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The effect of basalt fiber reinforcement at different ratios on the unconfined compressive strength of kaolin

Farklı oranlardaki bazalt fiber takviyesinin kaolinin serbest basınç dayanımına etkisi

Yasemin Aslan Topçuoğlu[1,*], Zülfü Gürocak[2]

[1,2] *Fırat University, Geological Engineering Department, 23119, Elazığ Türkiye*

Abstract

There are many materials used for stabilization or reinforcement of low strength soils. While additives such as fly ash, lime, tuff, silica fume are preferred in stabilization works, fibers are used in reinforcement works. The use of fiber, which has emerged as an alternative to traditional methods, has become widespread. The most preferred fiber types in soil reinforcement are glass, carbon, polypropylene and basalt fibers. Basalt fiber, which is produced from basalt rock and widely distributed in nature, was chosen as a reinforcement material in this study, which is increasingly used due to its high strength, economic, environmentally friendly, natural and many other superior properties. The aim of this study is to examine the effects of basalt fiber ratio on strength in low plasticity kaolin clay reinforced with basalt fiber. For this purpose, unconfined pressure tests were carried out on cylindrical samples prepared by adding 6 mm long basalt fiber at different rates to clay and compressing it at optimum water content. In the samples reinforced with basalt fiber, the maximum strength was obtained from the sample which has 2 % basalt fiber ratio. It was determined that the strength decreased in samples with higher basalt fiber content.

Keywords: Basalt fiber, Reinforcement, Kaolin clay, Unconfined compressive strength

Öz

Dayanımı düşük olan zeminleri stabilize etmek veya güçlendirmek amacıyla kullanılan birçok malzeme bulunmaktadır. Stabilize çalışmalarında uçucu kül, kireç, tüf, silis dumanı gibi katkı malzemeleri tercih edilirken, güçlendirme çalışmalarında ise fiber kullanımı yaygınlaşmaktadır. Geleneksel yöntemlere alternatif olarak ortaya çıkan fiber kullanımı yaygınlaşmıştır. Zemin güçlendirmede en fazla tercih edilen fiber türleri ise cam, karbon, polipropilen ve bazalt fiberlerdir. Doğada çok geniş yayılım gösteren bazalt kayasından üretilen, dayanımı yüksek, ekonomik, çevre dostu, doğal ve daha birçok üstün özelliğinden dolayı günümüzde kullanımı artan bazalt fiber bu çalışmada takviye malzemesi olarak seçilmiştir. Bu çalışmanın amacı, bazalt fiber ile güçlendirilen düşük plastisiteli kaolin kilinde bazalt fiber oranının dayanıma olan etkilerinin incelenmesidir. Bu amaçla 6 mm uzunluğundaki bazalt fiberin kile farklı oranlarda eklenmesi ve optimum su içeriğinde sıkıştırılmasıyla hazırlanan silindirik örneklerde serbest basınç deneyleri gerçekleştirilmiştir. Bazalt fiber ile güçlendirilen örneklerde maksimum dayanım % 2 bazalt fiber katkı oranına sahip örnekte elde edilmiştir. Bazalt fiber oranının daha fazla olduğu örneklerde ise dayanımın azaldığı belirlenmiştir.

Anahtar kelimeler: Bazalt fiber, Güçlendirme, Kaolin kili, Serbest basınç dayanımı

1 Introduction

New engineering materials are rapidly taking their place in different areas of use depending on the rapid technological progress and needs. One of the new products in geotechnical applications is artificial fibers and it has gained importance in recent years as an alternative to traditional methods. Ekincioğlu [1] defines fibers as materials that can be found naturally or can be produced by humans, with one dimension much larger than the other, and with a higher strength and modulus of elasticity than the larger shape of the same material.

There are two types of fiber, natural and artificial. Recently, artificial fibers are preferred because of their high strength, light weight, flexibility and resistance to environmental effects [2]. One of the newest artificial fibers is basalt fiber (BF) produced from basalt rock, which has attracted attention in recent years. Basalt, which is widely used in volcanic areas and preferred because of its durability with easy access, is also the raw material of BF. In addition, interest in basalt fibers is increasing day by day because of its high chemical resistance, resistance to microorganism effects and high temperature, and no additives are used during its production.

