Fırat Üniversitesi Deneysel ve Hesaplamalı Mühendislik Dergisi

FUJECE
Fırat University Journal of Experimental and Computational Engineering

Bazalt Fiber ile Takviye Edilen Killerin Sıkıştırılabilirliği Üzerine Deneysel Bir Çalışma

Yasemin ASLAN TOPÇUOĞLU[1*], Zülfü GÜROCAK[2]

[1, 2]Jeoloji Mühendisliği Bölümü, Mühendislik Fakültesi, Fırat Üniversitesi, Elazığ, Türkiye.
[1*] yaslan@firat.edu.tr , [2]zgurocak@firat.edu.tr

Geliş Tarihi: 15.02.2024
Kabul Tarihi: 14.04.2024
Düzeltme Tarihi: 24.03.2024
doi: 10.62520/fujece.1436305
Araştırma Makalesi

Alıntı: Y. Aslan Topçuoğlu ve Z. Gürocak, "Bazalt fiber ile takviye edilen killerin sıkıştırılabilirliği üzerine deneysel bir çalışma", Fırat Üni. Deny. ve Hes. Müh. Derg., vol. 3, no 3, pp. 241-254, Ekim 2024.

Öz

Geleneksel zemin iyileştirme yöntemlerine alternatif olarak ortaya çıkan ve farklı türdeki fiberler kullanılarak yapılan zemin güçlendirme çalışmalarında bazalt fiber kullanımı oldukça yaygın hale gelmiştir. Hammaddesi bazalt kayası olan bazalt fiber, yüksek dayanımlı, ekonomik, çevre dostu, doğal ve bol miktarda bulunması gibi özelliklerinden dolayı zemin güçlendirme çalışmalarında tercih edilmektedir. Bu çalışmada bazalt fiber takviyesinin yüksek plastisiteli bentonit kilinin sıkıştırılabilirliğine olan etkileri incelenmiştir. Bentonit kiline 24 mm uzunluğunda ve %0.5 ile %5.0 arasında farklı oranlarda bazalt fiber takviyesi yapılmış ve bu karışımlarda standard proktor deneyleri gerçekleştirilmiştir. Deneysel çalışmalar ile maksimum kuru yoğunluk (γ_{dmax}) ve optimum su içeriği (ω_{opt}) değerleri belirlenmiş ve bazalt fiber takviyesinin bu parametrelere olan etkileri değerlendirilmiştir. Deney sonuçlarına göre, %2.5 bazalt fiber takviye oranına kadar γ_{dmax} değerleri artmakta iken, ω_{opt} değerleri ise azalmıştır. Bazalt fiber oranının %2.5'dan daha fazla olduğu örneklerde ise γ_{dmax} değerleri azalmış, ω_{opt} değerleri ise artış göstermiştir. Elde edilen sonuçlar, bentonitin en iyi sıkıştırılabildiği bazalt fiber oranının %2.5 olduğunu ve bu orandan daha büyük oranlardaki bazalt fiber takviyesinin sıkıştırılabilirliği olumsuz yönde etkilediğini göstermiştir.

Anahtar kelimeler: Bazalt fiber, Bentonit kili, Güçlendirme, Sıkıştırabilirlik

---

*Yazışılan yazar

İntihal Kontrol: Evet – Turnitin
Şikayet: fujece@firat.edu.tr

Firat University Journal of Experimental and Computational Engineering

FUJECE

An Experimental Study on the Compressibility of Clays Reinforced with Basalt Fiber

Yasemin ASLAN TOPÇUOĞLU[1*], Zülfü GÜROCAK[2]

[1, 2]Department of Geological Engineering, Faculty of Engineering, Fırat University, Elazig, Türkiye.
[1*]yaslan@firat.edu.tr, [2]zgurocak@firat.edu.tr

Received: 15.02.2024
Accepted: 14.04.2024

Revision: 24.03.2024

doi: 10.62520/fujece.1436305
Research Article

Citation: Y. Aslan Topçuoğlu and Z. Gürocak, “An experimental study on the compressibility of clays reinforced with basalt fiber”, Firat Univ. Jour.of Exper. and Comp. Eng., vol. 3, no 3, pp. 241-254, October 2024.

Abstract

The use of basalt fiber has become quite common in soil reinforcement works, which emerged as an alternative to traditional soil improvement methods and are carried out using different types of fibers. Basalt fiber, whose raw material is basalt rock, is preferred in soil reinforcement works due to its features such as high strength, economical, environmentally friendly, natural and abundant. In this study, the effects of basalt fiber reinforcement on the compressibility of high plasticity bentonite clay were examined. Bentonite clay was reinforced with 24 mm long basalt fiber at different rates between 0.5% and 5.0%, and standard proctor tests were carried out on these mixtures. With experimental studies, maximum dry density (γ_{dmax}) and optimum water content (ω_{opt}) values were determined and the effects of basalt fiber reinforcement on these parameters were evaluated. According to the test results, while γ_{dmax} values increased up to 2.5% basalt fiber reinforcement ratio, ω_{opt} values decreased. In samples with basalt fiber ratio greater than 2.5%, γ_{dmax} values decreased and ω_{opt} values increased. The results obtained showed that the basalt fiber ratio at which bentonite can be compressed best is 2.5%, and basalt fiber reinforcement at rates greater than this ratio negatively affects the compressibility.

Keywords: Basalt fiber, Bentonite clay, Reinforcement, Compressibility

*Corresponding author

1. Introduction

In engineering studies, when soil properties do not have the desired values, there are many methods used to improve these properties, and these methods vary depending on the type of project. While methods such as compaction, stone columns, drainage and pre-loading are mostly used in improvement works on soil foundation, chemical stabilization is the most preferred method in filled soils. However, in recent years, the use of fiber as an alternative to chemical stabilization has become widespread. The use of fibers, which have been used in many engineering fields for many years, is still very new in geotechnical studies.

