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Enhancing the Mechanical Properties of Silty Soils Using Fibers Obtained from Waste Air Filters

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Anahtar Kelimeler

Sürdürülebilirlik,
Atık Hava Filtresi
Lif
Zemin Iyileştirme
Serbest Basınç Dayanımı

Graphical/Tabular Abstract (Grafik Özet)

Adding fibers obtained from waste vehicle air filters significantly improved silty soil samples' unconfined compressive strength and ductility. The optimum fiber content was determined to be 0.75%, yielding a maximum strength increase of 43.6%. This sustainable approach offers an alternative use for non-recyclable air filter wastes in geotechnical applications. /Atık araç hava filtrelerinden elde edilen liflerin ilavesi, siltli zemin numunelerinin serbest basınç dayanımını ve sünekliğini önemli ölçüde artırmıştır. Optimum lif içeriği %0.75 olarak belirlenmiş ve maksimum dayanım artışı %43.6 olmuştur. Bu sürdürülebilir yaklaşım, geri dönüştürülemeyen hava filtresi atıkları için jeoteknik uygulamalarda alternatif bir kullanım sunmaktadır.

Figure A*: Experimental process /****Şekil A:*** *Deneysel süreç*

Highlights (Önemli noktalar)

- *Fibers from waste air filters were successfully utilized in silty soil reinforcement. /Atık hava filtresi lifleri siltli zemin güçlendirmesinde başarıyla kullanıldı.*
- *Optimum fiber content was found to be 0.75%, achieving 43.6% UCS improvement. /Optimum lif oranı %0.75 olarak belirlenmiş ve %43.6 UCS artışı sağlanmıştır.*
- *Sustainable alternative to synthetic fibers with lower carbon footprint. /Sentetik liflere sürdürülebilir ve düşük karbon ayak izine sahip bir alternatif sunulmuştur.*
- *Enhanced ductility and deformation characteristics of treated soil. /İyileştirilen zeminde süneklik ve deformasyon özellikleri artmıştır.*

Aim (Amaç): *To investigate the effects of fibers obtained from waste vehicle air filters on the mechanical properties of silty soil. /Atık araç hava filtrelerinden elde edilen liflerin siltli zeminlerin mekanik özellikleri üzerindeki etkilerini araştırmak.*

Originality (Özgünlük): *This study proposes a sustainable and cost-effective approach by reusing waste vehicle air filters as a fiber additive for soil improvement, an application not widely explored in geotechnical literature. /Bu çalışma, atık araç hava filtrelerinin zemin iyileştirme amacıyla lif katkı maddesi olarak yeniden kullanılmasını önererek, jeoteknik literatürde geniş ölçekte araştırılmamış sürdürülebilir ve ekonomik bir yaklaşım sunmaktadır.*

Results (Bulgular): *The highest unconfined compressive strength increase (43.6%) was observed at 0.75% fiber content, with improved ductility and sustainability benefits. /En yüksek serbest basınç dayanım artışı (%43.6), %0.75 lif içeriğinde elde edilmiş ve süneklik ile sürdürülebilirlik avantajları sağlanmıştır.*

Conclusion (Sonuç): *Fibers obtained from waste vehicle air filters can serve as an effective, sustainable, and environmentally friendly additive for soil improvement applications. /Atık araç hava filtrelerinden elde edilen lifler, zemin iyileştirme uygulamaları için etkili, sürdürülebilir ve çevre dostu bir katkı maddesi olarak değerlendirilebilir.*

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Abstract

In this study, the effect of waste vehicle air filters on the strength of silty soil was investigated by converting them into 6 mm long fibers. With the increase in environmental awareness worldwide and the focus on sustainability in construction applications, waste materials in geotechnical applications have attracted significant attention in recent years. The fibers obtained from vehicle air filters were mixed into the soil at 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 2.50 and 3.00 percent of the dry weight of the soil, and their effects on shear strength parameters were evaluated under laboratory conditions. Unconfined compressive strength tests were performed on fiber-reinforced soil samples, and the results were compared with those of unreinforced soil. Experimental results show that fiber reinforcement increases shear strength, and the optimum fiber ratio for maximum stability improvement is 0.75%. This study reveals that fibers obtained from waste vehicle air filters can be a sustainable alternative to polypropylene and other costly fibers with high carbon footprints. It can also be considered a potential ground improvement additive contributing to reducing waste and improving the mechanical properties of the ground.