Looking at the studies on BF, it is possible to see that most of these studies are on soil reinforcement with BF and the optimum BF length-additive ratio. As a matter of fact,

* Sorumlu yazar / Corresponding author, e-posta / e-mail: yaslan@firat.edu.tr (Y. Aslan Topçuoğlu)
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Gao et al. [3] stated that the BF ratio, which has the highest soil strength in clay, was 0.25 % and the fiber length is 12 mm.

Ndepete and Sert [4] used BF as reinforcement in a silty soil. In the study, it was determined that the fiber length with maximum strength was 24 mm and the fiber ratio was 1.5 %.

Gisymol and Ramya [5] determined that the greatest increase in strength of organic soil occurred with the addition of 10 mm fiber at the rate of 0.05 % and after 28 days of curing.

Boz et al. [6] stated that the maximum strength increase occurred with the use of 9 % lime and 0.75 % of 19 mm long BF in high plasticity kaolin clay and a 90-day cure.

Kenan and Özocak [7] defined that 1.5 % fiber additive was the most appropriate ratio in a silty soil. Pandit et al. [8] determined that the maximum dry unit volume weight value increased, while the optimum water content value decreased with the use of 4 % BF.

Küçükosmanoğlu [9] used BF of different lengths (6, 12, 24 mm) and different proportions (2.0, 1.5, 1.0, 0.20, 0.15, 0.10, 0.05 by weight) as reinforcement in a low plasticity clay soil. According to the experimental study results, it was determined that the fiber ratio, which had the least swelling and maximum bearing capacity ratio (CBR), was 0.20 % and its length was 6 mm.

Ocakbaşı [10] stated that the highest strength values were obtained in the samples prepared with the addition of 2 % and 24 mm in length BF.

Kale et al. [11] in their experimental study on basalt fiber added soil, they determined that the maximum dry unit volume weight of the soil increased and the optimum water content value decreased with basalt fiber additive. They also stated that the undrained shear strength of the soil increased with the addition of basalt fiber and that the fiber content that provided the maximum improvement in strength was 3 %.

Sungur et al. [12] determined that shear strength increased with increasing the length of 1.5 % BF in clayey soil up to 15 mm, but shear strength decreased with larger fiber lengths.

Terzi [13] conducted experimental studies by adding BF at different rates (0, 1, 1.5, 2, 2.5 % by weight) and different lengths (6, 12, 24 mm) to high plasticity clay. The researchers determined the maximum cohesion value in a 12 mm long sample reinforced with 1.5 % BF. They determined the maximum internal friction angle in a 24 mm long sample with 2 % BF reinforcement.

Xu et al. [14] prepared samples with three different fiber lengths and four different fiber ratios in low plasticity loess and conducted experimental studies. According to the test results, it was stated that the shear strength of loess improved significantly if the maximum fiber ratio was 0.6 % and the fiber length was 12 mm.

Zhao et al. [15] examined the reinforcing effect of BF and polypropylene fiber on low plasticity clay. In the study, it was stated that the effect of fibers on strength came mainly from their improving effect on cohesion, but the fiber did not contribute much to the increase in the internal friction angle. It has been stated that the maximum improvement in strength can be achieved by using 0.2 % of 10-13 mm long fiber.

Saran and Demiröz [16] carried out unconfined pressure and splitting tensile experiments on the samples they prepared by adding BF and fly ash to high plasticity clay. Researchers achieved the maximum increase in strength with 1 % BF reinforcement and 10 % fly ash additive in 18 mm length and after 56 days of curing.

Gürocak and Aslan Topçuoğlu [17] carried out experimental studies in kaolin clay, in which water and BF were added in different ratios. They indicated that the maximum unconfined compressive strength was obtained by adding 25 % water at the rate of 1 % BF.

