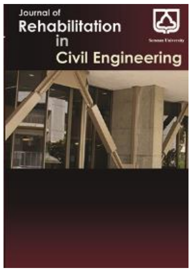
Journal of Rehabilitation in Civil Engineering 2-1 (2014) 93-105



journal homepage: http://civiljournal.semnan.ac.ir/

Stabilization of Subgrade Soil for Highway by Recycled Polyester Fiber

F. Changizi[1*] and A. Haddad[2]

1. Faculty of Civil Engineering, Semnan University, Semnan, Iran.
2. Assistant Professor, Faculty of Civil Engineering, Semnan, Iran.

* Corresponding author: foad.changizi@students.semnan.ac.ir

ARTICLE INFO

Article history:
Received: 21 May 2014
Accepted: 22 October 2014

Keywords:
Recycled polyester fiber,
Soil stabilization,
Shear strength,
CBR,
Atterberg limits.

ABSTRACT

Subgrade soil stabilization is one of the primary and major processes in the construction of any highway; also environmental authorities are concerned about the growing amount of polyethylene (PET) bottles produced by household sectors. This research is intended to study effect of adding recycled polyester fiber on soil engineering properties, especially shear strength and California Bearing Ratio (CBR) using clay soil with low liquid limit (CL) and atterberg limits used high liquid limit (CH). Recycled polyester fibers were mixed with soil in three different percentages 0.1%, 0.3% & 0.5% (the portion of stabilizer matters to soil net weight). The shear strength, CBR, atterberg limits of treated 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 fiber to reach to favorite strength is 0.5%.

1. Introduction

Emerging trend of using waste material in soil stabilizing or soil strengthening is being operational all over the world in present days. 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. Khattab et al. reported that a more limited reduction in compressive strength was obtained for the samples stabilized with industrial waste lime than those stabilized with lime [1]. Brooks reported that the soil stabilization with RHA and fly ash mixed with natural soil. In this study also showed improvement in CBR values and unconfined compression strength [2]. Kumar et al. studied the properties of polypropylene fibers-reinforced clay and reported that polypropylene fibers with aspect ratio 100, shear resistance and reminded equal to 2.7 and 2.3 times natural soil respectively [3]. Kumar et al. reported that the polypropylene fibers can improve CBR quantity of soil [4]. Mirzababaei et al. studied the effect of carpet wastage fibers on clay soil and resulted that fibers can decrease the soil dry special weight and increase the optimum moisture and these two parameters can decrease the swelling pressure [5]. Based on Park studies on sand cemented reinforced by Polyvinyl alcohol, it is obvious that unconfined compression resistance of sand with 2.0% cemented and 1.0% fiber, is 3.5 times of non-reinforcement soil [6]. Mohamed studied the properties of hay fibers-reinforced clay and reported that maximum dry density decreases with hay addition up to 1% and also the shrinkage limit increasing hay addition up to 1% [7]. Hamidi et al. reported that the addition of polypropylene fibers to the cemented soil increases the peak and residual shear strength and reduces the initial stiffness and brittleness index [8]. Freitag and Mesbah et al. studied different on fiber reinforced soils and all the results showed that indexes like length, quantity and aspect ratio could effect on reinforced soil behavior [9, ١٠]. Jiang et al. conducted a series of direct shear tests on clayey soil reinforced with polypropylene fibers on samples at fiber content of 0–0.4% by weight of soil and reported that the cohesion and internal friction angle of fiber reinforced soil was greater than those of the parent soil [11]. Estabragh et al. reported that the stiffness and shear strength of soil increase with increasing the nylon fiber content and also the friction angles in term of total stresses and effective stresses increase with fiber content [12]. Maliakal et al. 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 [13]. The main objective of this study is to examine the effect of recycled polyester fiber on resistance parameters of clay soil and presentation a method practical for stabilization of soil and reduction environmental pollution caused by polyethylene containers.

2. Materials and test methods

2.1. Materials

The soil that has been used in this research was collected from around the Behbahan city, located in the south of Iran. First all the soil was crashed by a hammer then was screened through 4.75 mm size sieve. The soil was contained clay and sand. Recycled polyester fiber used as reinforcement.

2.1.1. Properties of Soil

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.

2.1.2. Properties of reinforcement

Picture of recycled polyester fiber is shown in Fig. 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/m^3)	17.68	17.34

Fig. 1. Picture of recycled polyester fibers

Table 2. Properties of recycled polyester fibers

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 and 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 then was screened through 4.75 mm size sieve. 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, at first, the soil 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. This also caused pockets of low density. 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 resistance strength properties of recycled polyester fibers reinforced soil in direct shear test and CBR test.

