Advanced Engineering Science
http://publish.mersin.edu.tr/index.php/ades
e-ISSN 2791-8580

Assessment of the artificial fiber contribution on the shear strength parameters of soils

Özgür Lütfi Ertuğrul *[1], **Furkan İnal** [1]

[1]Mersin University, Department of Civil Engineering, Türkiye, ertugrul@mersin.edu.tr; furkaninal@mersin.edu.tr

Cite this study: Ertugrul, O. L., & Inal, F. (2022). Assessment of the artificial fiber contribution on the shear strength parameters of soils. Advanced Engineering Science, 2, 93-100

Keywords
Soil improvement
Soil reinforcement
Fiber
Regression Analysis

Research Article
Received: 16.01.2022
Revised: 26.02.2022
Accepted: 02.03.2022
Published:14.03.2022

Abstract

Soil stabilization is one of the methods of soil improvement that has been used since ancient times in human history. Soil mass reinforced with randomly distributed discrete fibers is one of the techniques for improving the properties of soils. Reinforcing the soil with randomly distributed discrete fibers has attracted the attention of many researchers over the past few decades. For this purpose, many studies have been carried out with fibers obtained from synthetic, natural and waste materials. Studies on soil reinforced with discrete fibers have revealed the effect of fibers are beneficial to strength parameters of soils. In this study multivariate regression analysis were performed by using data from literature to formulate the effect of fibers on the soil. The formulas obtained from multivariate regression analyses are in harmony with the values of unconfined compression and shear strength.

1. Introduction

As is known, almost all types of structures, from high-rise buildings to the construction of roads, railways, tunnels and viaducts, are built either on the soil or in the soil. In this regard, the structures are in constant interaction with the soil. Unfortunately, the soil that is supposed to carry the constructed structure may not always have sufficient engineering properties. The fact that the soil has insufficient engineering properties may cause the existing soil to be discarded and a new filling to be made or it can bring up the construction of deep foundation. But it may not be possible to implement these solutions for economic reasons. At this point, engineers go to ways to improve the soil on the site.

Soil stabilization is one of the methods of soil improvement that has been used since ancient times in human history. The stabilization of soils has been performed for millennia. For instance, the Mesopotamians and Romans separately discovered that it was possible to improve the ability of pathways to carry traffic by mixing the weak soils with a stabilizing agent like pulverized limestone or calcium [1]. Random distribution of fibers on the ground also improves the strength parameters of the soil by simulating the behavior of plant roots [2]. Also in ancient civilizations, straw was a material used for reinforcing building blocks obtained from slurry [1]. At present, the reinforcing of the soil to improve its properties is attributed to the Vidal [3]. One of the methods of reinforcing the soil is use of fiber. Reinforcing the soil with randomly distributed discrete fibers has attracted the attention of many researchers over the past few decades. For this purpose, many studies have been carried out with fibers obtained from synthetic [4-9], natural [10-19] or recycled/waste materials [20-25] in order to study the effect of fibers on the engineering properties of the soil.

2. Literature Review

Uysal, carried out a laboratory study by mixing sand samples having different relative density values (20%, 30% and 40%) with kapolymer and virgin homopolymer fibers in ratios of 0.50%, 1.0% and 1.50% of the dry weight of the soil. Shear box tests were conducted in order to observe the effect of relative density and fiber content on the shear strength. It was observed that the samples having a high relative density has a higher shear strength, and the angle of internal friction also increases as the fiber ratio increases [9].

Wei et al. performed laboratory tests by mixing a silty clay soil with both lime and fibers to investigate the mechanical properties of the soil. Wheat straw, rice straw, hemp and polypropylene fibers were added to the soil-lime mixtures. Unconfined compression and triaxial compression tests were performed on samples in order to examine the shear strength properties. The optimum fiber content was found to be 0.2% or 0.25% and the optimum fiber length was found to be 30%-40% of the sample diameter. Fiber reinforcement has significantly increased cohesion and slightly improved the angle of internal friction. When the performance of fiber varieties in cohesion increases was compared, it was determined that polypropylene, jute, rice straw and wheat straw were from the best to the lowest [18].