By adding fiber to a clay soil, fiber and soil particles interact with each other and limit each other. A single small fiber in the soil is surrounded by soil particles, and the soil and fiber particles come into contact with each other, creating an interface force [18]. When the basalt fiber content is quite low, the fiber spacing is wide, the intersection between fiber – soil columns is difficult, and therefore the fiber and soil cannot form an effective fiber – soil network. As the fiber content gradually increases, the fiber spacing decreases, which makes adjacent fiber – soil columns easily intersect to form an effective fiber – soil network. When the fiber content is high, many fiber filaments are collected in clusters in the soil sample due to electrostatic interaction, making it difficult to distribute the fibers properly. Thus, the excess of fibers reduces the effect of fiber reinforcement. Figure 1 shows model of fiber and soil column – net [3].

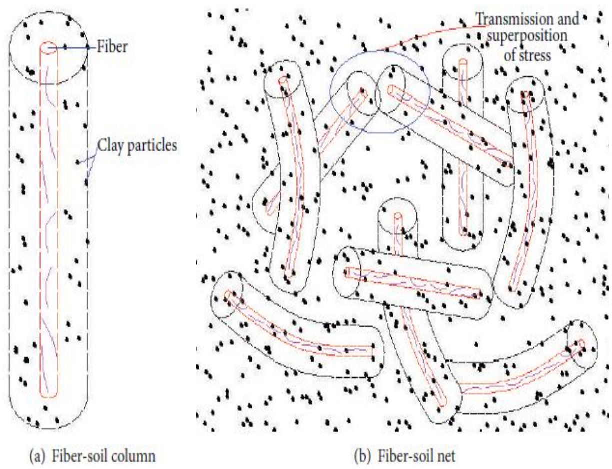

Figure 1. Model of fiber and soil column – net [3]

The aim of this study is to determine the changes in the unconfined compressive strength of the soil reinforced with BF at different rates and optimum BF ratio. The results of the study will contribute to future studies on the use of BF in soil reinforcement.

2 Material and method

In this study, kaolin clay (K) was used as the clayey soil, and BF, which has increased in use in recent years and still needs to strengthen the database with new studies, was used as the reinforcement material.

2.1 K and BF

Kaolin is a clay group, the main mineral of which is kaolinite, formed as a result of in situ weathering of granite and other igneous/volcanic rocks. Kaolinite ($Al_2Si_2O_5(OH)_4$) is the most important mineral that forms the raw material of kaolin, a white, plastic, grain size 2 µm soft clay type, and it has aluminum hydrosilicate composition [19]. In this study, pure K produced in Balıkesir - Sındırgı (Turkey) clay quarry was used (Figure 2).

Figure 2. The K used in the study

BF is obtained from a natural material called basalt, which is a dark-colored and fine-grained volcanic rock. Basalt, a hard and dense rock commonly found around the world, is of igneous origin and melts when heated like thermo-plastic materials [20]. The fact that it is economical, abundant and natural in nature and durable has been remarkable in the use of BF for soil reinforcement. The BF used in the study was obtained from the company that sells fiber and is 6 mm long (Figure 3).

2.2 Experimental studies

Laboratory experiments in this study were carried out in Firat University, Department of Geological Engineering, Rock-Soil Mechanics Laboratory. In the first stage, liquid limit, plastic limit and standard proctor tests were performed in K. In the second stage, different ratios of BF were added to K and compressed at optimum water content. Finally, unconfined compressive strength tests were carried out on the prepared samples.

2.2.1 Liquid and plastic limit tests

At this stage of the laboratory studies, a total of 10 tests were carried out according to the [21] standard to determine the LL and PL values of unreinforced K. According to the test results, the average LL value was 45 %, the PL value was 24 %, and the PI value was calculated as 21 %. The clay used in the study is in the low plasticity (CL) clay class according to the Unified Soil Classification (USCS) (Table 1).