2.2.2. 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 unreinforced and reinforced specimen with glass fibers. The plastic limit test and the shrinkage limit are performed according to standard ASTM D 4318-84 and ASTM D 427-83 respectively.

2.2.3. Direct shear test

Recycled polyester fibers reinforced clay was compacted in the shear box of 60 × 60 mm in plan and 25 mm in depth by tamping, until obtain density 18.9 kN/m3 for the specimens for direct shear tests. This test is performed under in unconsolidated untrained conditions and according to standard ASTM D3080-90 under normal stresses of 100, 200 & 300 kPa. The velocity of test was 1.25mm/min. in this paper, horizontal displacement had recorded up to after rupture and the parameters of shear resistance of reinforced and non-reinforced soil has been evaluated.

2.2.4 CBR test

Recycled polyester fibers reinforced clay was compacted in a cylindrical mould of 150 mm diameter and 180 mm high to standard Proctor's maximum density. This test is performed under fixed conditions and according to standard ASTM D 1883-94. The velocity of test was 1.25mm/min. In this paper the load-penetration curves were plotted and the CBR values were computed.

3. Results and discussions

In this study various tests were conducted on soil without reinforcement and with randomly distributed discrete fiber-reinforcement. The effects of recycled polyester fibers on stress-displacement behaviour, shear parameters, CBR strength and atterberg limits were also studied. The results are presented in Tables 3, 4 and Figures 2-14.

3.1. Atterberg Limits Test

3.1.1. Effect of recycled polyester fibers on the liquid limit of clay

The liquid limit of soil reinforced with varying fiber content is presented in Fig. 2. The observation of this Fig. indicates that with increase in fiber content the liquid limit of reinforced soil increase. With inclusion 0.5% of fibers, the liquid limit increases by factors 1.04. The observed changes are attributed to the replacement of soil grains by fibres also recycled polyester fibers do not absorb moisture, consequently the liquid limit of reinforced soil decrease.

3.1.2. Effect of recycled polyester fibers on the plastic limit of clay

The plastic limit of soil reinforced with varying fiber content is presented in Fig. 3. The observation of this Fig. indicates that with increase in fiber content the plastic limit of reinforced soil increase. With inclusion of fibers, the plastic limit increases by factors 1.29, 1.42, 1.44 respectively for fiber content of 0.5, 1.0 and 1.5%.

Fig. 2 and Fig. 3 indicate that with increase in fiber content the plasticity index of reinforced soil decrease. With inclusion of fibers, the plasticity index (PI) decreases by factors 0.65, 0.7, 0.8 respectively for fiber content of 0.5, 1.0 and 1.5%. Fauzi et al. 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% [14]. With compare of results, can be observed that the plasticity index (PI) of recycled polyester fiber is further than the HDPE fiber greater reduced, thus recycled polyester fiber an aspect economic problems is affordable.

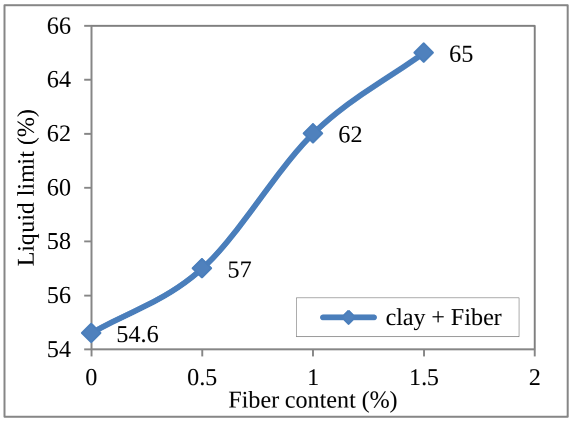


Fig. 2. Variation of liquid limit with recycled polyester fibers content

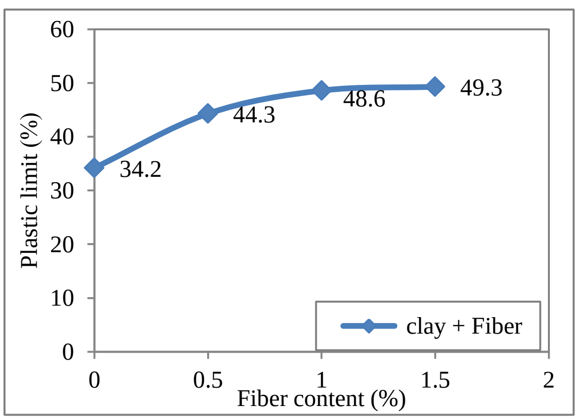


Fig. 3. Variation of plastic limit with recycled polyester fibers content

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

The shrinkage limit of soil reinforced with varying fiber content is presented in Fig. 4. From this Fig., 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 1.36, 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.