Fibers, defined by Ekincioğlu [1] as naturally occurring or artificially produced materials with higher strength and elasticity modulus than the material from which they are obtained, contain fewer structural errors than large mass structures because they are produced with a thin diameter. For this reason, the fiber form of the same material has superior mechanical properties [2]. Another type of artificial fibers, which are of many types such as glass, polyester, acrylic and carbon, and which are increasingly used today, is basalt fiber (BF). Its raw material is basalt rock, which is very common in volcanic areas. BFs, which are preferred due to their easy access and durability, attract attention due to their features such as being more economical and ecological, being naturally and abundantly found in nature, as well as having high strength and chemical resistance. The use of BFs in concrete production is older than its use in soil reinforcement works. Although there are many studies on the effects of BF on concrete, studies on the use of BF in different lengths and ratios in soil reinforcement studies, especially in different soil types, are not sufficient and new research is needed on this subject. Many of the studies on the use of BF in soil reinforcement studies aimed to determine the most effective BF length and ratio [3-13]. However, there are almost no studies investigating the effect of fibers on the compressibility of soils.

In the study conducted by Sabat [14] on this subject, polypropylene fiber was added to the soil stabilized with rice husk powder and lime and the change in soil properties was examined. The researcher revealed that the polypropylene fiber ratio decreased γ_{dmax} and increased the ω_{opt} value. Kulkarni and Patil [15] carried out a series of experiments using different proportions of slag and glass fibers of 6 mm and 12 mm length. It was determined that γ_{dmax} and California Bearing Rate (CBR) value for aqueous conditions increased as a result of mixing optimum proportions of slag and varying proportions of 6 mm and 12 mm glass fiber with the soil. According to the results of the research, 12 mm length fiber reinforcement showed better performance than 6 mm length fiber reinforcement. In his study, Baruah [16] added 10 mm length glass fiber to the soil at different rates (0.5, 1.0 and 1.5% by weight) and as a result of experimental studies, it was determined that the ω_{opt} and unconfined compressive strength values increased and the γ_{dmax} value decreased with the increasing fiber ratio. Balagoudra et al. [17] it was determined that the ω_{opt} value of the soil reinforced with 0.25%, 0.50, 0.75, 1.00% polypropylene fiber and 4% lime decreased until the 0.75% fiber ratio, and then the ω_{opt} value increased. Researchers stated that the γ_{dmax} value increased up to 0.75% fiber content and then decreased.

In their study, Aravalli et al. [18] used 12 mm long BF in the ratios of 0.15% and 0.25% as reinforcement in the soil and examined the changes in the index properties of the soil. Researchers found that as the BF ratio increases, the ω_{opt} value decreases and the γ_{dmax} value increases. In the research, it was stated that the high tensile strength of the fiber caused the fiber to elongate, and this elongation in the fiber caused the void ratio to decrease, the γ_{dmax} value to increase and the ω_{opt} value to decrease. Ayininuola & Balogun [19] used glass fiber as reinforcement in two different substrates at rates of 0.4, 0.8, 1.2, 1.6, 2.0, 2.5 and 3.0% by weight. According to the results of experimental studies, it was stated that γ_{dmax} and CBR values increased in both soils with the glass fiber additive. Pandit et al. [10] in their study where they used 12 mm long BF as reinforcement at 2, 4, 6 and 8% by weight, they determined that the γ_{dmax} value of samples with 4% BF reinforcement increased by 9.56% compared to the unreinforced soil, and the ω_{opt} value decreased by 41%. While the ω_{opt} value decreases up to 4% fiber content, γ_{dmax} increases. If the fiber ratio exceeds 4%, the ω_{opt} value increases and the γ_{dmax} value decreases.

According to the results of the study by Kale et al. [20], which used BF reinforcement at 1.5%, 3.0%, 4.5% and 6.0% in 12 mm, 18 mm and 24 mm lengths, the γ_{dmax} value of the soil increases up to 3% BF ratio, while the ω_{opt} value decreases. Kehinde et al. [21] determined that γ_{dmax} values increased with increasing glass fiber ratio in two different soils and reached the maximum value at 0.6% fiber ratio. However, the researchers stated that γ_{dmax} values decreased when more fiber was used, and stated that the change in ω_{opt} value with fiber content is complex and difficult to interpret. They stated that the reason for this may be the swelling of the glass fiber as a result of the high degree of interaction of the glass fiber with water and the increase in volume, thus decreasing the density. In general, the researchers determined that glass fiber reinforcement affects the compression properties and an optimal fiber ratio should be determined for γ_{dmax}, and if this optimal ratio is exceeded, the density decreases due to fiber swelling.

In his study where Chaudhary [22] used BF as reinforcement at different rates (3, 6, 9, 12 and 15%), he stated that ω_{opt} values were not affected much by the BF ratio, but some increase was due to the moisture absorption feature of the fiber. In the study, it was stated that there was a slight decrease in γ_{dmax} values as the BF ratio increased. In the study conducted by Kambale and Rakkaraddi [23], glass, basalt and polypropylene fiber were used in varying amounts (0.5, 1 and 2%) on different soils. Especially with the increase of BF ratio, γ_{dmax} value first increased and then decreased. ω_{opt} values showed different changes, increasing and decreasing, depending on the increase in fiber ratio for different soil types. Al-Kaream et al. [24] used 0.5, 1.0 and 1.5% polypropylene fiber as reinforcement in clay soil. As a result of the research, it was determined that 1% polypropylene fiber reinforcement reduced the compressibility of the soil, and the specific gravity and γ_{dmax} values decreased with the increase in fiber ratio. At the same time, it was stated that the optimum water content values increased continuously with the increase in the polypropylene fiber ratio. Hamirani and Kumar [25] preferred polypropylene fiber as a reinforcement material in the soil at rates of 0.5, 1.0, 1.5 and 2.0% by dry weight. Researchers have determined that as the fiber ratio increases, the γ_{dmax} value decreases and the ω_{opt} value increases. Data obtained from studies conducted with fiber reinforcement in the literature are given in the Table 1.