Table 1. Consistency limits of K and proctor test results

Parameters	Values
LL (%)	45
PL (%)	24
PI (%)	21
Soil class (USCS)	CL
w_{opt} (%)	25.00
γ_{kmax} (kN/m^3)	13.01
Fines Content (FC, %)	100

2.2.2 Standard proctor tests

The optimum water content (w_{opt}) of K was determined by standard proctor tests according to [22]. The test is carried out by releasing a 2.5 kg load to free fall on the soil from a height of 30.5 cm and compressing the soil in three layers in the formwork. According to the results of the standard proctor test, the w_{opt} value of kaolin clay was determined as 25.00 % and the γ_{kmax} value was determined as 13.01 kN/m^3 (Table 1).

2.2.3 Sample preparation

In the sample preparation stage, the K passed through the sieve no. 200 was dried in an oven at 105 °C for 24 hours and mixed with a mixer by adding BF (by dry weight), which was separated with the help of a compressor (Figure 3). During the mixture preparation process, distilled water was sprayed into the mixture and mixed again with the help of a mixer (Figure 4). Manual mixing was also applied in order to ensure that the distribution of the fibers in the soil is homogeneous and to prevent fiber aggregation and agglomeration. The mixing time was set at 10 minutes. Fiber ratios in a total of 5 different mixtures created by adding BF at different rates are given in Table 2. This mixture with BF added is compressed at optimum water content.

Figure 3. Unseparated (a) and separated (b) BF used in the study

Figure 4. Preparation of K and BF mixtures

Table 2. BF ratios of the mixtures used in experimental studies

BF length (mm)	BF rate (%)	Samples
6	0	K
	1	K + 1 % BF
	2	K + 2 % BF
	3	K + 3 % BF
	4	K + 4 % BF
	5	K + 5 % BF

2.2.4 *Unconfined compressive tests*

In order to determine the unconfined compressive strength (q_u) of the samples, unconfined compression tests were carried out on cylindrical soil samples whose length is twice the diameter and the q_u values of samples were determined. Experiments were carried out on 30 samples according to [23] standard (Figure 5).

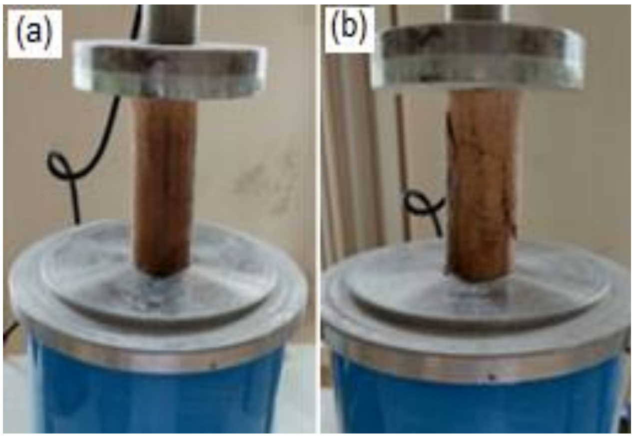

Figure 5. Sample before unconfined compressive test (a) and after test (b)

According to the results of unconfined pressure tests, the average q_u value of unreinforced clay was determined as 294.08 kPa. It was determined that the average q_u values of BF reinforced samples varied between 501.11 – 854.16 kPa (Table 3).

Some examples of experimental studies are given in the Figure 6.

Figure 6. Samples used in laboratory studies

Table 3. Minimum, maximum and average q_u values of unreinforced and reinforced samples

Samples	q_u (kPa) Min	Max	Avrg.
K	280.76	311.25	294.08
K + 1 % BF	581.41	606.84	593.09
K + 2 % BF	846.74	863.14	854.16
K + 3 % BF	711.02	741.66	726.43
K + 4 % BF	562.99	600.02	581.41
K + 5 % BF	485.25	513.21	501.11

The stress - strain graphs of the unconfined compressive strength test performed on each mixture of unreinforced clay and BF reinforced mixtures are shown in Figure 7.