3.2. Direct shear test

3.2.1. 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 Fig. 5. From Fig. 5, one can conclude that the peak strength of fiber-reinforced soil occured at higher horizontal displacement in majority of specimens investigated compared to the unreinforced soil. Fig. 4 shows that with increase in normal stress and fiber content the peak strength of reinforced soil increases.

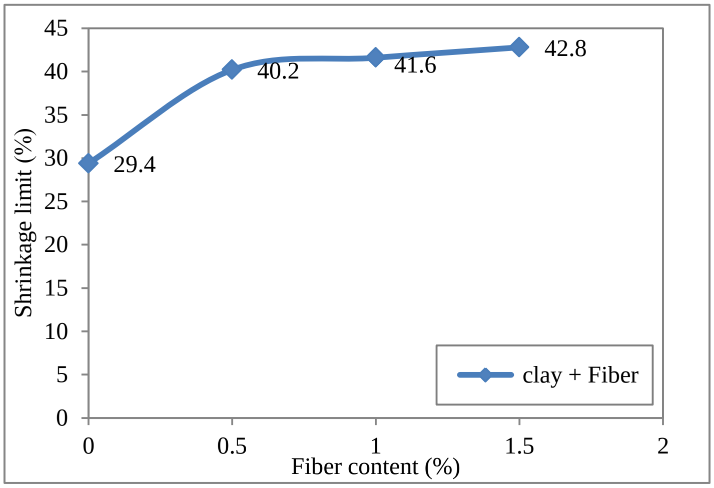
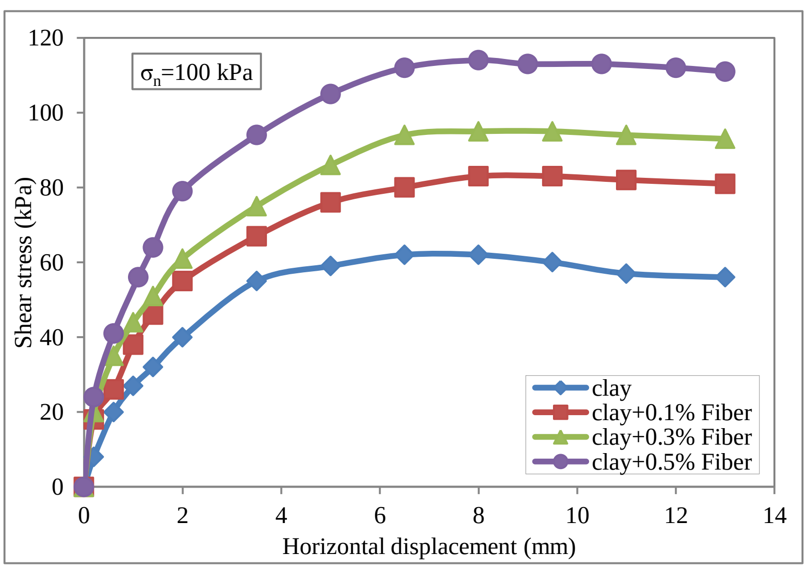


Fig. 4. Variation of shrinkage limit with recycled polyester fibers content

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 increases by factors 1.2, 1.56, 1.8 respectively for fiber content of 0.1, 0.3 and 0.5%. Interlock between soil particles and fiber surface caused improvement the shear strength. Similar results were obtained by Tang et al. [15].