Özdemir, investigated the consistency limits, compaction characteristics, unconfined compression and freeze-thaw properties of fiber-clay samples obtained by adding natural (straw, hemp) and synthetic (polyester) fibers to a cohesive soil sample. It was observed that the unconfined compression strength of the samples increased with an increase in the percentage of fiber, and improvements in the unconfined compression strength after freezing and thawing also occurred when compared to natural clay. The samples with hemp additives exhibited superior behavior against freezing and thawing [15].

Pradhan et al. investigated the effect of polypropylene fiber contribution on the shear strength and unconfined compression strength of cohesive soils. They observed that the addition of fibers increased the peak and residual shear strength as well as unconfined compression strength and CBR values [26].

Consoli et al. carried out a study to determine the differences in the strength of artificially cemented sandy soil with and without fiber reinforcement. The controlling parameters evaluated were the amount of cement, porosity, moisture content, and voids/cement ratio. A series of unconfined compression tests were performed. Results show that the fiber addition increased the unconfined compression strength of the samples at all cement ratios [27].

Nezhad et al. in their study, aimed to investigate the effect of natural fibers on the strength behavior of clayey soils as sustainable fibers containing basalt (BS) and bagasse (BG) and synthetic polyester (PET) fibers. For this purpose, the effects of various fiber contents (0.5%, 1% and 2%) and lengths (2.5 mm, 5 mm and 7.5 mm) were evaluated experimentally. By performing indirect tensile strength (ITS) and CBR tests, it was found that increased fiber content and length had a significant effect on CBR and values. In addition, the CBR and ITS values obtained by mixing the 7.5 mm long fibers with the soil at 2% density caused the highest values [14].

Valipour et al. have investigated the effects of recycled tire polymer fibers (RTFP) and glass fibers (GF) on improving the strength/deformation properties of clays. A series of compaction, unconfined pressure and shear box tests were carried out on clay soils with RTFP and GF, with various lengths (5 mm and 10 mm) and fiber ratios (0.5, 1.0 and 1.5%). It was seen that the fiber addition was more effective on the cohesion value, while the changes in the internal friction angle values remained at a minimum level. The highest shear stress values were obtained at 0.5% for RTPF and 1.0% for GF. It has been observed that fiber reinforced soils show higher ductility and load bearing capacity compared to non-reinforced soils [25].

Bao et al. studied the mechanical performance of clayey soil (fiber density: 1.0%, 2.0% and 3.0% fiber lengths: 3 mm, 6 mm and 12 mm) reinforced with carbon fibers (CF). Unconfined compressive strength tests were performed on soil samples under optimum water content. The unconfined compressive strength of the soil samples improved significantly with increasing fiber content. The samples reinforced with 3% CF content of 6 mm have reached the highest unconfined pressure value [5].

Yetimoglu and Salbas investigated the shear strength of sands reinforced with randomly distributed fiber by shear box test. The test results showed that the peak shear strength and stiffness did not change significantly with the addition of fiber. Horizontal displacements during failure under equal stresses in the vertical direction were found to be comparable in fiber-reinforced and unreinforced sands. Fiber reinforcement reduced the brittleness of the soils and reduced post-peak strength losses. Thus, fiber reinforcement to the sandy soil led to an increase in the residual strength [28].

Çetinkaya used clay, fly ash and polypropylene fiber materials in his study. CBR and free pressure experiments were performed on mixtures prepared by mixing clay and fly ash samples with polypropylene fibers. According to the results of the experiments, it was observed that the CBR value increased by 100% and the unconfined compression strength increased by 48% in the mixtures prepared with fiber additives at a rate of 1.0% by weight of the clay-fly ash mixture [6].