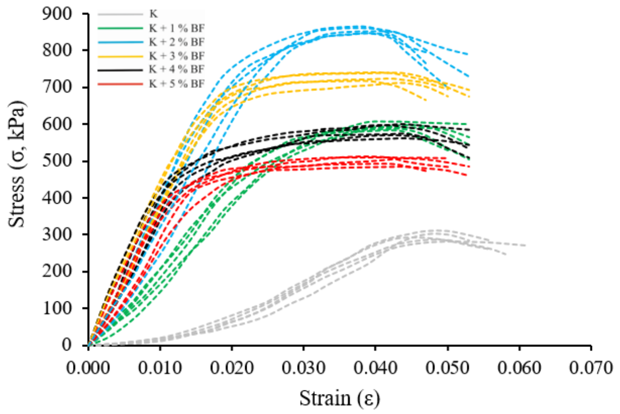

Figure 7. Stress – strain curves of unreinforced K and BF reinforced samples

Maximum stress (σ_{max}), strain (ε) and percentage of axial deformation of unreinforced and reinforced samples are given in Table 4. The unit length change in unreinforced K is 5.29 %. In reinforced samples, it is between 0.036 % and 0.044 %, and the lowest value was determined in the K + 2 % BF sample (Table 4).

Table 4. σ_{max}, ε, % ε values of unreinforced clay and BF reinforced samples

Samples	σ_{max}	ε	ε (%)
K	311.25	0.050	5.29
K + 1 % BF	606.84	0.042	4.41
K + 2 % BF	863.14	0.036	3.70
K + 3 % BF	741.66	0.039	4.06
K + 4 % BF	600.02	0.044	4.59
K + 5 % BF	513.21	0.039	4.06

Mohr graphs of unreinforced clay and BF reinforced samples are shown in Figure 8.

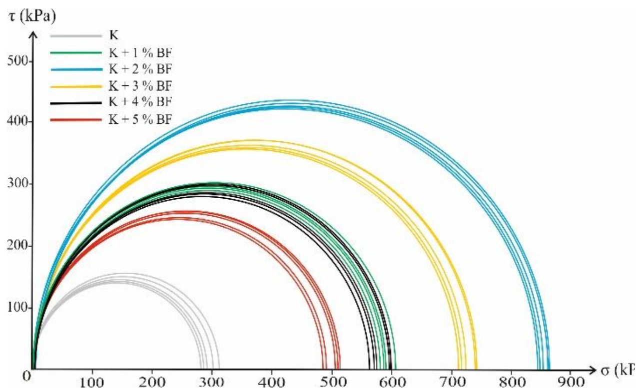

Figure 8. Mohr graphs of unreinforced clay and BF reinforced samples

3 Findings and discussion

The changes in the unconfined compressive strength of the unreinforced and BF reinforced samples were determined with experimental studies. The average q_u value of unreinforced K was determined as 294.08 kPa. The q_u values of the clay showed a significant increase for all ratios of BF. The maximum q_u value was determined as 854.16 kPa in the K + 2 % BF sample, and the lowest q_u value was 501.11 kPa in the K + 5 % BF sample. It was determined that q_u values increased until 2 % BF ratio, but decreased at higher BF ratios (Table 5, Figure 9).

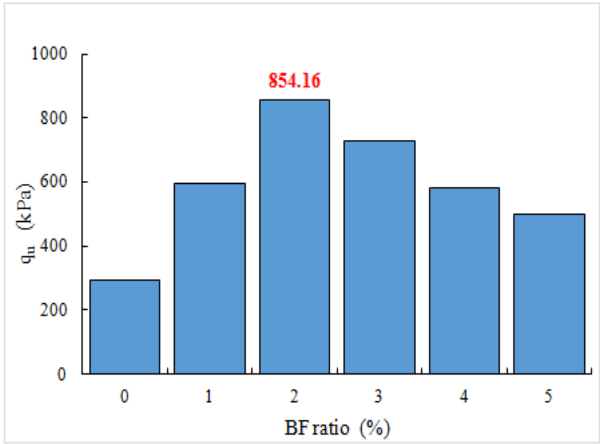

Figure 9. The relation of q_u - BF ratio of unreinforced and reinforced clay samples

The increases in the q_u values of the samples were 101.68 % in the 1 % BF sample, 190.45 % in the 2 % BF sample, 147.02 in the 3 % BF sample, 97.70 % in the 4 % BF sample, and 70.40 % in the 5 BF sample, respectively (Table 5, Figure 10).