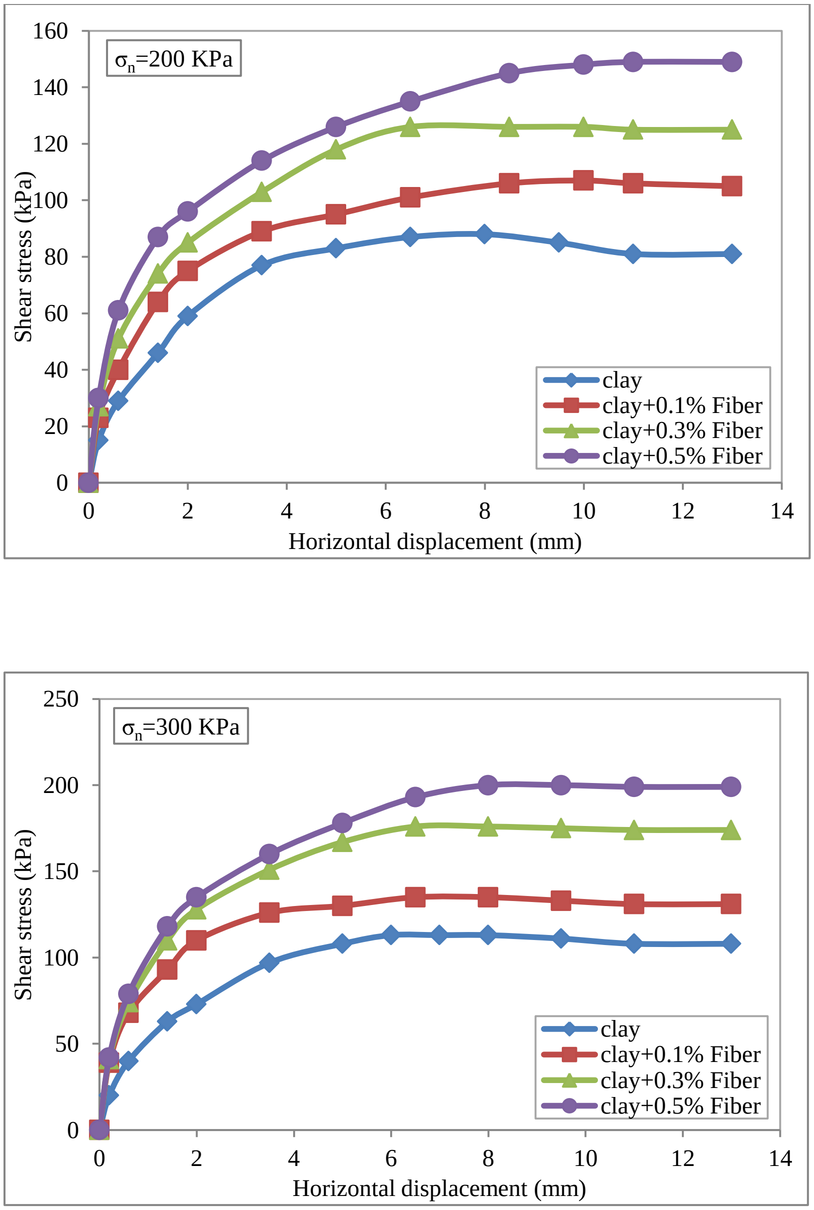


Fig. 5. Stress-displacement curves for recycled polyester fiber reinforced soil obtained from direct shear test

The failure envelopes corresponding to peak shear stresses obtained from direct shear tests is presented in Fig. 6. The shear parameters presented in Table 3. From this Table, it is observed that recycled polyester fibers causes increasing the angle of internal friction and the cohesion. The angle of internal friction and the cohesion increase by factors 1.16, 1.43, 1.72 and 1.47, 1.55, 1.68 respectively for fiber content of 0.1, 0.3 and 0.5%. It increasing in the shear parameters may be due to interaction between the soil particles and recycled polyester fibers.

Table 3. Shear parameters of fiber reinforced soil

Specimens	Fiber content (%)	Cohesion (c), kPa	Angle of internal friction (Φ), degrees
1	0.0	38	13.5
2	0.1	56	14.6
3	0.3	59	19.3
4	0.5	64	23.3

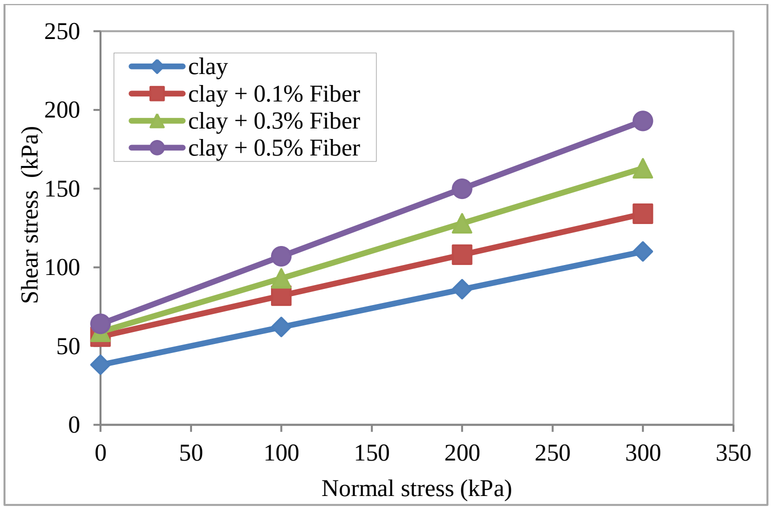


Fig. 6. Failure envelopes for fiber reinforced soil obtained from direct shear test

