Nevşehir Bilim ve Teknoloji Dergisi Cilt 6(ICOCEE 2017 Özel Sayı) 341-348 2017
DOI: 10.17100/nevbiltek.322678
URL: http://dx.doi.org/10.17100/nevbiltek.322678

Experimental Investigation of Mechanical Behavior of Basalt Fiber Reinforced Saturated Silty Soil

Cyrille P. NDEPETE[1] and Sedat SERT[2,*]

[1]Sakarya University, Sakarya University, Institute of Natural Sciences, Sakarya-TURKEY

[2]Sakarya University, Civil Engineering Department, Sakarya-TURKEY

Abstract

In order to find solutions to the increasing environmental problems in general and civil engineering in particular, several methods have been adopted. For example, synthetic and natural materials are increasingly used for soil improvement. In recent years, basalt fibers have been used for reinforcing concrete. But it is difficult to find the articles on the use of basalt fibers to strengthen the soil. It is in this perspective that this work is oriented on the study of mechanical behavior of consolidated saturated silty soils reinforced by basalt fibers. This study is conducted by using basalt fiber which is a natural and non-polluting material to improve the mechanical and physical properties of the soil by offering additional resistance to shear strength. The study involves adding different percentages (1%, 1.5% and 2%) of basalt fibers of different lengths of 6 mm, 12 mm and 24 mm in the silty soil. To properly conduct this study, 40 triaxial undrained unconsolidated tests (UU) were conducted on saturated silty soils which were consolidated under 100 kPa vertical stress. The results of these tests show that the addition of the basalt fiber has greatly enhanced the shear strength of the soil used in this study. The best improvement is observed for basalt fiber at 1.5% and 24 mm long. This improvement is expressed by an increase in the cohesion of this soil.

Keywords: Soil improvement, consolidated saturated silty soil, basalt fiber, triaxial test.

Bazalt Fiberle Güçlendirilmiş Doygun Silt Zeminin Mekanik Davranışının Deneysel İncelemesi

Öz

Artan çevresel problemlere çözüm bulabilmek için her alanda, özellikle de inşaat mühendisliğinde birçok yöntem uygulanagelmektedir. Örneğin zemin iyileştirmesinde yapay ve doğal malzemelerin kullanımı artarak devam etmektedir. Son yıllarda doğal bir malzeme olan bazalttan üretilen fiberler betonarme yapıların güçlendirmesinde yaygın bir şekilde kullanılmakta iken bazalt fiberlerin zemin iyileştirmesinde kullanılmasına yönelik çalışmaların sayısı son derece azdır. Buradan hareketle bu çalışmada doğal bir malzeme olan ve kirletici özelliği olmayan bazalttan üretilen bazalt fiberle güçlendirilmiş ve konsolide edilmiş doygun silt zeminin mekanik özelliklerinden kayma direncindeki artış incelenmiştir. Çalışmada, öncelikle doğal, sonrasında 6 mm, 12 mm ve 24 mm uzunluğundaki bazalt fiberlerin silt zemine %1, %1.5 ve %2 oranında katılmasıyla elde edilen numuneler 100 kPa düşey gerilme altında konsolide edilmiş ve doygun haldeki silt zeminden elde edilen toplam 40 numune üç eksenli hücre kesme deneyine tabi tutulmuştur. Deney sonuçlarına göre; doğal silt zemine basalt fiber ilavesi denenen her durumda drenajsız kayma direncini artırmış, en iyi iyileştirme 24 mm boyundaki fiberin %1.5 oranında zemine karıştırıldığı durumda elde edilmiştir.

Anahtar Kelimeler: Zemin iyileştirme, konsolide edilmiş doygun silt zemin, bazalt fiber, üç eksenli deney

[*] e-mail: sert@sakarya.edu.tr

1. Introduction

The reinforcement consists of adding certain materials (natural or synthetic), with certain desired properties, to the original material in order to provide a property (mechanical, physical or chemical) better than before [1]. Therefore, soil reinforcement is an old technique used in civil engineering to improve soil characteristics such as shear strength, compressibility, density and permeability [2].

Silty soils generally have low tensile and shear strength and their characteristics can be highly dependent on environmental conditions [3]. The aim of this work is to mix a certain percentage of different length of basalt fibers with a saturated silty soil at the first stage, next submit it to a vertical stress of 100 kPa, and then conduct undrained-unconsolidated triaxial tests (UU) in order to find shear strength.