In his study, Fındıkçı homogeneously mixed 3, 6, 12 mm long glass fibers into bentonite clay at 1%, 2%, and 3% ratios in his study. As a result of the unconfined compression experiments, the optimum values were obtained from samples containing 12% fiber with a length of 12 mm [7].

Ayraçma carried out shear box experiments by mixing 0.25% and 0.5% glass fiber into white silica sand with different relative density values (20% and 60%). During the experiments, due to the difficulties in ensuring the homogeneous distribution of the glass fiber in the sample, material changes were made and sand-polypropylene fibers were used in the rest of the study. Shear box tests were carried out on sand-polypropylene fiber blends mixed at 0.25%, 0.5% and 1.0% ratios. The shear box results performed on the fiber-reinforced samples showed that the peak internal friction angle of the fiber-reinforced soils increased. Also, the post-peak strength loss after fracture decreased [4].

Consoli et al. applied unconfined compression tests, split tensile tests and drained triaxial pressure tests to fine grained sand classified as SP. The inclusion of PET fiber increased the peak and ultimate strength and energy absorption capacity. While the cohesion did not change, the internal friction angle increased with the inclusion of the fiber and the length of the fiber. The addition of fiber did not affect the initial stiffness or ductility. The unconfined compressive strength and tensile strength of cemented sand significantly increased by fiber reinforcement [20].

Terzi, has added basalt fiber in certain proportions to soil samples classified as high plasticity clay (CH), shear box tests were applied under different vertical stresses after the samples were first consolidated under 45 kPa load for 7 days. The samples were prepared by slurry method by adding 6 mm, 12 mm and 24 mm long basalt fiber at 0%, 1%, 1.5%, 2% and 2.5% by weight of the clay sample. According to the results of 39 experiments; As the basalt fiber ratio and length increased, a non-linear increase was observed in the internal friction angle, while peak values were observed at different basalt fiber ratios depending on the basalt fiber length in the cohesion value. While the cohesion value peaked at 2% fiber in the samples worked with 6 mm fiber length, the highest improvements were obtained in the cohesion value of 1.5% in the samples worked with 12 mm fiber length, and the cohesion value at 1% fiber in the samples worked with 24 mm fiber length [29].

Sevencan, investigated the unconfined compressive strength of the samples by mixing them with different ratios of fly ash (10.0%, 20.0% and 30.0%) and polypropylene fibers of different ratios (0.50% and 1.0%) and lengths (6 mm and 19 mm) on the clayey soil. As a result of standard proctor tests of clayey soils with fly ash additive, it was observed that the dry unit volume weight values increased and the optimum water content decreased with the increase in the fly ash content. The use of fiber alone (without adding fly ash) reduces the unconfined compressive strength somewhat. Only 1.0% M19 fiber reinforced sample increases the strength slightly. A similar behavior is observed for mixtures containing 10% fly ash. On the other hand, it was observed that the unconfined compressive strength of the mixtures containing 30% fly ash decreased slightly with 0.5% fiber content, while the unconfined compressive strength of the mixture was increased with 1.0% fiber content [8].

Prabakar and Sridhar, applied sisal fibers to soil samples in four different densities (0.25, 0.5, 0.75 and 1%) and 4 different lengths (10, 15, 20, 25 mm) on low plasticity clayey soils, which they classified as CL in their study. have supplemented. Compaction and triaxial compression tests were applied to the prepared samples. According to the test results, the shear stress of the fiber reinforced soil is improved by the addition of sisal fiber. Shear stress increases non-linearly with increasing fiber length up to 20 mm and beyond, where an increase in length decreases shear stress. The shear stress of the reinforced soil also increases with the increase in cell pressure (σ3). The percentage of fiber content also affects shear strength as shear stress develops non-linearly with increase in fiber content. But beyond 0.75% fiber content, shear stress decreases with increase in fiber content. The cohesion value is increased due to the inclusion of sisal fiber. The maximum cohesion value is achieved as 66 kPa versus 18 kPa (unreinforced soil). Up to 20 mm long, the increase in fiber length increases the cohesion value. There is no particular trend for the internal friction angle to change with fiber length. It has been determined that the cohesion improves linearly with the increase in fiber content, thanks to the fiber content of up to 0.75%. But for the same fiber content of different lengths, the amount of increase in cohesion is less [16].