3.2.2. Effect of recycled polyester fibers on the shear modulus

The shear modulus, G_{50}, was calculated from one half of peak shear stress. The test results direct shear tests indicates that the shear modulus with increase in normal stress and fiber content the shear modulus of reinforced soil increased. With inclusion of recycled polyester fibers in the soil, the maximum increase in the shear modulus is observed at normal stress 300 kPa. With inclusion of fibers, in normal stress 300 kPa, the shear modulus is 2.29, 2.41 and 2.5 MPa respectively for fiber content of 0.1, 0.3 and 0.5% and the shear modulus is 2.05for unreinforced soil, thus with inclusion of recycled polyester fibers, the shear modulus increases by factors 1.12, 1.17 and 1.21 respectively for fiber content of 0.1, 0.3 and 0.5%. The shear modulus presented in Table 4.

Table 4. Shear modulus of fiber reinforced soil

Specimens	Fiber content (%)	Shear Modulus		
		Normal stress 100 (MPa)	Normal stress 200 (MPa)	Normal stress 300 (MPa)
1	0.0	0.92	1.58	2.05
2	0.1	1	1.75	2.29
3	0.3	1.15	1.83	2.41
4	0.5	1.25	1.9	2.5

3.3. CBR test

The results of CBR tests are presented in Fig. 7. The results indicate that with inclusion of fibers, the CBR values increase. The CBR values increases by factors 1.2, 1.53 and 1.59 respectively for fiber content of 0.1, 0.3 and 0.5%, when compared with that of unreinforced soil. It is also observed that the CBR values increase with increase in fiber content up to 0.3% and with increase of fiber this incremental process reduced. Fauzi et al. studied the CBR of high density polyethylene reinforced clay and results of CBR tests are presented in Fig. 8 [14]. With compare of results, it is observed that the CBR values of reinforced soil with 12% (HDPE) increased by factors 1.16, whereas the CBR values of reinforced soil with 0.5% recycled polyester fibers increases by factors 1.59. From this results, can be observed that recycled polyester fibers, the CBR values greater increased also for increase strength of soil need lower fiber content, thus recycled polyester fiber an aspect economic problems is affordable.

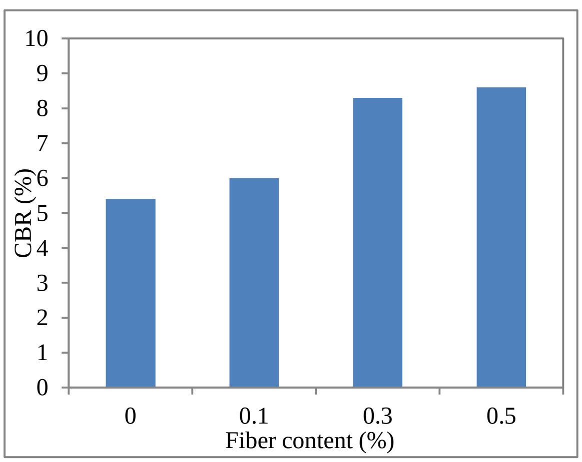


Fig. 7. CBR values for fiber reinforced soil at different fiber contents

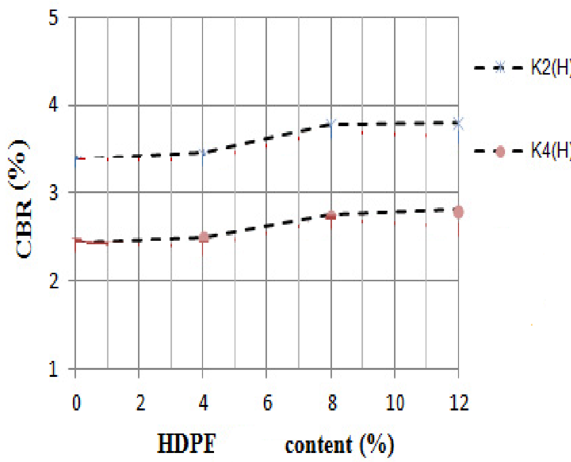


Fig. 8. CBR values for fiber reinforced soil at different (HDPE) contents. (Fauzi et al. 2013)

The elastic modulus of subgrade (E, MPa) was determined by the following equation (1). :

$$E = 176 * (CBR)^{0.64} \quad (1)$$

Eq (1). indicates that with increase in the CBR values of soil, elastic modulus of soil increase. According to Eq (1). with inclusion of recycled polyester fibers, the elastic modulus was increased by factors 1.1, 1.31 and 1.34 respectively for fiber content of 0.1, 0.3 and 0.5%. The vertical deflection w can be determined from equation (2). :

$$W = 2(1-\upsilon^2)\, q*a/E \quad (2)$$

where W = vertical deflection

υ = Poisson's ratio

q = stress

a = width of stress

E = elastic modulus

parameter of Eq (2). is shown in Fig. 9. Eq (2). indicates that with increase in the elastic modulus of soil