2. Background

According to the soil problems in the field of civil engineering in the past, many researchers have started to use techniques that improve soil properties. The main aim of soil mass reinforcement, which is an improving technique, is to improve soil stability, increase bearing capacity (CBR) and reduce lateral deformations [4 and 5].

To investigate the effects of thermal stabilization and stabilization with lime, heat treatment with six different temperatures of 105, 200, 400, 600, 800 and 1050 ^{o}C and a treatment with 4% of lime based on the sample weight were used on clay. The two techniques were used first separately and secondly together at the same time. The results show that after each treatment technique, the compressive strength of the samples treated with lime and heat treatment showed similar strength gains up to 3000 kPa. With the double-treatment technique (thermal-lime), the resistance gain increases significantly to 12000 kPa and beyond [6].

The results of the work on the shear strength of clays reinforced by Polypropylene (PP) fibers under the consolidated undrained isotropic triaxial tests and the drained consolidated Isotropic (CIU-CID) have shown that the presence of PP fibers modifies the behavior of the clay during shearing [7].

In one of the pioneering studies using basalt fiber, basalt fibers of different lengths and percentages were used to study the effects of basalt fibers on the shear strength behavior of silty soils. Compaction tests at different water content and then series of unconsolidated undrained triaxial shear tests (UU) were carried out on unsaturated natural and improved silty soils. The results of the study show that inclusions of basalt fibers have increased the unconsolidated undrained shear strength (UUS) of silty soils [8].

3. Materials and Methods

3.1. Materials

The materials used in this study are silty soil samples and basalt fibers. The silty soil samples were taken from between 2 and 3 meters depth in the city of Adapazarı (Turkey) and the basalt fibers was provided from a private textile manufacturing company. Figures 1 and 2 show the materials and Tables 1 and 2 show physical properties of the materials used in this study.

Figure 1. Silty soil samples: (a) natural soil, (b) fibrous soil

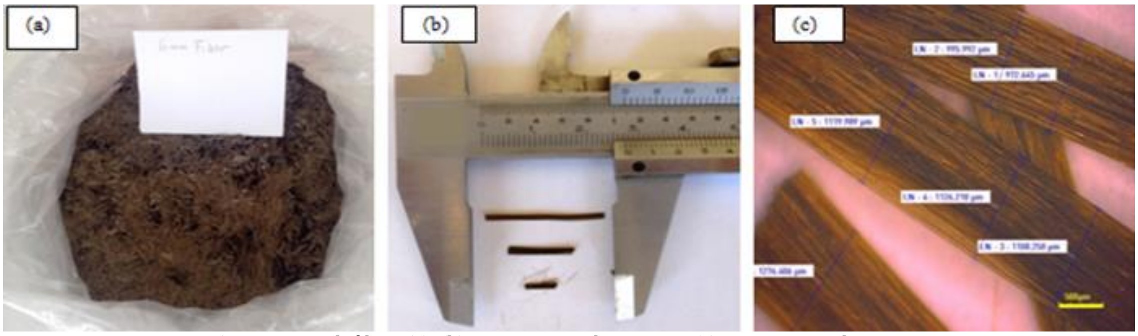

Figure 2. Basalt fibers (a), (b) macroscopic observation, (c) microscopic observation

Table 1. Physical properties of soil samples

Silty Soil		
Characteristics	**Values**	**Units**
-No 200	92	%
Liquid Limit (LL)	32	%
Plastic limit (PL)	23,27	%
Plasticity Index (IP)	8,73	%
Water content for 100 kPa (w)	31	%
Soil classification: Silty soil with low pasticity (ML)		

Table 2. Physical properties of basalt fibers

Characteristics	Values	Units
Specific weight	2.60-2.65	g / cm^3
Modulus of elasticity	70-90	GPa
Tensile strength	2800-3000	MPa
Breaking limit	3.1	%
Diameter	6 - 25	μ
Temperature of application	450-550	^{0}C
Melting point	1350	^{0}C
Price	6	USD/Kg

The classification test results reported in Table 1 indicate that the soil used in this study is a silty soil of low plasticity (ML) according to USCS and TS classification systems. Figure 3 shows the grain size distribution curve of the silty soil sample used in this study.