In the studies summarized above, different fiber types were used on different soil types. In each study, different fiber ratios were determined and the effect of fiber reinforcement on soil properties was demonstrated. However, studies examining the effect of BF reinforcement on soil compressibility are quite limited. Therefore, it is important to examine the effects of BF reinforcement on the compressibility of clayey soils. When the literature is examined, 12 mm basalt fiber [10, 18] and mostly low plasticity clay [20, 22, 23] were used in the studies. However, in this study, 24 mm long BF and bentonite clay with very high plasticity (PI = 466%) were used and in this respect it differs from the literature. In this study, compaction experiments were carried out on samples prepared by adding 24 mm long BF to bentonite at rates of 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0% by dry weight, and the effects of BF ratio on the compaction parameters of bentonite (γ_{dmax} and ω_{opt}) were examined.

Table 1. Fiber reinforcement and its effects on the soil in the literature

Researcher Researchers/	Soil type	Additive/Reinforcement type and rate	Fiber length (mm)	Effect on the soil
Sabat [14]	CH	RHA: 5, 10, 15, 20% L:1, 2, 3, 4, 5% PF: 0.5, 1, 1.5, 2%	12	With fiber reinforcement, γ_{dmax} decreased and ω_{opt} increased
Kulkarni and Patil [15]	CH	BFS: 5, 10, 15, 20, 25, 30% GF: 0.25, 0.50, 0.75, 1.00, 1.25%	6, 12	γ_{dmax} increased with fiber reinforcement
Baruah [16]	CL	GF: 0.5, 1.0, 1.5%	10	With increased fiber ratio, ω_{opt} increased and γ_{dmax} decreased
Balagoudra et al. [17]	C	PF: 0.25, 0.50, 0.75, 1% L: 4%	12	ω_{opt} decreased up to 0.75% fiber ratio and increased with increasing fiber content, γ_{dmax} increased up to 0.75% fiber ratio and decreased with increasing fiber content
Aravalli et al. [18]	CH	BF: 0.15, 0.20, 0.25%	12	As the fiber ratio increased, ω_{opt} decreased and γ_{dmax} increased.
Ayininuola and Balogun [19]	CL ML	GF: 0.4, 0.8, 1.2, 1.6, 2.0, 2.5, 3.0%	25	γ_{dmax} increased in both soils with fiber reinforcement
Pandit et al. [10]	CH	BF: 2, 4, 6, 8%	12	As the fiber ratio increased, ω_{opt} decreased and γ_{dmax} increased. As the fiber ratio increased from 4% to 8%, ω_{opt} increased and γ_{dmax} decreased.
Kale et al. [20]	C	BF: 1.5, 3.0, 4.5, 6.0%	12, 18, 24	Up to 3% fiber content, γ_{dmax} increased and ω_{opt} decreased
Kehinde et al. [21]	CL ML	GF: 0.5, 1, 1.5%	25	γ_{dmax} increased up to 0.6% fiber content and decreased with increasing fiber content. The change in ω_{opt} value with fiber addition is complex
Chaudhary [22]	CH	BF: 3, 6, 9, 12, 15%	13	ω_{opt} does not change much with fiber reinforcement, γ_{dmax}, decreased as the fiber ratio increased.
Kambale and Rakkaraddi [23]	SC MH-OH CH	GF, BF, PF: 0.5, 1, 2%	12	As the basalt fiber ratio increased, the γ_{dmax}, first increased and then decreased. ω_{opt} showed different changes, increased and decreased depending on the increase in fiber ratio.
Al-Kaream et al. [24]	CL	PF: 0.5, 1, 1.5%	12	As the fiber ratio increased, γ_{dmax} decreased and ω_{opt} increased continuously.
Hamirani and Kumar [25]	C	PF: 0.5, 1, 1.5, 2%	-	As the fiber ratio increased, γ_{dmax} decreased and ω_{opt} increased
This Study	CH	BF: 0.5, 1, 1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5%	24	γ_{dmax} increased up to 2.5% BF ratio, decreased with increasing fiber content, ω_{opt} decreased up to 2.5% BF ratio, increases with increasing fiber content

RHA: Rice Husk Ash, L: Lime, PF: Polypropylene Fiber, BFS: Blast Furnace Slag, GF: Glass Fiber; BF: Basalt Fiber, C: Clay
ML: Low plasticity silt, CL: Low plasticity clay, CH: High plasticity clay, SC: Clay sand, OH: High plasticity organic clays and silts,
MH: High plasticity inorganic silts and clayey silts

2. Material

2.1. Properties of bentonite clay and basalt fiber

Bentonite is a clay used in many different areas such as mining, industry, agriculture and engineering. It is formed as a result of the chemical decomposition of volcanic ash, tuff and lava, which predominantly contain montmorillonite and are rich in aluminum and magnesium. Na - bentonite, which has three different types of bentonites: Ca-bentonite, Na - bentonite and Na - Ca-bentonite, has a high swelling capacity. The general chemical formula of bentonite is; (Na, Ca) (Al, Mg) $6(Si_4O_{10})$ $3(OH)_6$ nH_2O [26]. In this study, the chemical and engineering properties of bentonite clay (Figure 1) obtained from the Tokat - Reşadiye clay quarry were determined by Aslan Topçuoğlu [27] and presented in Table 2.

