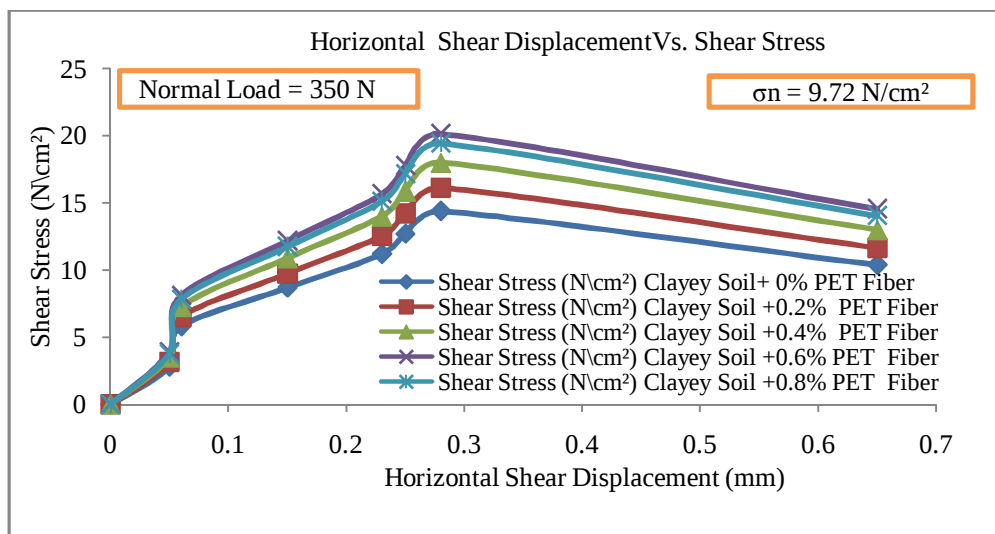


Fig. 3 Horizontal displacement and shear Stress at normal stress 9.72 N/cm²

Fig. 3 shows that with increase in normal stress and fiber content the peak strength of reinforced soil increases. With addition of recycled PET fibers in the soil, the maximum increase in the peak strength is observed at normal stress 9.72 N/cm². With addition of fibers, at normal stress 9.72 N/cm², the peak shear stress increases by factors 1.12, 1.25, 1.40 & 1.35 respectively for PET fiber content of 0.2%, 0.4%, 0.6% & 0.8%.

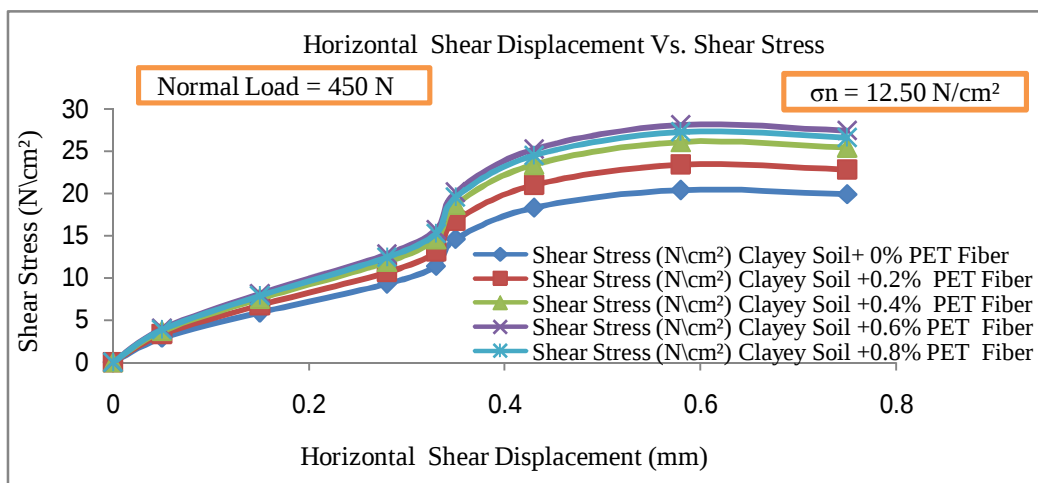


Fig. 4 Horizontal displacement and shear Stress at normal stress 12.50 N/cm²

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Fig. 4 shows that with increase in normal stress and fiber content the peak strength of reinforced soil increases. With addition of recycled PET fibers in the soil, the maximum increase in the peak strength is observed at normal stress 12.50 N/cm². With addition of fibers, at normal stress 12.50 N/cm², the peak shear stress increases by factors 1.15, 1.28, 1.38 & 1.34 respectively for PET fiber content of 0.2%, 0.4%, 0.6% & 0.8%.