Atık Araç Hava Filtrelerinden Elde Edilen Liflerin Kullanılmasının Siltli Zeminlerin Mekanik Özellikleri Üzerindeki Etkisi

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Öz

Bu çalışmada, atık araç hava filtrelerinin 6 mm uzunluğunda lifler haline dönüştürülerek siltli zeminin mukavemeti üzerindeki etkisi incelenmiştir. Dünyada çevresel farkındalığın artması ve buna bağlı olarak sürdürülebilirliğin inşaat uygulamalarının odağı haline gelmesiyle, atık malzemelerin geoteknik uygulamalarda kullanımı son yıllarda önemli bir ilgi görmektedir. Araç hava filtrelerinden elde edilen lifler, zeminin kuru ağırlığının yüzde 0.25, 0.50, 0.75, 1.00, 1.50, 2.00, 2.50. 3.00 oranlarında zemine karıştırılarak laboratuvar koşullarında kayma mukavemeti parametreleri üzerindeki etkileri değerlendirilmiştir. Atık lif takviyeli zemin numuneleri üzerinde serbest basınç dayanımı testleri yapılmış ve sonuçlar, takviyesiz zeminle karşılaştırılmıştır. Deneysel sonuçlar, lif takviyesinin kayma mukavemetini artırdığını ve maksimum stabilite iyileştirmesi için optimum lif oranının % 0.75 olarak göstermektedir. Bu çalışma, atık araç hava filtrelerinden elde edilen liflerin, yüksek karbon ayak izine sahip polipropilen ve diğer maliyetli liflere sürdürülebilir bir alternatif olabileceğini ve aynı zamanda atıkların azaltılmasına ve zeminin mekanik özelliklerinin iyileştirilmesine katkıda bulunan potansiyel bir zemin iyileştirme katkı maddesi olarak değerlendirilebileceğini ortaya koymaktadır.

1. INTRODUCTION (GİRİŞ)

Soils are multi-phase compact particle systems containing soil grains of varying sizes and volumes, as well as water and air. Fine-grained (cohesive) soils generally exhibit low load-bearing capacity, high compressibility, and significant swelling potential. Therefore, improving the cohesion of soils in project sites to enhance their strength will not only reduce project costs but also extend the service life of the structures. Soil improvement refers to the enhancement of soil properties using various engineering methods [1-6]. Geotechnical challenges in soil improvement continue to be an ongoing focus of engineering research and development. Cement and lime binders are frequently used in soil stabilization [7-13]. However, while these methods increase soil

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strength, they are not considered environmentally sustainable or eco-friendly techniques. Like all engineering disciplines, there is an increasing emphasis on using environmentally friendly and sustainable materials in geotechnical engineering. In this context, recycling industrial waste without negatively affecting the environment holds particular importance. Today, soil improvement methods have an essential place in civil engineering applications. Although different techniques are distinguished in terms of cost, ease of application, and the effects they provide, traditional materials such as Portland cement and lime are frequently used as binding agents in soil improvement. Although these materials effectively increase soil strength, they have sustainability limitations [7,9-13]. In recent years, many studies have been conducted in the literature using chemical and mineral additives and fibers to increase the uniaxial compressive strength of clays [13-16]. Studies show that the PP fiber ratio is optimum between 0.4% and 0.6%, and the strength increase varies between 80% and 150%.In recent years, the use of industrial waste in soil stabilization has become an increasingly researched topic to support sustainability in the construction sector. Large amounts of different types of waste are produced yearly, and it is essential to dispose of these materials without harming the environment. In the context of increasing environmental problems, the fact that the additives used in the soil improvement process are both environmentally friendly and obtained from waste materials further increases the value of these materials. From this perspective, using vehicle air filter waste, which cannot be recycled, as fiber additives in the soil improvement process can offer an environmentally sustainable solution.