Ahmad et al. conducted triaxial compression tests to evaluate the response of randomly distributed fibers on the strength of silty sand. In this study, palm fiber (OPEFB) was mixed with silty sand soil to investigate the increase in shear strength during triaxial compression. Samples were tested under drained and undrained conditions with different lengths (i. e. 15mm, 30mm and 45mm) and different ratios (0.25% and 0.5%). In addition, OPEFB fibers coated with acrylic butadiene styrene thermoplastic were also tested to determine the effect of the coating on reinforcement. The inclusion of randomly dispersed discrete fibers significantly increased the shear strength of the silty sand. Coated OPEFB fibers increased the shear strength of silty sand much more than uncoated fibers. The coating increased the surface area of the fibers, increasing the interface friction between the fiber and soil particles. Reinforced silty sand containing 0.5% coated fiber with a length of 30 mm showed approximately 25% increase in internal friction angle and 35% increase in cohesion under undrained loading conditions compared to that of unreinforced silty sand. The results show that the shear strength parameters of the soil-fiber mixture can be significantly improved [10].

Wu et al. aim to determine the behavior of randomly distributed sisal fiber reinforced soil in silty clay in their study. The fibers were cut in different lengths (5, 10 and 15 mm) and randomly mixed with the soil at different percentages (0.5%, 1.0% and 1.5%). In this article, the researchers evaluated the effect of sisal fiber on the engineering properties of silty clay soil using the triaxial shear test. As a result of the test results, the cohesion of the fiber-reinforced soil and the peak of the principal stress difference improved after the fiber reinforcement to the soil. With increasing fiber content, the peak of the principal stress difference increases. When the fiber content reached 1.0%, the increase in the bearing capacity of the soil body was limited by mixing more fiber. Compared to the 5 mm long fiber, a significant improvement in cohesion values and the peak of the principal stress difference was observed for the 10 mm long fiber. The level of recovery occurred at about 20% [19].

Kaniraj and Gayathri, conducted an experimental study to investigate the effect of randomly oriented fiber additives on the geotechnical behavior of two different (DA, RA) fly ash. In the experiments, two different types of polyester fiber and 1% fixed fiber content (based on dry weight) were chosen as the fiber ratio. The polyester fibers used in the experiments were produced from 100% recycled plastic waste. This article presents the results of unconfined compression tests and triaxial compression tests on fiber-reinforced fly ash. In all triaxial compression tests, fiber reinforcement had a significant effect on the stress-strain behavior of the samples. In the unconfined pressure tests, when the lean fly ash samples reached the axial deformation values of 1.5-2.5%, the samples collapsed. However, fiber-reinforced samples exhibited a highly ductile behavior. F6DA and F6RA samples reached peak axial stresses at relatively higher axial strain values than raw fly ash samples and then continued to deform under decreasing axial stress. In unconsolidated and undrained tests, the deviator stress reached a peak in the range of 11-14% for DA specimens and 6-10% for RA specimens as axial deformation, after which it remained almost constant. In the F6DA and F6RA samples, the peak deflection stress could not be reached even at 20% axial deformation. The behavior of fly ash and fly ash–fiber samples in the drained tests were similar to the behaviors in the unconsolidated and undrained tests. The fiber additive increased the strength of the raw fly ash samples and changed the brittle behavior to ductile behavior [30].