Figure 1. Bentonite clay used in the study

Table 2. Chemical and geotechnical properties of the clay used in the study [27]

Main Oxides (%)	Value
SiO_2	62.50
Al_2O_3	17.60
Fe_2O_3	3.63
CaO	2.86
Na_2O	2.58
K_2O	0.92
TiO_2	0.32
SO_3	0.076
Cr_2O_3	<0.01
Loss on ignition	6.60
Bentonite Type	Na - Bentonite
Liquid Limit (LL, %)	507
Plastic Limit (PL, %)	41
Plasticity Index (PI, %)	466
Soil Class (USCS)	CH

The raw material of BF used as reinforcement material in this study was basalt and this rock was an important natural building material that has been used throughout human history. Basalt, which is a dark-colored, fine-grained rock type formed by the cooling of lava erupted as a result of volcanism, melts when heated like hard, dense, thermo-plastic materials [28]. Basalt which is the raw material of BF, is an important raw material due to its wide distribution in volcanic regions and easy accessibility. Basalt rock is melted into fibers by centrifugal blowing at temperatures above 1500°C to form fibers with a diameter of 7 - 13 μm and a length of 60 - 100 mm [29]. BFs attract attention due to their high strength and corrosion resistance, resistance to high temperatures and easy processing. BF has low density, is cheaper than carbon fiber and has higher strength than glass fiber [30]. With these properties, BF is used in many areas such as construction, automotive and electronics. The BF used in this study has a length of 24 mm (Figure 2) and physical and mechanical properties are given in Table 3.

Figure 2. BF used in the study

Table 3. Mechanical and physical properties of BF used in the study

Feature	Value
Length fiber (mm)	24
Diameter of monofilament (µm)	15 ±1,5
Humidity, Max (%)	2
Modulus of elasticity (GPa)	90
Tensile strength (MPa)	3000
Thermal conductivity (W/mK)	0.031- 0.038
Elongation at break (%)	3.5
Density (gr/cm^3)	2.63

2.2. Method

2.2.1. Sample preparation and experimental studies

Bentonite clay (BC) obtained from Tokat – Reşadiye (Turkey) clay quarry was dried in an oven at 105 ^{o}C for 24 hours and BF purchased from a commercial company was separated with the help of a compressor (Figure 3a). Then 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5 and 5.0% by weight BF was added to bentonite and mixed by hand and mixer for 10 minutes to prepare mixture samples (Figure 3b). Standard proctor tests were performed on each mixture and the ω_{opt} and γ_{dmax} values of the unreinforced and BF reinforced samples were determined. Table 4 shows the BC and BF ratios of the mixtures prepared for the standard proctor tests.

Figure 3. Seperated BF used in the study (a) and preparation of mixtures (b)

Table 4. BC and BF ratios used in proctor experiments

Sample Number	BC (%)	BF (%)
BC	100	0.0
BC + 0.5% BF	99.5	0.5
BC + 1.0% BF	99.0	1.0
BC + 1.5% BF	98.5	1.5
BC + 2.0% BF	98.0	2.0
BC + 2.5% BF	97.5	2.5
BC + 3.0% BF	97.0	3.0
BC + 3.5% BF	96.5	3.5
BC + 4.0% BF	96.0	4.0
BC + 4.5% BF	95.5	4.5
BC + 5.0% BF	95.0	5.0

BC: Bentonite Clay, BF: Basalt fiber

2.2.2. Standard proctor experiments

The standard proctor test is performed to determine the compressibility properties of soils at different water contents and the compaction parameters ω_{opt} and γ_{dmax}. The test is carried out by compressing the soil into the mold in three layers under a load of 2.5 kg, which is allowed to free fall from a height of 30.5 cm. In this study, a total of 55 standard proctor tests were performed on both unreinforced bentonite and 10 mixtures reinforced with BF according to ASTM D698-12e2 [31] standard (Figure 4a, b). The experiments were carried out at the Rock-Soil Mechanics Laboratory, Department of Geological Engineering, Firat University and the results of the standard proctor tests are presented in Table 5. γ- ω curves of all samples are shown in Figure 5.

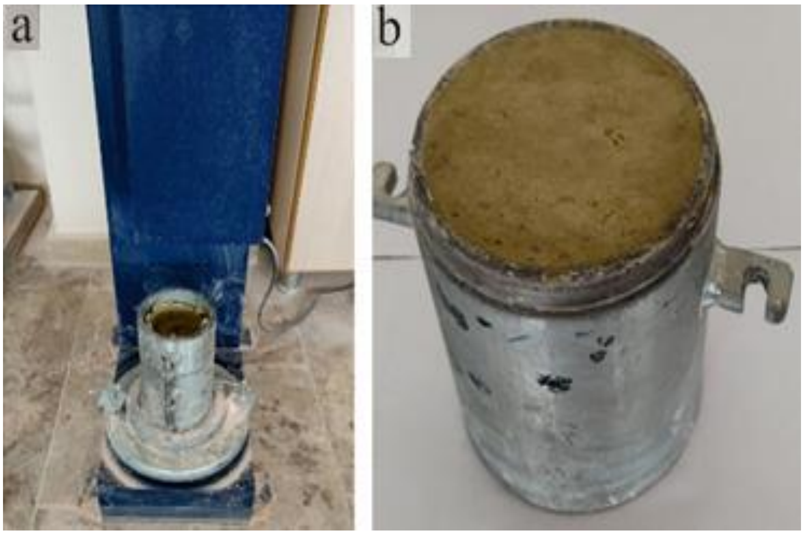

Figure 4. Compressing the sample in the proctor mold (a) and compressed sample (b)

Table 5. γ_{dmax} and ω_{opt} values of unreinforced and reinforced clay samples

Sample	γ_{dmax} (kN/m^3)	ω_{opt} (%)
BC	12.36	38.50
BC + 0.5% BF	12.51	38.40
BC + 1.0% BF	12.60	38.32
BC + 1.5% BF	12.71	38.10
BC + 2.0% BF	12.84	37.50
BC + 2.5% BF	12.91	37.00
BC + 3.0% BF	12.78	37.10
BC + 3.5% BF	12.61	37.25
BC + 4.0% BF	12.48	38.12
BC + 4.5% BF	12.22	38.85
BC + 5.0% BF	11.90	39.00