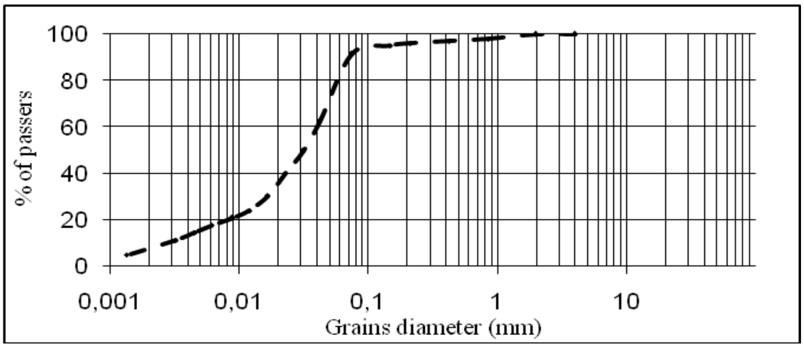

Figure 3. Grain size distribution curve of the silt

3.2. Methods

3.2.1. Test procedures

In this study, saturated silty soil was first submitted to a vertical stress of 100 kPa for 5 days minimum and then four specimens were submitted to unconsolidated undrained triaxial tests. In the same way, the same soil was reinforced by the inclusion of fibers of different lengths (6 mm, 12 mm and 24 mm) and different percentages (1%, 1.5% and 2%). In total, 40 unconsolidated undrained tests (UU) were conducted.

3.2.2. Saturation and consolidation phase

This phase consists of making the soil sample saturated according to predefined standards. For 1.5 kg of the soil sample, 600 ml or 40% of water was added and then mixed until the sample was homogeneous. Once the soil was homogeneous, it was placed in the desiccator for extraction of air bubbles for at least 1 hour to make it saturated (Figure 4).

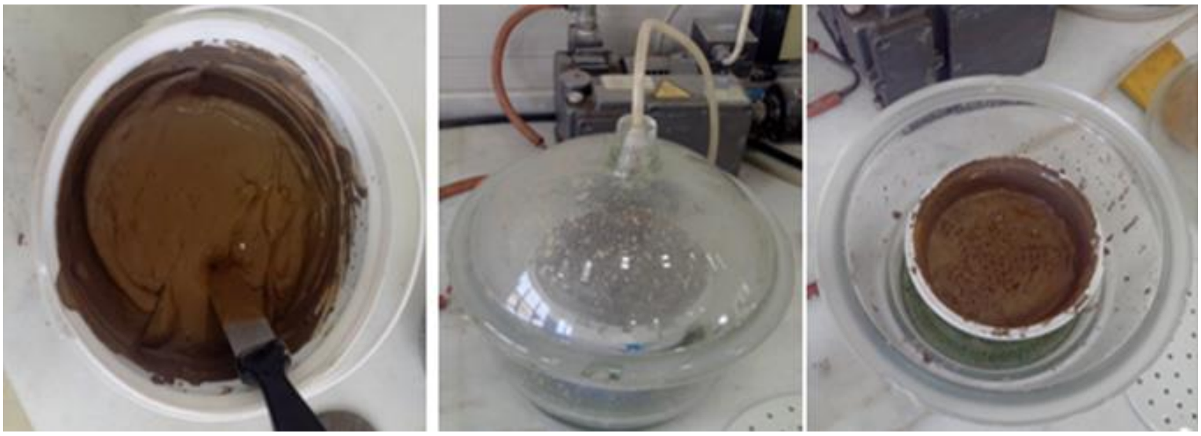

Figure 4. The saturation procedure of soil sample

After the saturation phase, an amount of saturated soil (12 cm) is placed in a cell of at least 17 cm long and 10 cm of diameter. After filling the cell, the upper end of the cell is carefully blocked by screws and the assembly is maintained under a vertical load of 1 kg for 1 day. After, additional loads were applied gradually for 5 days minimum until a vertical stress of 100 kPa was obtained (Figure 5).