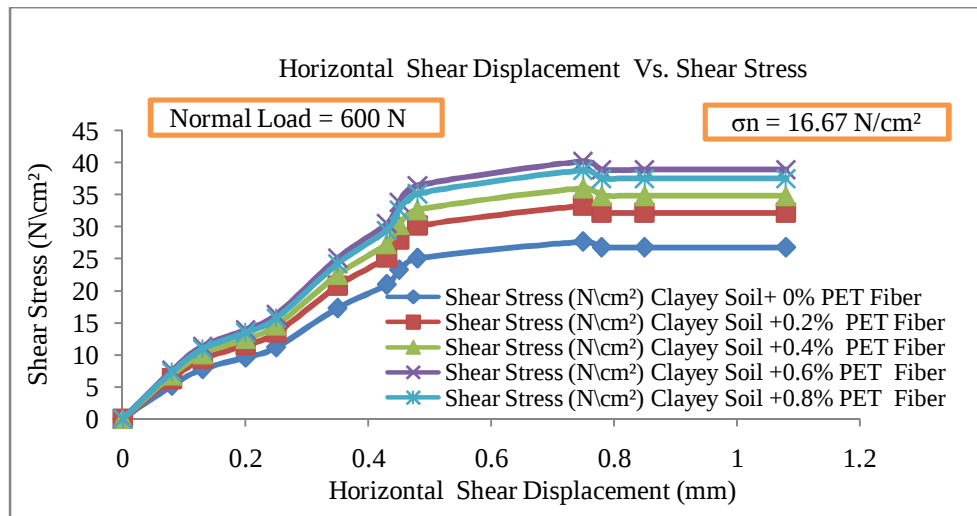


Fig. 5 Horizontal displacement and shear Stress at normal stress 16.67 N/cm²

Fig. 5 shows that with increase in normal stress and fiber content the peak strength of reinforced soil increases. With addition of recycled PET fibers in the soil, the maximum increase in the peak strength is observed at normal stress 16.67 N/cm². With addition of fibers, at normal stress 16.67 N/cm², the peak shear stress increases by factors 1.20, 1.30, 1.45 & 1.40 respectively for PET fiber content of 0.2%, 0.4%, 0.6% & 0.8%. Interlock between soil particles and fiber surface caused improvement the shear strength. From figure 5, one can conclude that the peak strength of fiber-reinforced soil occurred at higher horizontal displacement in majority of specimens investigated compared to the unreinforced soil. The maximum value was observed at 0.6% PET fiber content.

Table-3 Shear parameters of PET fiber reinforced soil

Samples	PET Fiber content (%)	Cohesion (c) KPa	Angle of internal friction (°)
1	0.0	36	13.2
2	0.2	54	14.2
3	0.4	57	19.2
4	0.6	63	22.8
5	0.8	59	21.4

The shear parameters shown in Table 3. From the data, it was observed that recycled PET fibers were responsible for increasing the angle of internal friction and the cohesion. The angle of internal friction and the cohesion increased by factors 1.08, 1.45, 1.73, 1.62 and 1.50, 1.58, 1.75, 1.64 respectively for fiber content of 0.2%, 0.4%, 0.6% and 0.8%. Increase in the shear parameters may be due to interaction between the soil particles and recycled PET

3.5. Effect of recycled PET fibers on the shear modulus: The shear modulus was calculated from one half of peak shear stress. The test results of direct shear tests indicate that the shear modulus with increase in normal stress and fiber content the shear modulus of reinforced soil increases. With inclusion of recycled PET fibers in the soil, the maximum increase in the shear modulus is observed at normal stress 16.67 N/cm². By introduction of fibers at normal stress 16.67 N/cm², the shear modulus is 2.21, 2.37, 2.48 and 2.33 MPa respectively for fiber content of 0.2%, 0.4%, 0.6% and 0.8%

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and the shear modulus is 2.01 for unreinforced soil, thus with introduction of recycled PET fibers, the shear modulus increases by factors 1.10, 1.18, 1.23 and 1.16 respectively for PET fiber content of 0.2%, 0.4%, 0.6% and 0.8%. The values of shear modulus are tabulated in Table no-4.