BC: Bentonite clay, BF: Basalt fiber

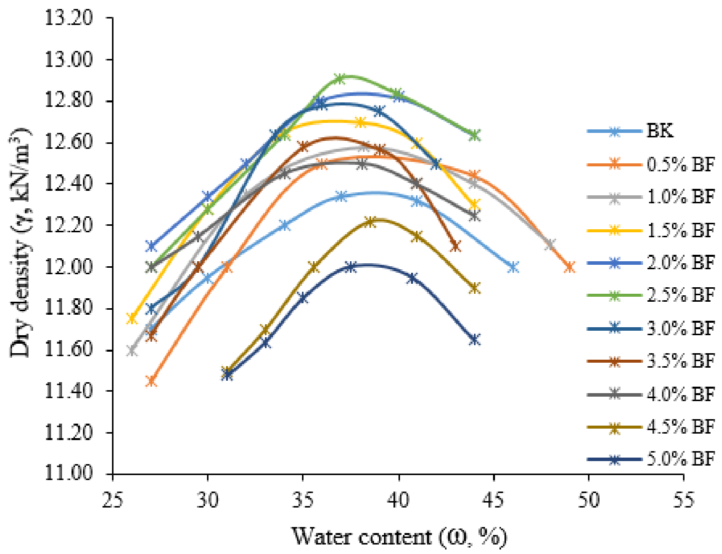

Figure 5. γ- ω curves of all samples

3. Findings and Discussion

According to the results obtained in the experimental studies, the γ_{dmax} value of unreinforced bentonite was 12.36 kN/m^3 and the ω_{opt} value was 38.50%. The γ_{dmax} values of BF reinforced mixtures vary between 11.90 - 12.91 kN/m^3. There was an increase in γ_{dmax} values up to 2.5% BF ratio and γ_{dmax} value reached 12.91 kN/m^3 in the BC + 2.5% BF sample. However, as the BF ratio exceeded 2.5%, γ_{dmax} values started to decrease and γ_{dmax} value decreased to 11.90 kN/m^3 in the BC + 5.0% BF sample. This value was even lower than the γ_{dmax} value of unreinforced bentonite (Figure 6). The ω_{opt} values of BF reinforced samples ranged between 37.00% and 39.00%. The minimum ω_{opt} value was determined in the BC + 2.5% BF sample and the maximum ω_{opt} value was found in the BC + 5.0% BF sample. Depending on the increase in BF ratio, it was observed that the ω_{opt} values first decreased until 2.5% BF ratio and then increased with increasing fiber ratio (Figure 7).