Figure 5. Soil consolidation phase

3.2.3. Unconsolidated undrained triaxial test (UU)

After the consolidation phase, 4 uniaxially consolidated saturated soil samples were taken by using cylindrical steel tubes of 7 cm long and 3.5 cm in diameter and placed in the cell of the (UU) triaxial test (Figure 6). The (UU) triaxial tests for this study were carried out in accordance with the Turkish Standard Norm (TS1900-2) at ambient pressures from 100 kPa to 400 kPa.

Figure 6. Triaxial test (UU)

4. Obtained Results

The effects of fiber inclusions on silty soil behavior can be observed and deduced from the Figure 7, 8, 9 10 and the values in Table 3.

The microscopic observation of these samples shows the arrangement of basalt fibers and particles behavior of silty soil (Figure 7). These particles tend to bind to basalt fibers. This behavior proves that the inclusion of basalt fibers brings more adhesion to this soil sample. This is demonstrated by the results in Table 3.

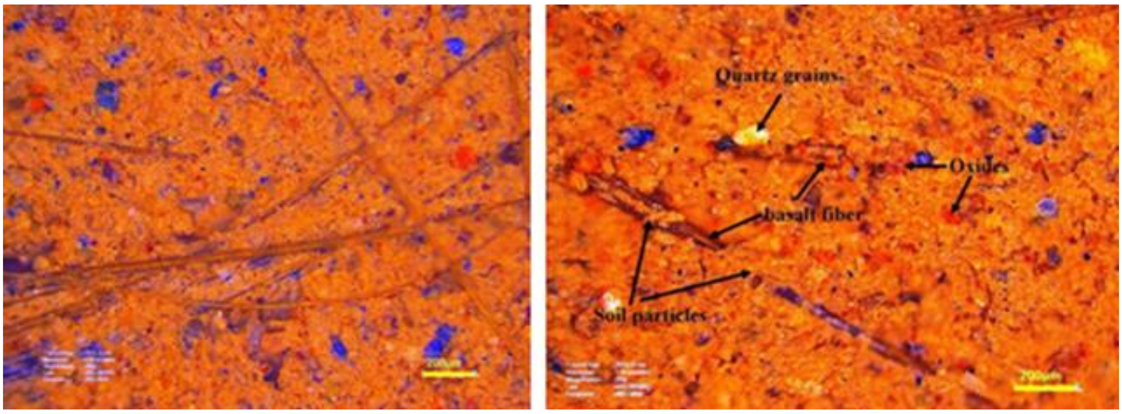

Figure 7. Microscopic observation (polarised light microscopy): Disposition of basalt fibers in the soil sample

Table 3. Estimation of the maximum stress as a function of the percentages and the length of the basalt fibers

		σ_3=100 kPa	σ_3=200 kPa	σ_3=300 kPa	σ_3=400 kPa
Fiber length (mm)	**% of fiber**	$\sigma_{d,\,max}$ **(kPa)**	$\sigma_{d,\,max}$ **(kPa)**	$\sigma_{d,\,max}$ **(kPa)**	$\sigma_{d,\,max}$ **(kPa)**
--	0	43,41	47,17	49,08	52,67
6	1	47,14	48,42	51,58	57,28
6	2	50,93	61,92	71,58	75,39
12	1	50,97	54,05	57,60	59,97
12	1,5	68,58	78,03	85,79	89,63
12	2	54,19	60,60	64,81	69,05
24	1	53,61	59,31	63,45	67,02
24	1,5	75,64	82,46	91,16	99,35
24	2	65,95	71,80	81,26	90,16