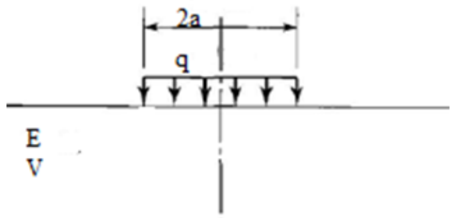


Fig. 9. Picture of parameter Eq (2).

vertical deflection of pavement decrease. According to Eq (1).and Eq (2). with increase in the CBR values of soil, the vertical deflection of pavement was decreased by factors 0.9, 0.76 and 0.74 respectively for fiber content of 0.1, 0.3 and 0.5%. The total thickness of subbase, base, and pavement will be governed by the CBR of the compacted subgrade. From the flexible pavement design curves shown in Fig. 10. Observation of this Fig indicates that with increase in the CBR values of soil, thickness of Flexible pavement decrease.

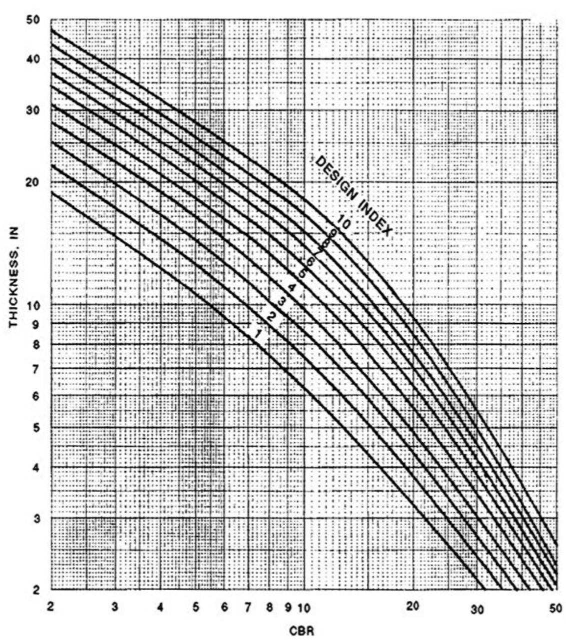


Fig. 10. Flexible pavement design curve for roads and streets (Paul Guyer, 2009)

The modulus of subgrade reaction (KS, MN/m3) was determined by the following equation (3). :

$$K_S = \sigma_{2.5\,mm}/0.0025m \quad (3)$$

According to Eq (3).the secant modulus is increased by factors 1.3, 1.9 and 2.23 respectively for fiber content of 0.1, 0.3 and 0.5%, when compared with that of unreinforced soil. It can be concluded that; the modulus of subgrade reaction substantially affected by increase in fiber inclusion. Similar observations were made by Marandi et al. (2008) on palm fiber-reinforced Silty-sand soils. Estimate the relative damage U corresponding to each seasonal modulus of subgrade reaction by the following equation (4):

$$U = (D^{0.75} - 0.39k^{0.25})^{3.42} \quad (4)$$

where U is dimensionless, D is the projected slab thickness in inches, and k is modulus of subgrade reaction. Instead of Eq (4), Fig. 11 can be used to obtain U. According to Eq (3).and Fig. 11, it is observed that recycled polyester fibers caused reduction the relative damage. The deflection of the slab for rigid pavement was determined by the following equation (5).:

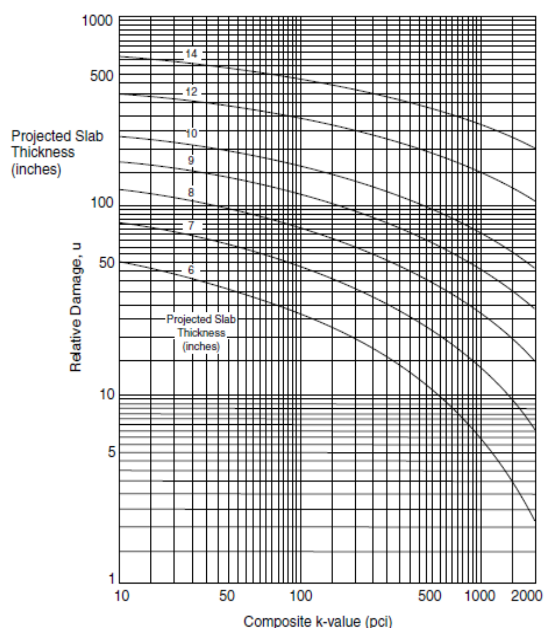


Fig. 11. Chart for estimating relative damage to rigid pavements (AASHTO, 1993)

$$Ϫ = P/K \quad (5)$$

where Δ is deflection of the slab, P is the reactive pressure, and k is modulus of subgrade reaction. Parameter of Eq (5). is shown in Fig. 12. . According to Eq (3).and Eq (5), it is observed that recycled polyester fibers caused reduction the deflection of the slab.