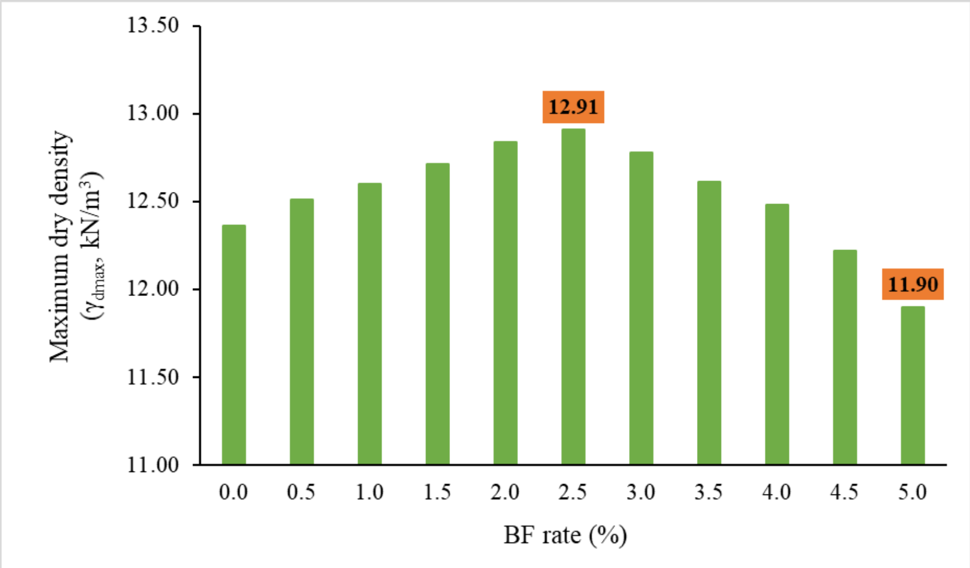

Figure 6. BF ratio - γ_{dmax} change graph

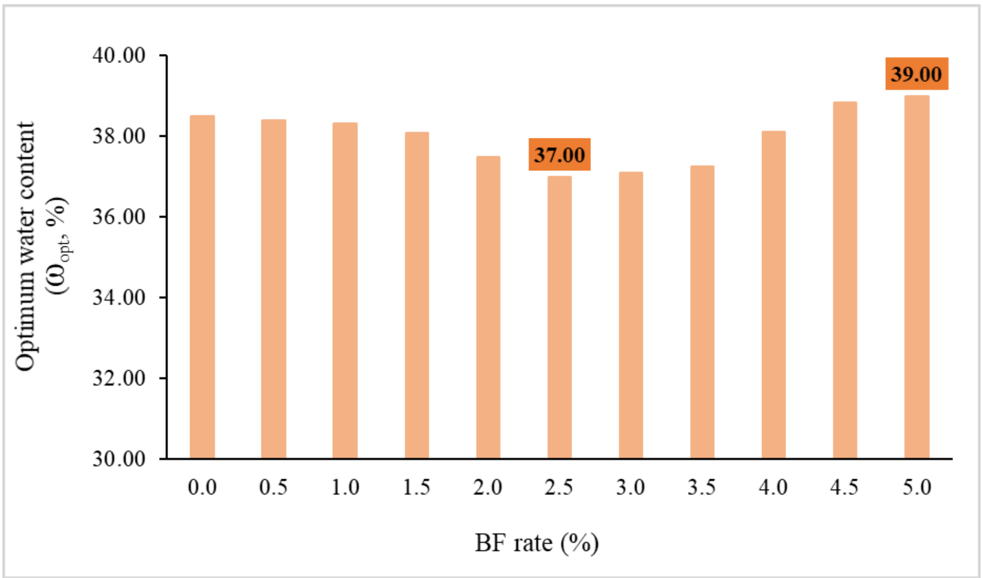

Figure 7. BF ratio - ω_{opt} change graph

When the rates of change in the γ_{dmax} values of the reinforced clay samples compared to the unreinforced clay sample (Table 6), it was determined that the rate of increase in the γ_{dmax} value of the sample reinforced with 2.5% BF was 4.45%, the rate of increase in the γ_{dmax} values decreased with the increase in the BF ratio, and even in the BC + 4.5% BF and the BC + 5.0% BF samples, there was a decrease of 1.13% and 3.72% (Table 6, Figure 8).

Table 6. % γ_{dmax} and % ω_{opt} changes of reinforced samples compared to unreinforced clay

Sample Number	γ_{dmax} (% change)	ω_{opt} (% change)
BC	-	-
BC + 0.5% BF	1.21	-0.26
BC + 1.0% BF	1.94	-0.47
BC + 1.5% BF	2.83	-1.04
BC + 2.0% BF	3.88	-2.60
BC + 2.5% BF	4.45	-3.90
BC + 3.0% BF	3.40	-3.64
BC + 3.5% BF	2.02	-3.25
BC + 4.0% BF	0.97	-0.99
BC + 4.5% BF	-1.13	0.91
BC + 5.0% BF	-3.72	1.30

BC: Bentonite clay, BF: Basalt fiber
(-) shows decreasing values

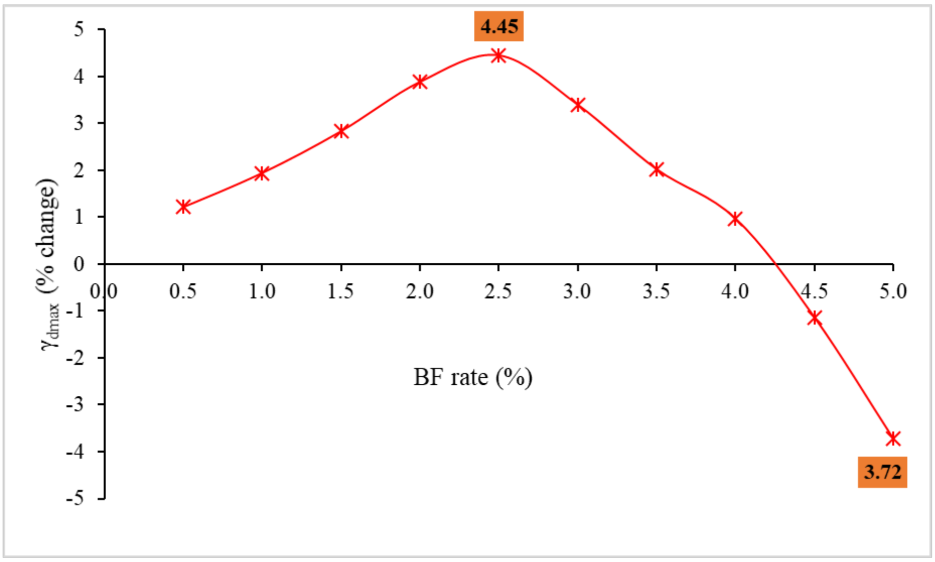

Figure 8. BF ratio - % γ_{dmax} change graph

When the rates of change in the ω_{opt} values of BF reinforced samples were examined (Table 6); a decrease rate of approximately 4% was observed in the the BC + 2.5% BF sample. This rate of decrease depending on the BF additive ratio gradually decreased with the increase in BF ratio, and there was a small increase of 0.91% and 1.30% in BC + 4.5% BF and BC + 5.0% BF samples (Table 6, Figure 9).