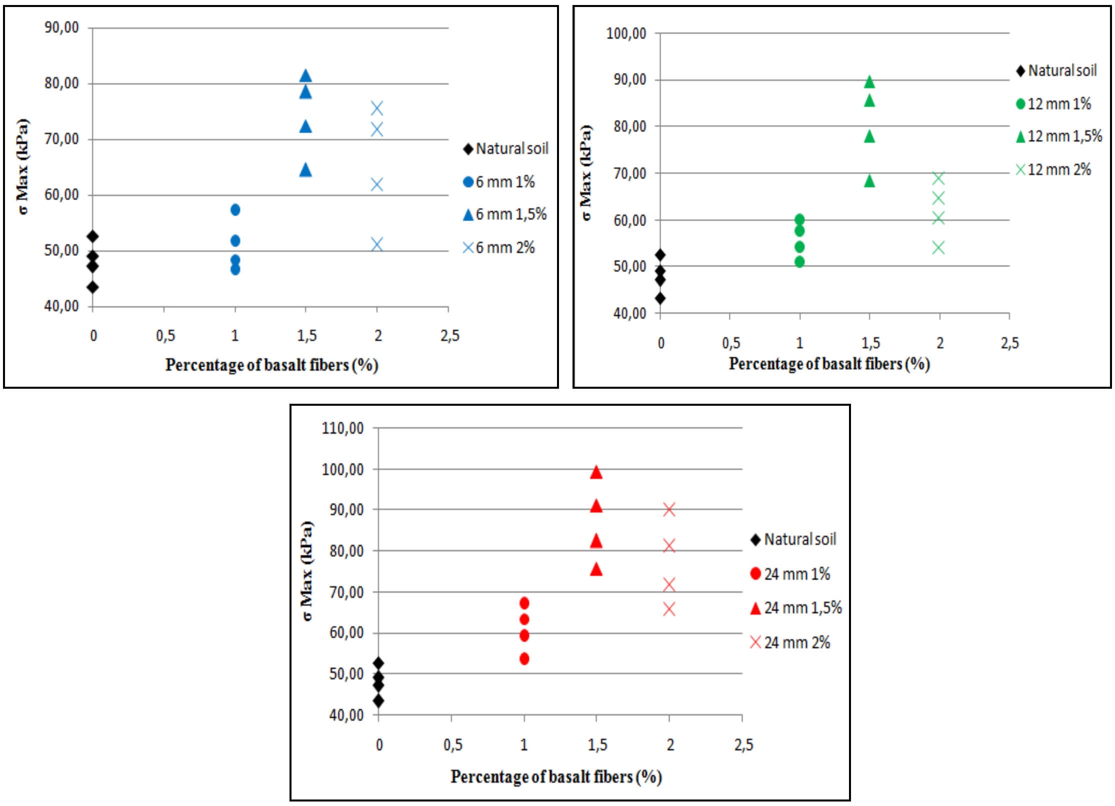

Figure 8. $\sigma_{d,\,max}$ as a function of % of basalt fibers

The results of 40 UU tests in Table 3 and Figure 8 show an improvement of unconsolidated undrained strength of the soil sample used in this study. This improvement is expressed for all basalt fibers with better improvement for 1.5% inclusion.

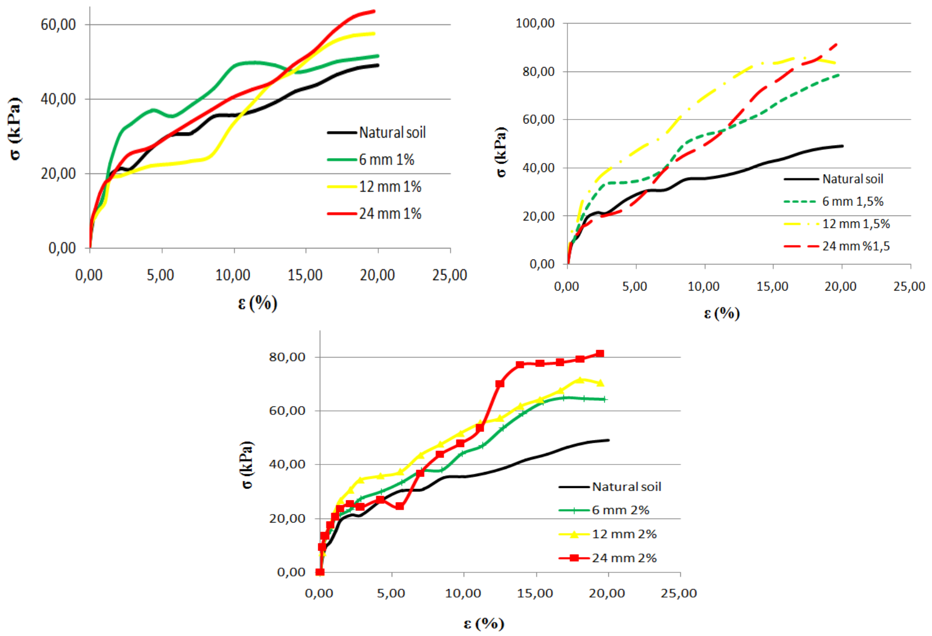

Figure 9. Estimation of stress as a function of fiber size (σ_3=300 kPa)