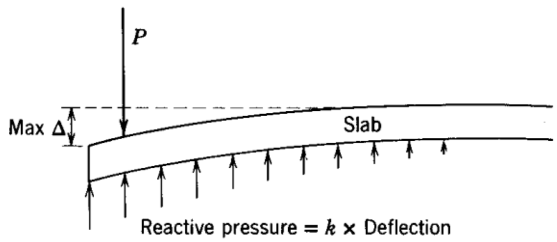


Fig. 12. Picture of parameter Eq (5). (Yoder and Witczak, 1975)

Depressions in rigid pavement occur across a crack or joint, as shown in Fig. 13, and are generally associated with significant cracking. Poor compaction, weak subgrade support, and differential settlement of subgrade are possible causes for depressions. An unreinforced and reinforced sample after desiccation is shown in Fig. 14.

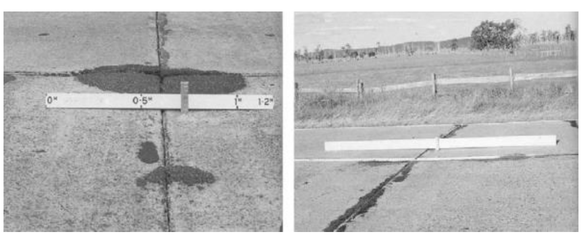


Fig. 13. Depressions in rigid pavements (Austroads, 1987)

Observational examination of samples after desiccation showed that by increasing the fiber contents the extent and depth of cracks were significantly reduced. As an example, in Fig. 14 surface cracking features of the unreinforced sample and the sample reinforced with 0.5% fibers are shown for comparison. It can be seen that extensive, deep and wide cracks were formed in the unreinforced sample. This clearly shows the effectiveness of random recycled polyester fibers inclusion in resisting and reducing desiccation cracking which is of paramount importance in surface cracking of clay covers used in landfills. Therefore, it can be concluded that random fiber inclusion seems to be an effective method of increasing tensile strength of the clayey soils to resist volumetric changes.

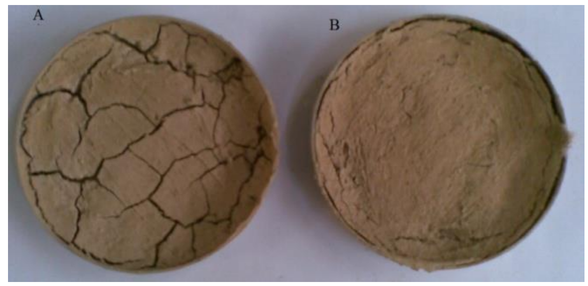


Fig. 14. Desiccation cracking (A) unreinforced sample (B) reinforced sample

4. Conclusions

In consideration of the concern over environmental pollution and cost effectiveness, soil reinforcement with fibers has been leaning towards the use of recycled fibers and locally available materials. 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 compaction and direct shear tests. Based on the results presented in this paper the following conclusions are drawn:

1- With 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- With increase in fiber content the peak shear strength of reinforced soil increases in such a way that with inclusion of 0.5%

recycled polyester fibers, in normal stress 300 kPa, the shear strength of reinforced-soil, become 1.8 times of shear strength of natural soil also the peak strength of fiber-reinforced soil occured at higher horizontal displacement in majority of specimens investigated compared to the unreinforced soil.

3- Both angle of internal friction and cohesion increase with increase in fiber content. With inclusion 0.5% of recycled polyester fibers the angle of internal friction and the cohesion get increased by factors1.72 and 1.68 respectively.

4- Shear modulus increase with increase in fiber content. With inclusion 0.5% of recycled polyester fibers, in normal stress 300 kPa, the shear modulus was increased by factors1.21.

5- With increase in fiber content, the CBR values and the modulus of subgrade reaction of reinforced soil increases in such a way that with inclusion of 0.5% recycled polyester fibers, the CBR values and the modulus of subgrade reaction and elastic modulus of reinforced-soil, become 1.59 , 2.23 and 1.34 times of unconfined compression strength of natural soil respectively.