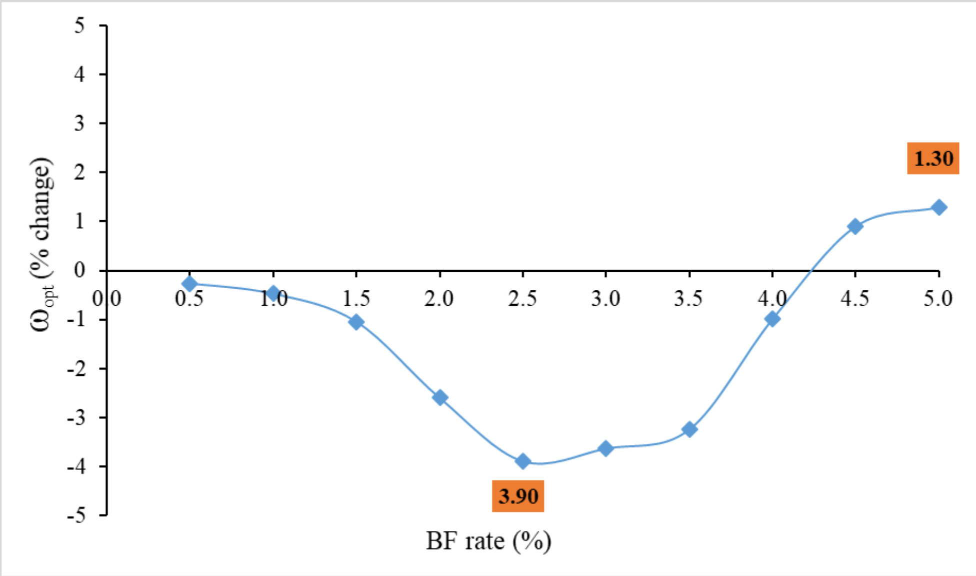

Figure 9. BF ratio - % ω_{opt} change graph

The results obtained from this study were compared with the results in the literature and the results were found to be compatible. In studies conducted by various researchers such as [10, 17-21] it was stated that γ_{dmax} values increase and ω_{opt} values decrease as the fiber ratio increases for different soil and fiber types. Especially in some studies [17, 21], it was specified that the γ_{dmax} value increases up to a certain fiber ratio, that was, up to a peak value, and decreases with further increasing fiber ratio. In the same studies, it was indicated that ω_{opt} values decrease up to a peak fiber ratio and increase with increasing fiber ratio. Aravalli et al. [18] attributed the increase in γ_{dmax} value and decrease in ω_{opt} value to the elongation of the fiber due to the high tensile strength of the fiber and this elongation causes a decrease in the void ratio. The increase in ω_{opt} value with increasing fiber ratio was associated with the water absorption feature of the fiber by Chaudhary [22]. On the other hand, Kehinde et al. [21] stated that due to the high chemical interaction of glass fiber with water at increasing fiber ratios, excess fiber swells and causes volume increase, thus decreasing the density. Ayininuola and Balogun [19], on the other hand, stated that the fiber contribution contributes to holding the soil particles together and thus the bond force between the soil particles develops, arguing that the increase in γ_{dmax} values up to a certain BF ratio was related to this bond force. Considering the information in the literature, it can be said that when the fiber ratio was very high, light fibers replace heavy fibers, thus γ_{dmax} decreases, and ω_{opt} value increases due to the water absorption feature of the fiber. Consistent with the literature, in this study, if more than 2.5% BF was used, ω_{opt} values increased due to the water absorption feature of the fiber. Since the fiber additive contributes to holding the soil particles together, if a low amount of fiber was used, these forces will be very weak and γ_{dmax} values decrease. Additionally, if the optimum fiber ratio was more than 2.5%, the fiber will not be distributed homogeneously in the soil and γ_{dmax} values will decrease as fiber clusters/clumps will occur. As a matter of fact, in this study, there was a decrease in γ_{dmax} values after 2.5% BF rate. This can be explained by the fact that the fibers increase in volume by absorbing high amounts of water, the fibers replace the heavier soil grains, and the increasing fiber ratio in the soil matrix creates resistance to compression. Thus, compressibility becomes difficult. When the results of this study investigating the effect of BF reinforcement on the compressibility of bentonite clay were evaluated on the basis of the literature, it can be said that up to a certain BF ratio, γ_{dmax} values increase and the soil gains a better compressibility due to the increased integration between the fibers and the soil grains and the improved bond forces.

4. Conclusions

In this study, the effects of BF reinforcement on the compressibility of bentonite were investigated. The γ_{dmax} value of unreinforced bentonite is 12.36 kN/m^3 and the ω_{opt} value is 38.50%. With BF reinforcement of bentonite, γ_{dmax} values increased and reached 12.91 kN/m^3 in the BC + 2.5% BF sample. However, γ_{dmax} values decreased at BF ratios above 2.5%. Depending on the increase in BF ratio, ω_{opt} values decreased up to 2.5% BF reinforcement ratio, and ω_{opt} values increased with BF ratio exceeding 2.5%. With the BF reinforcement used at different rates in bentonite, which is a clay with a length of 24 mm and very high plasticity, 2.5% BF was determined as the optimum value. Thus, it can be said that the BF reinforcement ratio where the best compressibility for bentonite occurs is 2.5% and the compressibility of the soil decreases after this BF ratio. Significant increases in soil strength occur by reinforcing at the optimum fiber ratio determined in current studies. This situation has been clearly stated in similar studies [3 - 7, 11 - 13]. When the optimum BF ratio is used, the ground becomes more durable and less deformable. The results obtained from this study showed that when BF reinforced soils are used as backfill, not only the effect of BF reinforcement on strength but also its effect on compressibility should be considered when determining the BF reinforcement ratio.

5. Author Contribution Statement

There is no conflict of interest with any person/institution in the prepared article. YAT and ZG prepared the study concept and design, performed the experiments, and analysed and interpreted the data.

6. Ethics Committee Approval and Conflict of Interest

There is no need for an ethics committee approval in the prepared article. There is no conflict of interest with any person/institution in the prepared article

7. References

[1] Ö. Ekincioğlu, “Mechanical behavior of cement based composites reinforced with hybrid fibres-an optimum design”, Istanbul Technical University Institute of Science and Technology, 2003.
[2] D. Asi, “Cam elyaf katkılı kompozit malzemelerin aşınma performansının incelenmesi”, Yüksek Lisans Tezi, Afyon Kocatepe Üniversitesi Fen Bilimleri Enstitüsü, Afyon, 2008.
[3] L. Gao, G. Hu, N. Xu, J. Fu, C. Xiang and C. Yang, “Experimental study on unconfined compressive strength of basalt fiber reinforced clay soil”, Adva. in Mat. Scie. and Engin., pp. 1-8, 2015.
[4] C.P. Ndepete and S. Sert, “Use of basalt fibers for soil improvement”, Acta Phys. Polon., vol. 130, no. 1, pp. 355-356, 2016.
[5] T. Özdemir, G.E. Polat, O. Azdeniz, A. Boz and A. Sezer, “Bazalt fiber ve kireç ile güçlendirilmiş kil zeminin dayanım özellikleri”, 2016.
[6] W. Yixian, G. Panpan, S. Shengbiao, Y. Haiping and Y. Binxiang, “Study on strength influence mechanism of fiber-reinforced expansive soil using jute”, Geotech. and Geol. Engin., vol. 34, pp. 1079-1088, 2016.
[7] P.G. Gisymol and K. Ramya, “A study on the effect of basalt fiber in organic soil”, IOSR Jour. of Mech. and Civil Eng. (IOSR-JMCE), vol. 14, no. 4, pp. 13-17, 2017.
[8] A. Boz, A. Sezer, T. Özdemir, G.E. Hızal and O. Azdeniz Dolmacı, “Mechanical properties of lime-treated clay reinforced with different types of randomly distributed fibers”, Arab. Jour.of Geosc., vol. 11, no. 6, pp. 122, 2018.
[9] A. Kenan and A. Özocak, “Effect of basalt fiber addition on shear strength of silty soils”, International Symposium on Natural Hazards and Disaster Management, pp. 918-924, 2018.
[10] V.M. Pandit, C. Rohit, K. Tushar, C. Ayushi, G. Bhushan and C. Deepali, “Study of basalt fiber on compaction characteristics of black cotton soil”, 6th International Conference on Recent Trends in Engineering & Technology (ICRTET), pp. 850-853, 2018.