According to all these data, it is possible to say that the optimum BF ratio in reinforced samples compressed at the optimum water content of unreinforced kaolin clay is 2 %.

Table 5. Percentages of change in the q_u values of the samples

BF length (mm)	Sample name	q_u (% change)
6	K	-
	K + 1 % BF	101.68
	K + 2 % BF	190.45
	K + 3 % BF	147.02
	K + 4 % BF	97.70
	K + 5 % BF	70.40

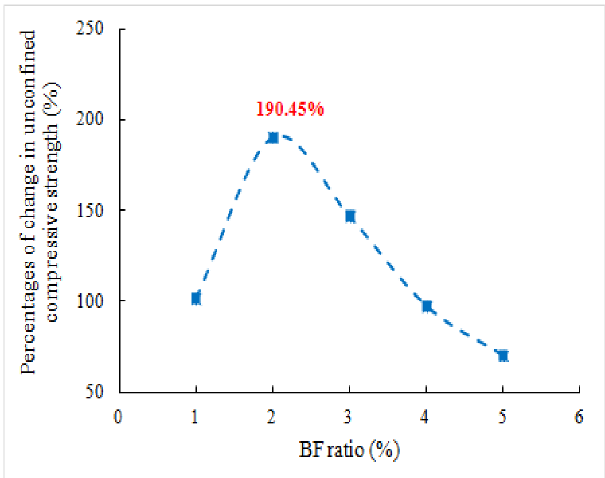

Figure 10. Relation of change percentages of q_u - BF ratio in samples

The q_u value of the clay increased up to the 2 % BF ratio, but after the 2 % BF ratio, the q_u values decreased. The reason for this can be explained as the fiber accumulation caused by the increased fiber ratio in the soil and the difficulty encountered in distributing the fiber homogeneously within the soil [3, 9, 12, 13]. When the fiber ratio in the soil is high, electrostatic interaction occurs between the fibers and the fibers that are not homogeneously dispersed in the soil are collected in clusters and thus the strength is reduced [3].

When studies on BF in the literature are examined [4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17] it is seen that the type, plasticity, water content and BF length of the soil have a significant effect on the optimum BF ratio.

In studies conducted on low plasticity clays [9, 11, 12, 14, 17] it is seen that the optimum BF ratio varies between 0.2 and 3 % depending on the BF size. It can be said that the optimum 2 % BF rate determined in this study is compatible with the literature.

4 Results

The results of this experimental study, which was carried out to determine the optimum BF ratio in the reinforcement of low plasticity clayey soils, are briefly summarized below.

The average strength value of unreinforced K was determined as 294.08 kPa and the average q_u values of BF reinforced samples vary between 501.11 – 854.16 kPa in the unconfined pressure tests. The q_u values increased with BF reinforcement at all BF ratios.

It is possible to say that the BF ratio that provides the highest increase in the q_u value for BF reinforced kaolin compressed at the optimum water content of unreinforced kaolin is 2 % (190.45 % increase).

In the BF – reinforced samples, q_u values increased up to 2 % BF, but more BF reinforcement caused a decrease in the q_u values. It can be said that the reason for this is fiber agglomerations due to the increased fiber ratio.

The data revealed in this study will contribute to the studies on the use of BF, which is natural, environmentally friendly and abundant in nature, which has attracted a lot of attention in recent years.

In applications where BF will be used, it should not be forgotten that BF size, water content, soil type and plasticity have a significant impact on the optimum BF ratio for successful reinforcement.

Conflict of interest

The authors declare that there is no conflict of interest.

Similarity rate (iThenticate): 7 %

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