Muntohar et al. investigated the engineering behavior of stabilized (rice husk ash blended with lime) clayey/silty soil reinforced with randomly distributed discrete plastic waste fibers. 12% lime, 12% ricejusk ash and plastic waste fibers in different proportions (0.1%, 0.2%, 0.4%, 0.8% and 1.2%) were mixed into the highly plastic silty soil. unconfined compression test, split tensile test, triaxial compression test and CBR tests were applied to the prepared samples. The results show that the proposed method further improves the engineering properties, stability and durability of the clayey-silty soil. Depending on compressive strength, California strength ratio (CBR), shear strength and failure properties, optimum fiber content in soil-lime-rice ash ash mixtures was determined to vary between 0.4-0.8% of dry mass [24].

Babu and Vasudevan (2008) tried to present the results of the strength and stiffness behavior of soil reinforced with coconut fibers in their study. Cylindrical soil samples reinforced with coconut fibers mixed with soil of different sizes (10 cm, 15 cm, 25 cm, 30 cm) and densities (0.5%, 1.0%, 1.25%, 1.5%, 2.0%, 2.5%) to determine the strength and stiffness of the samples. It was tested on a triaxial shear device and the results were compared with unreinforced soils. The stress–strain behavior of the soil was improved by incorporating coconut fibers into the soil, the deviator stress at failure was observed to increase up to 3.5 times compared to the unreinforced soil with fiber inclusion. In fiber-reinforced soils, the deviator stress increased as the fiber diameter increased. The maximum stress increase was observed when the fiber length was between 15 and 25 mm and the length was between 40 and 60% of the smallest lateral dimension of the sample. As the fiber content increased, the energy absorption capacity of the fibrous samples increased. The results show that the addition of 1-2% coconut as a random reinforcement material increases both the strength and stiffness of the clayey soil studied in the study [12].

Mirzababaei et al. conducted comprehensive research on the use of carpet waste fibers in the reinforcement of clay soils in their study. The effects of adding two different types of shredded carpet waste fibers in proportional amounts to clayey soils (i. e., 1, 3 and 5% according to the dry weight of the soil) were investigated and evaluated. The research was carried out on samples prepared with maximum dry unit weight and optimum water content, and samples prepared under variable dry unit weight and water content conditions. A comparison was also made on the samples prepared at the same fiber content by changing the dry unit weight while keeping the water content unchanged or by changing both the dry unit weight and the water content. The research revealed that the incorporation of carpet waste fibers into prepared clayey soils at the same dry unit weight can significantly increase the unconfined compression strength (UCS), reduce the post-peak strength loss, and change the failure behavior from brittle to ductile. It has been observed that the benefit of the fiber to increase the unconfined compression strength of clay soils is highly dependent on the initial dry unit weight and water content of the soil [23].

3. Material and Method

Current state of the art on fiber addition to soils shows that synthetic fiber reinforcement of soils has positive effects on the unconfined compressive strength and shear strength parameters of soils.

In this study, the effects of synthetic fiber addition on the unconfined compression strength, cohesion and internal friction angle of soils were formulated by multivariate regression analysis method. In order to formulate the fiber effects with multivariate regression analysis, the relative density and fiber percent in sandy soils, and the fiber percent and length parameters in cohesive soils were selected from the data in the previous studies and the unconfined compressive strength and shear strength parameters were tried to be determined by regression analysis. The data used in the analyses are given in Table 1.