[11] A. Sungur, M.F. Yazıcı and S.N. Keskin, "Experimental research on the engineering properties of basalt fiber reinforced clayey soil", Europ. Jour. of Sc. and Techn. Spec. Issue, vol. 28, pp. 895-899, 2021.
[12] Z. Gürocak and Y. Aslan Topçuoğlu, "The effect of basalt fiber use on the unconfined compressive strength of low plasticity clay", *Gümüşhane Uni. Jour. of Sci.e and Techno., vol. 13, no. 3, pp. 688-701, 2023.
[13] Y. Aslan Topçuoğlu and Z. Gürocak, "Determination of the optimum basalt fiber ratio for maximum strength in sodium bentonite clay reinforcement", Dicle Uni. Jour. of Eng., vol. 14, no. 3, pp. 479-487, 2023.
[14] A.K. Sabat, "Effect of polypropylene fiber on engineering properties of rice husk ash-lime stabilised expansive soil", *EJGE*, vol. 17, 2012.
[15] V.R. Kulkarni and G.K. Patil, "Experimental study of stabilization of BC soil by using slag and glass fibers", *Jour. of Civil Eng. and Envir. Tech., vol. 1, no. 2, pp. 107-112, 2014.
[16] H. Baruah, "Effect of glass fiber on red soil", Intern. Jour. of Adv. Techn. in Eng. and Sci., vol. 3, no. 1, pp. 217-223, 2015.
[17] R.S. Balagoudra, V. Krishna, H.S. Yaligar, T. Jayasurya and G.C. Shwetha, "Soil stabilization using lime and polypropylene fiber material", Intern. Jour. of Eng. Sci.e and Comp., vol. 7, no. 5, 2017.
[18] A.B. Aravalli, A.M. Hulagabali, C.H. Solanki and G.R. Dodagoudar, "Enhancement of index and engineering properties of expansive soil using chopped basalt fibers", 2017.
[19] G.M. Ayininuola and L.O. Balogun, "Investigation of glass fiber potential in soil stabilization", *Internat. Jour. of Eng. and Adv. Techn., vol. 7, no. 5, 2018.
[20] R.Y. Kale, N.D. Dahake, S.M. Sahu, G.A. Gawande, P.J. Wailker, V.R. Patekar and C.R. Pawar, "Soil stabilization by using basalt fibers", Intern. Jour. of Sci. Res.& Eng. Tren., vol. 6, no. 3, pp. 1931-1935, 2020.
[21] A.S. Kehinde, I.E. Igbokwe, J.E. Okon and B.E. Koku-Ojumu, "Geotechnical properties of lateritic soil stabilized with glass fiber", Intern. Jour. of Eng. Res. & Tech., vol. 9, no. 9, pp. 1078-1081, 2020.
[22] R. Chaudhary, "Enhancing the properties of soil by stabilization technique using basalt fiber", Civil Engineering Department, Delhi Technological University, 2021.
[23] N. Kambale and P.G. Rakkaraddi, "Comparative study of soil stabilization with addition of glass, basalt and polypropylene fibres", Internat. Jour. of Creat. Res. Thoug. (IJCRT)*, vol. 10, no. 9, pp. b674-b681, 2022.
[24] K.W.A. Al-Kaream, M.Y. Fattah and M.K. Hameedi, "Compressibility and strength development of soft soil by polypropylene fiber", Internat. Jour. of GEOMATE, vol. 22, no. 93, pp. 91-97, 2022.
[25] S.N. Hamirani and A. Kumar, "Effects of polypropylene fibers on soil reinforcement", Intern. Res. Jour. of Moder. in Eng. Tech. and Sci., vol. 4, no. 12, 2022.
[26] MTA-Maden Tetkik Arama, *https://www.mta.gov.tr/v3.0/sayfalar/bilgi-merkezi/maden-serisi/img/kaolen.pdf*, 2023.
[27] Y. A. Topçuoğlu, "The effect of different additive materials on the engineering properties of soils", PhD Thesis, Fırat University, Elazığ, Türkiye, 2020.
[28] H. Jamshaid and R. Mishra, "A green material from rock: basalt fiber-a review", The Jour. of the Textile Instit., vol. 107, no. 7, pp. 923-937, 2015.
[29] T. Czigany, J. Vad and K. Poloskei, "Basalt fiber as a reinforcement of polymer composites", Period. Polyt. of Mech. Eng., vol. 49, pp. 3-14, 2005.
[30] K. Singha, "A short review on basalt fiber", *Intern. Jour. of Text. Sci., vol. 1, no. 4, pp. 19-28, 2012.
[31] ASTM D698-12e2, "Standard test methods for laboratory compaction characteristics of soil using standard effort", ASTM International, West Conshohocken, PA, 2012.