An air filter is a fundamental filtration system found in most vehicles. It is typically made from paper or fiber material and provides medium-level filtration. Air filters capture large particles from the air, allowing cleaner air to flow into the engine. Due to the materials used in their production, air filters have a high potential for being used as fibers.

In this study, classification tests were conducted to determine the class of the soil used in the experiments. Then, fibers obtained from waste vehicle air filters were added to the soil at the following percentages: 0.25%, 0.50%, 0.75%, 1.00%, 1.50%, 2.00%, 2.50%, and 3.00%. The optimum water content for the standard Proctor energy was determined. Laboratory samples were prepared with maximum dry unit weight and optimum water content in static conditions, and were subjected to uniaxial compression tests. The effect of fibers obtained from waste vehicle air filters on the free compressive strength of silty soils was investigated.

2.MATERIALS AND METHODS (MATERYAL VE METOD)

The aim of this study is to determine the effect of fibers obtained from waste vehicle air filters on the unconfined compressive strength of silty soil when mixed at various ratios with the dry weight of the soil. The laboratory experimental program consists of three stages. In the first stage, the physical properties of the soil and the fibers obtained from waste vehicle air filters were determined, and soil samples along with waste fibers for the experiment were prepared. In the second stage, the maximum dry unit weight and optimum water content of soil mixtures with waste fibers at the specified proportions were determined. In the third stage, unconfined compressive tests were conducted on samples prepared with different fiber ratios at maximum dry unit weight and optimum water content, and the unconfined compressive strengths were measured.

2.1. Used Material (Kullanılan Malzemeler)

The soil samples were collected from 3-4 meters deep at Yukarıbatak Village, located in the Central District of Kastamonu Province. After the organic materials in the 200 kg excess soil sample were removed, the soil was spread on a suitable surface to dry to air-dried conditions. Once air-dried, the samples were mixed to achieve homogeneity, and any existing flocculates were crushed. The soil sample was sieved through a No. 40 sieve to pass particles smaller than the most significant grain diameter. The permanent water content of the air-dried sieved soil sample ranged between 1.0% and 1.05%. The air-dried soil sample was stored in laboratory conditions. The material used in the experimental study is a silty soil containing a low amount of clay. The properties of the silty soil sample, according to ASTM D4318 [18], are presented in Table 1. The soil sample was classified as low-plasticity silt (ML) according to the Unified Soil Classification System (USCS).

Automotive engine air filters are manufactured from cellulose-based paper, synthetic polymers (e.g., polyester, polypropylene), or cotton-based materials. In some filters, these materials are combined in different proportions to form hybrid structures to provide higher durability and filtration performance. This study did not use filters of a specific brand or model for WAFF production, and mixed filters with different properties were evaluated. WAFF obtained from polymer-based air filters has the potential to increase the mechanical strength of the soil thanks to its high tensile strength and flexibility properties. On the other hand, WAFF produced from cellulose-based air filters may have lower durability in terms of long-term stabilization due to its biodegradable properties. This situation may show differences in soil improvement performance depending on the composition of the WAFF.