Table 1. A summary of the data used from literature

Soil Type	Dr (%)	Fiber Percent (%)	Fiber Length (mm)	Φ (^{0})	Soil Type	Fiber Percent (%)	Fiber Length (mm)	q_u (kPa)
SP	20	0	0	28	CL	0	0	157
SP	30	0	0	31	CL	0,5	2	340
SP	40	0	0	33	CL	1	2	380
SP	20	0,5	15	31	CL	1,5	2	397
SP	20	1	15	33	CL	0,5	5	301
SP	20	1,5	15	34	CL	1	5	340
SP	30	0,5	15	33	CL	1,5	5	345
SP	30	1	15	34	Soil Type	Fiber Percent (%)	Fiber Length (mm)	c (kPa)
SP	30	1,5	15	36	CL	0	0	291
SP	40	0,5	15	36	CL	0,2	12	301
SP	40	1	15	38	CL	0,25	12	331
SP	40	1,5	15	39	CL	0,3	12	307
SP	20	0,5	15	29	CL	0,2	19	326
SP	20	1	15	30	CL	0,25	19	358
SP	20	1,5	15	32	CL	0,3	19	344
SP	30	0,5	15	32	Soil Type	Fiber Percent (%)	Fiber Length (mm)	Φ (^{0})
SP	30	1	15	33	CL	0	0	32
SP	30	1,5	15	35	CL	0,2	12	32
SP	40	0,5	15	34	CL	0,25	12	33
SP	40	1	15	35	CL	0,3	12	31
SP	40	1,5	15	37	CL	0,2	19	32
SP	40	0,5	15	36	CL	0,25	19	33
SP	40	1	15	38	CL	0,3	19	33

The soil used to determine cohesion has a salt content of 2.64%, was collected from coastal area, and was air dried and sieved (2 mm). The physical properties indices of soil are presented in Table 2 [18].

Table 2. Physical properties of soil used to determine cohesion (c, kPa) [18].

Properties	Value
Specific gravity	2.72
Grain size distribution	
Gravel (%)	0
Sand (%)	2.2
Silt (%)	62.6
Clay (%)	35.2
Atterberg limits	
Liquid limit (%)	32.6
Plastic limit (%)	16.8
Plasticity index	15.8
Optimal moisture content (%)	18
Maximum dry density (g/m^3)	1.81

Sand sample was used for the calculation of the internal friction angle and the percentage of sand was found to be 99% according to the results of the sieve analysis. The parameters of the soil are given in Table 3 [9].

Table 3. Physical properties of soil used to calculate internal friction angle (Φ, °) [9].

Properties	Value
Gravel (%)	0
Sand (%)	99
Clay and Silt (%)	1
D_{60}	0,315
D_{30}	0,256
D_{10}	0,215
C_c	0.968
C_u	1.465
USCS	SP

To determine the free compressive strength, the researchers used a sample of natural clay. After drying the sample in the laboratory for 24 hours, they pulverize it in the Los Angeles abrasion device until it was crumbly enough. The soil parameters are given in Table 4 [15].

Table 4. Physical properties of soil used to determine unconfined compression strength (q_u) [15]

Properties	Value
< 0,002 mm (%)	42
Unit volume of grain, (kN/m^3)	25,9
Liquid limit, (%)	60,8
Plastic limit, (%)	26,5
Plasticity Index, (%)	34,3
USCS	CH

4. Results and Discussion

Based on the multiple variate regression analyses, the following equations were obtained for the relationship between fiber percent, fiber length and relative density with the internal angle of friction (Φ, °), cohesion (c, kPa) and undrained compressive strength:

$$q_u = a + bF_p + cF_L + d\left(F_p{}^2\right) + e\left(F_p.F_L\right) + f\left(F_L{}^2\right) \quad (1)$$

In this equation, q_u represents undrained compressive strength in kPa whereas F_p, and F_L denotes fiber percent and fiber length. The constant parameters of *a, b, c, d, e* and *f* will be taken as 157, 179.7 81.67, -57, -4.333 and -13.13, respectively. For the relationship between fiber percent and relative density with the internal angle of friction (Φ, °) of cohesionless soils:

$$\mathbf{\Phi} = g + hF_p + iD_r \quad (2)$$

where F_p, and D_r denotes fiber percent and soil relative density (divided by 100). The constant parameters of *g, h, i* will be taken as: 22.95, 26.57, and 3.106, respectively. The coefficient of determination is found as 0.90 for the suggested formula. For the relationship between fiber percent and fiber length with the cohesion (c, kPa) of cohesive soils:

$$\mathbf{c} = j + kF_p + lF_L + m\left(F_p{}^2\right) + n\left(F_L{}^2\right) \quad (3)$$

The constant parameters of *j, k, l, m* and *n* will be taken as: 291, 5120, -86.48, -1e+04, 2.926 respectively. The coefficient of determination is found as 0.99 for the suggested formula.