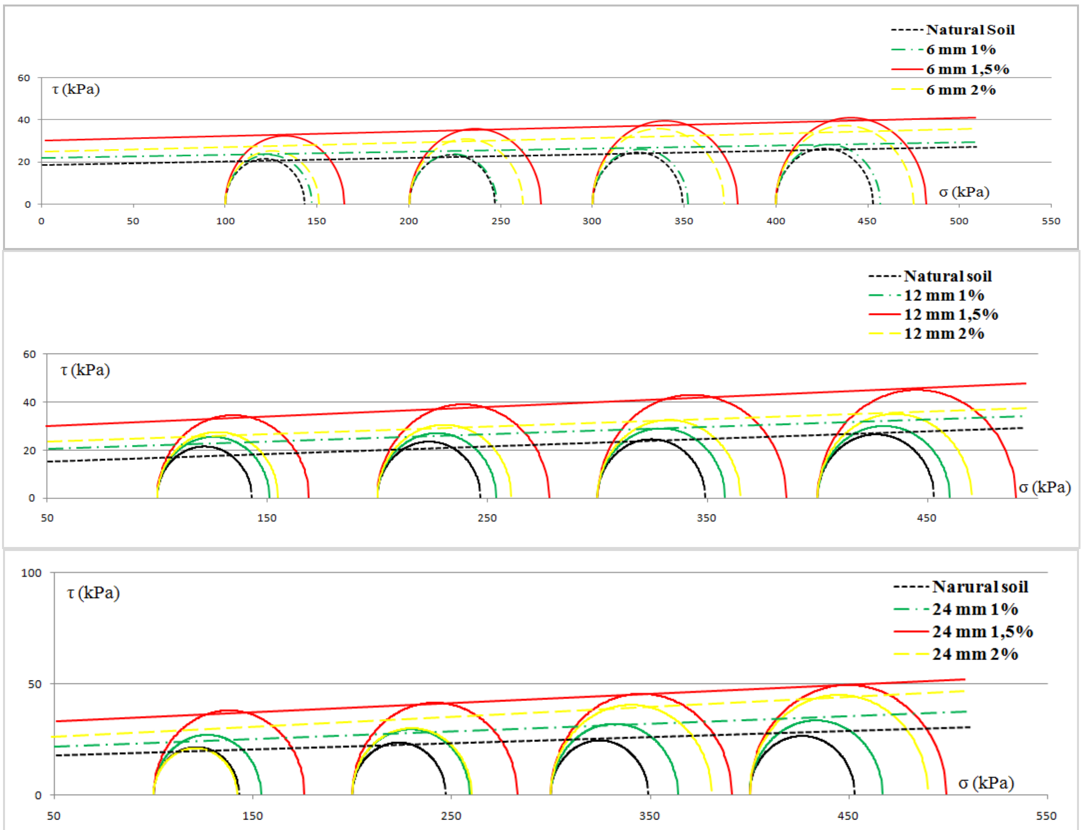

Figure 10. Mohr circles of the improved soil sample

According to the results obtained from Figures 9 and 10, there is a marked improvement in the resistance for all of the improved soils with basalt fibers of different lengths and different percentages. However, the best improvement is obtained for fibers of 24 mm and 1.5% of inclusion. Looking at Figure 10 (Mohr circles), all friction angles defined by the intrinsic curves are almost equal.

5. Conclusion

The results of this study show that the undrained unconsolidated strength (UUS) of the silty soil can be improved with basalt fibers. When the length of the fiber increases, the strength also increases and the best improvement is obtained for fibers of 24 mm length.

The strength increases first, then decreases with increasing fiber content, and the best content is 1.5%. Compared to natural soil, fibrous soil has higher breaking strength and more stable performance.

Concerning failure mechanism of silty soil reinforced by basalt fibers, its resistance is influenced by the interfacial forces exerted by the basalt fibers on soil particles on the model of the arrangement of basalt fibers and soil particles as observed in Figure 7 (microscopic observation). The inclusion of basalt fibers constitutes effective barriers to breaks in the soil.

6. Acknowledgements

This research has been supported by Sakarya University Scientific Research Project Unit (Project 2017-50-002-009). Its generous support is gratefully acknowledged.

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