Table-4 Shear modulus of fiber reinforced soil

Samples	PET Fiber content (%)	Shear Modulus MPa		
		Normal stress 9.72 N/cm ² ,	Normal stress 12.50 N/cm ²	Normal stress 16.67 N/cm ²
1	0.0	0.90	1.52	2.01
2	0.2	0.98	1.67	2.21
3	0.4	1.12	1.81	2.37
4	0.6	1.22	1.88	2.48
5	0.8	1.18	1.79	2.33

3.6. Results of C.B.R. Test: Data obtained from CBR test results are plotted in figure-6. The results indicate that with addition of PET fibers, the CBR value increases. The CBR values increase by factors 1.16, 1.60, 1.67 and 1.65 respectively for fiber content of 0.2%, 0.4%, 0.6% and 0.8% when compared with that of unreinforced soil. The increase in CBR value is responsible for improvement in the soil strength and hence a reduced crust thickness for road pavement will serve the purpose and ultimately it will result in economy in the cost of construction. The highest value of CBR was observed on addition of 0.6% of PET fiber content by weight of soil.

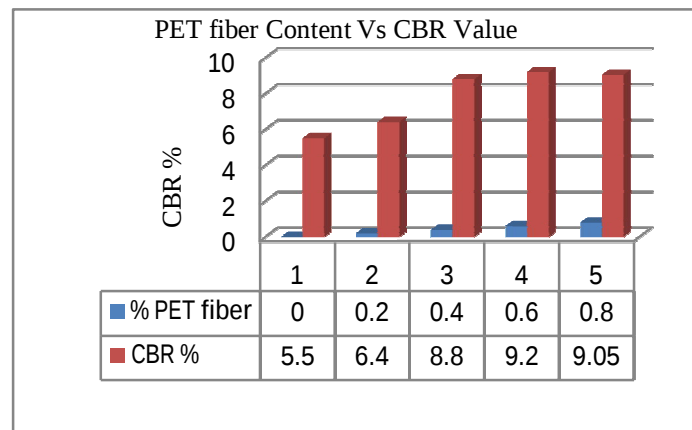


Fig. 6 Variation in CBR value with PET fiber content in soil

Examination of samples after aridness showed that by increasing the fiber content the extent and depth of cracks were significantly reduced. These features are shown in figure no-7 for comparison of samples between reinforced sample with 0.6% of PET fiber and unreinforced soil.

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Fig. 7 Aridness cracking (X) unreinforced sample (Y) reinforced sample

It can be seen that extensive, deep and wide cracks were formed in the unreinforced sample. This clearly shows the effectiveness of random recycled PET fibers addition in resisting and reducing aridness cracking which is of supreme importance in surface cracking of clay covers used in landfills. Therefore, it can be concluded that random fiber addition seems to be an effective method of increasing tensile strength of the clayey soils to resist volumetric changes.

IV. CONCLUSION

Considering the aspect of environmental pollution and cost effectiveness, soil reinforcement with fibers has been inclination towards the use of recycled fibers and other locally available materials. This study investigated the effect of adding recycled PET fibers on the strength behavior of clay soil. The effects of PET fiber reinforcement on clayey soil were studied by using results obtained from various experimental investigations. On the basis of study and experimental investigations the following conclusions can be drawn:-

1. Liquid limit and plastic limit of reinforced soil with recycled PET fibers, increases with increase in content of PET fiber. With addition of PET fibers, the plasticity index was decreased by factors 0.77 for PET fiber content of 1.2%.
2. With increase in PET fiber content the shear strength of reinforced soil increases in such a way that with addition of 0.6% recycled PET fibers, at normal stress 16.67 N/cm², the shear strength of reinforced-soil, become 1.45 times of shear strength of unreinforced natural soil.
3. Both angle of internal friction and cohesion increase with increase in PET fiber content. By Introduction of 0.6% dose of recycled PET fibers the angle of internal friction and the cohesion got increased by a factors 1.73 and 1.75 respectively.
4. Shear modulus also increases with increase in PET fiber content. With introduction of 0.6% of recycled PET fibers, at normal stress 16.67 N/cm², the shear modulus was increased by factors 1.23.
5. With increase in PET fiber content, the CBR value increases. On introduction of 0.6% recycled PET fibers, the CBR value fiber reinforced-soil, becomes 1.67 times of natural or unreinforced soil. The increase in CBR value is responsible for improvement in the soil strength and hence a reduced crust thickness for road pavement will serve the purpose and ultimately it will result in economy in the cost of construction.
6. Number, depth and width of cracks due to aridness were reduced significantly with increase in PET fiber content in fiber reinforcement-soil as compared to natural or unreinforced soil.
7. Last but not least, waste PET bottles can be utilized in the construction activities, giving a way for its safe and eco-friendly disposal to protect the environment as well.

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