5. Conclusion

Researchers conducted laboratory tests in order to investigate the mechanical behavior of fiber reinforced soils. Based on the carried-out tests, it was observed that reinforcing soil with fibers, the peak strength loss is decreased, and thus the behavior of the material changed from brittle to ductile, the swelling pressure and desiccation cracks decreased, in short, the behavior of the soil improved in the desired direction. When compared to classical soil improvement techniques, the main advantage of mixing randomly distributed fibers is the maintenance of strength isotropy and absence of potential failure plane that can develop parallel to the oriented reinforcement [16]. By using the results of the previous laboratory tests reported in the literature, multivariate regression analyses were performed. Formulas were suggested to be used for the practical purposes for the site engineers and designers.

Acknowledgement

This study was partly presented in 1st Advanced Engineering Days [31].

Funding

This research received no external funding.

Author contributions

Özgür Lütfi Ertuğrul: Data curation, Validation, Writing-Reviewing and Editing. **Furkan İnal:** Investigation, draft preparation

Conflicts of interest

The authors declare no conflicts of interest.

References

1. Hejazi, S. M., Sheikhzadeh, M., Abtahi, M. S., & Zadhoush, A. (2012). A simple review of soil reinforcement by using natural and synthetic fibers. Construction and Building Materials, 100-116.
2. Wu, T. H., McOmber, R. M., Erb, R. T., & Beal, P. E. (1988). Study of soil-root interaction. Journal of Geotechnical Engineering, 114(12), 1351-1375.
3. Vidal, H. (1969). The Principle of Reinforced Earth. Highway Research Board, Geology and Foundations, 1-16.
4. Ayraçma, B. B. (2015). Sentetik Fiber ve Çimento Katkılı Kumların Mukavemet Özellikleri. İstanbul Teknik University, Institute of Science and Technology, Master's Thesis.
5. Bao, X., Jin, Z., Xiao, X., Tang, W., Cui, H., & Chen, X. (2021). Experimental investigation on mechanical properties of clay soil reinforced with carbon fiber. Construction and Building Materials, 1-9.
6. Çetinkaya, M. (2012). Polipropilen Liflerin Uçucu Kül Zemin Karışımlarında Geoteknik Özelliklere Etkisi. İstanbul Teknik University, Institute of Science and Technology, Master's Thesis.
7. Fındıkçı, B. (2020). Bentonit Kilinin Cam Fiber ile İyileştirilmesi. Kocaeli University, Institute of Science and Technology, Master's Thesis.
8. Sevencan, Ü. (2009). Polipropilen Fiber ve Uçucu Kül Katkılı Ankara Kilinin Geoteknik Özelliklerinin Araştırılması. Kırıkkale University, Institute of Science and Technology, Master's Thesis.
9. Uysal, N. (2014). Polimer ile Stabilize Edilmiş Kumların Kayma Mukavemetinin Laboratuvar Deneyleri ile Belirlenmesi. İstanbul Teknik University, Institute of Science and Technology, Master's Thesis.
10. Ahmad, F., Bateni, F., & Azmi, M. (2010). Performance evaluation of silty sand reinforced with fibres. Geotextiles and Geomembranes, 93-99.
11. Al Adili, A., Azzam, R., & Spagnoli, G. (2012). Strength of soil reinforced with fiber materials (Papyrus). Soil Mechanics and Foundation Engineering, 241-247.
12. Babu, G. S., & Vasudevan, A. K. (2008). Strength and Stiffness Response of Coir Fiber-Reinforced Tropical Soil. Journal of Metarials in Civil Engineering, 571-577.
13. Dang, L. C., Fatahi, B., & Khabbaz, H. (2016). Behaviour of Expansive Soils Stabilized with Hydrated Lime and Bagasse Fibres. Procedia Engineering, 658-665.
14. Nezhad, M. G., Tabarsa, A., & Latif, N. (2021). Effect of natural and synthetic fibers reinforcement on California bearing ratio and tensile strength of clay. Journal of Rock Mechanics and Geotechnical Engineering, 1-17.
15. Özdemir, B. (2019). Doğal/Sentetik Lif ve Uçucu Kül Katkılı Killerin Bazı Geoteknik Özelliklerinin Araştırılması. Atatürk University, Institute of Science and Technology, Master's Thesis.
16. Prabakar, J., & Sridhar, R. S. (2002). Effect of random inclusion of sisal fibre on strength behaviour of soil . Construction and Building Materials, 123-131.