6- - With increase in fiber content , fiber reinforcement soil significantly reduced the extent of cracks due to desiccation as observed by the reduced number, depth and width of cracks.

Acknowledgments

This study has performed in “soil mechanical laboratory” of Semnan University. The authors appreciate the head of soil mechanics laboratory of Semnan University, Mr Doost Mohammadi for his cooperation in this research.

REFERENCES

[1] Khattab, S.A.A., Al-Juari, K.A.K., Al-Kiki, I.M.A. (2008). “Strength, durability and hydraulic properties of clay soil stabilized with lime and industrial waste lime”. Al-Rafidain Engineering Journal, Vol. 16(1), pp. 102–116.

[2] Brooks, R. M. (2009). “Soil stabilization with fly ash and rice husk ash”. International Journal of Research and Reviews in Applied Sciences, Vol. 1(3), pp. 209-217.

[3] Kumar, P., Kar, R., Naik, A. (2012). “Effect of random inclusion of polypropylene fibers on strength characteristics of cohesive soil”. Geotechnical and Geological Engineering, Vol. 30, pp. 15-25.

[4] Kumar, P., Mehndiratta, H.C., Chandranarayana, S., Singh, S.P. (2005). “Effect of randomly distributed fibres on fly ash embankments”. International Engineering Journal- CV, Vol. 86, pp.113–118.

[5] Mirzababaei, M., Miraftab, M., Mohamed, M., McMahon, P. (2013). “Impact of carpet waste fibre addition on swelling properties of compacted clays”. Geotechnical and Geological Engineering, Vol. 31, pp. 173-182.

[6] Park, S.S. (2013). “Unconfined compressive strength and ductility of fiber-reinforced cemented sand”. Construction and Building Materials, Vol. 25, pp. 1134–1138.

[7] Mohamed, A.E.M. (2013). “Improvement of swelling clay properties using hay fibers”. Construction and Building Materials, Vol. 38, pp. 242-247.

[8] Hamidi, A., Hooresfand, M. (2013). “Effect of fiber reinforcement on triaxial shear behavior of cement treated sand”. Geotextiles and Geomembranes, Vol. 36, pp. 1-9.

[9] Freitag, D.R. (1986). “Soil randomly reinforced with fibers”. Journal

Geotechnical Engineering, Vol. 112(8), pp. 823–826.

[10] Mesbah, A., Morel, J.C., Walker, P., Ghavami, Kh. (2004). "Development of a direct tensile test for compacted earth blocks reinforced with natural fibers". Journal Material Civil Engineering, Vol. 16, pp. 95-98.

[11] Jiang, H., Cai, Y., Liu, J. (2010). "Engineering properties of soils reinforced by short discrete polypropylene fiber". Journal Material Civil Engineering, Vol. 22(12), pp. 13-15.

[12] Estabragh, A.R., Bordbar, A.T., Javadi, A.A. (2013). "Mechanical behavior of a clay soil reinforced with nylon fibers". Geotechnical and Geological Engineering, Vol. 29, pp. 899-908.

[13] Maliakal, T., Thiyyakkandi, S. (2013). "Influence of randomly distributed coir fibers on shear strength of clay". Geotechnical and Geological Engineering, Vol. 31, pp. 425–433.

[14] Fauzi, A., Abdul Rahman, W.M.N., Jauhari, Z. (2013). "Utilization waste material as stabilizer on kuantan clayey soil stabilization". Journal Procedia Engineering, Vol. 53, pp. 42 – 47.

[15] Tang, Ch. Sh., Shi, B., Zhao, L.Z. (2010). "Interfacial shear strength of fiber reinforced soil". Geotextiles and Geomembranes, Vol. 28, pp. 54-62.

[16] Paul Guyer, J. (2009). "Introduction to flexible pavement design". Continuing Education and Development, Inc. 9 Greyridge Farm Court Stony Point, NY 10980.

[17] Marandi, S.M., Bagheripour, M.H., Rahgozar, R., Zare, H. (2008). "Strength and ductility of randomly distributed palm fibers reinforced silty-sand soils. American Journal of Applied Sciences, Vol. 5 (3), pp. 209-220.

[18] AASHTO. (1993). "AASHTO guide for design of pavement structures". American association of state highway and transportation officials, Washington, DC.

[19] Yoder, E.J., Witczak, M.W. (1975). "Principles of pavement design". A Wiley – Interscience Publication.

[20] Austroads, (1987). "A guide to the visual assessment of pavement condition". Austroads, Sydney, Australia.