17. Wang, Y. X., Guo, P. P., Ren, W. X., Yuan, B. X., Yuan, H. P., Zhao, Y. L., & Cao, P. (2017). Laboratory Investigation on Strength Characteristics of Expansive Soil Treated with Jute Fiber Reinforcement. International Journal of Geomechanics, 1-12.
18. Wei, L., Chai, S. X., Zhang, H. Y., & Shi, Q. (2018). Mechanical properties of soil reinforced with both lime and four kinds of fiber. Construction and Building Materials, 300-308.
19. Wu, Y. K., Li, Y. B., & Niu, B. (2014). Investigation of mechanical properties of randomly distributed sisal fibre reinforced soil. Materials Research Innovations, 953-959.
20. Consoli, N. C., Montardo, J. P., Prietto, P. M., & Pasa, G. S. (2002). Engineering Behavior of a Sand Reinforced with Plastic Waste. Journal of Geotechnical and Geoenvironmental Engineering, 462-472.
21. Edinçliler, A., & Cagatay, A. (2013). Weak subgrade improvement with rubber fibre inclusions. Geosynthetics International, 39-46.
22. Kalkan, E. (2013). Preparation of scrap tire rubber fiber–silica fume mixtures for modification of clayey soils. Applied Clay Science, 117-125.
23. Mirzababaei, M., Miraftab, M., Mohamed, M., & Mcmahon, P. (2013). Unconfined Compression Strength of Reinforced Clays with Carpet Waste Fibers. Journal of Geotechnical and Geoenvironmental Engineering, 483-493.
24. Muntohar, A. S., Widianti, A., Hartono, E., & Diana, W. (2013). Engineering Properties of Silty Soil Stabilized with Lime and Rice Husk Ash and Reinforced with Waste Plastic Fiber. Journal of Materials in Civil Engineering, 1260-1270.
25. Valipour, M., Shourijeh, P. T., & Mohammadina, A. (2021). Application of recycled tire polymer fibers and glass fibers for clay reinforcement. Transportation Geotechnics, 1-14
26. Pradhan, P. K., Kar, R. K., & Naik, A. (2012). Effect of Random Inclusion of Polypropylene Fibers on Strength Characteristics of Cohesive Soil. Geotechnical and Geological Engineering, 15-25.
27. Consoli, N. C., Bassani, M. A., & Festugato, L. (2010). Effect of fiber-reinforcement on the strength of cemented soils. Geotextiles and Geomembranes, 344-351.
28. Yetimoglu, T., & Salbas, O. (2003). A study on shear strength of sands reinforced with randomly distributed discrete fibers. Geotextiles and Geomembranes, 103-110.
29. Terzi, S. (2021). Killi Zeminlerin Kayma Direncine Bazalt Fiberin Katkısı. Sakarya University Institute of Science and Technology, Master's Thesis.
30. Kaniraj, S. R., & Gayathri, V. (2003). Geotechnical behavior of fly ash mixed with randomly oriented fiber inclusions. Geotextiles and Geomembranes, 123-149.
31. Ertuğrul, Ö. L., & İnal, F. (2021). Assessment of the artificial fiber contribution on the shear strength parameters of soils. *Advanced Engineering Days (AED)*, *1*, 114-117.