Table 1. Physical properties of the soil used in experimental study (Çalışmada kullanılan zeminin fiziksel özellikleri)

Property	Value	Symbol and Unit
No 200#	66.5	FC (%)
Liquid limit	32	LL (%)
Plastic limit	24.8	PL (%)
Plasticity index	7.2	IP (%)
Specific gravity	2.54	Gs
Clay ratio	19.9	C (%)
Silt ratio	46.6	M (%)
Sand ratio	33.5	S (%)
Soil class: Low Plasticity Silt (ML)		

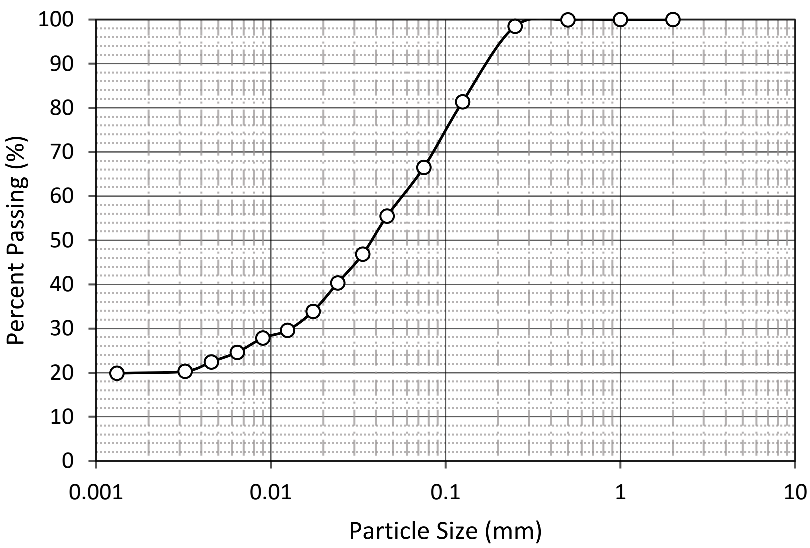

Figure 1. Grain size distribution curve (Dane boyutu dağılım eğrisi)

2.2. Sample Preparation (Numune Hazırlama)

Waste vehicle air filters were collected from the automotive industrial zone in Kastamonu, Turkey, and fibers were produced using a Mapi S-45 brand model grinder with a thickness of 1.5 mm and a height of 10 mm (Figure 2a). The silty soil sample was initially air-dried in the laboratory environment. The air-dried sample was manually ground into a powder. To ensure the samples were prepared homogeneously at the specified moisture contents, the sample was sieved through a No. 40 sieve, suitable for the maximum particle size, to prevent flocculation and remove organic materials (Figure 2b). The fibers obtained from vehicle air filters were mixed homogeneously with the soil using a cement mixer at the rates of 0.25%, 0.50%, 0.75%, 1.00%, 1.50%, 2.00%, 2.50% and 3.00% of the dry weight of the soil. Proctor tests were performed on the soil samples to which WAFF was added by the ASTM D698-12 [19] standard (Figure 3). When Figure 3 is examined, it is observed that the increase in the WAFF percentage causes a decrease in the dry unit volume weight and an increase in the optimum water content.

To prepare samples at the optimum water content determined for each fiber ratio, 2 kg of sieved soil material and WAFF were moistened with distilled (deionized and deaired) water until the targeted optimum moisture content was reached using a sample preparation mixer. In this way, a homogeneous mixture was obtained. The soil samples prepared in 2 kg groups were placed in airtight containers and left to cure at room temperature for 4 hours. This process was repeated for each waste filter fiber ratio and optimum moisture content. The prepared soil samples yielded a homogeneous soil-water mixture with no measurable difference for the desired water contents following this procedure. After the 4-hour curing period, samples were taken from different locations of each airtight container to check the moisture content. It was confirmed that the water contents of all the mixtures in the containers were uniform, with a ±0.5% evaporation/moisture change error margin.

(a) (b) (c)

Figure 2. a) Filter waste fiber, **b**) Silty soil sample, **c)** Sample preparation equipments (a)Atık filtre lifi, b) Siltli zemin numunesi, c) Numune hazırlama ekipmanları)

The prepared soil samples were placed statically using a jack system in a specially designed tank to obtain 50 mm diameter and 100 mm height specimens (Figure 2c). A manually operated hydraulic cylinder jack was used as the compaction device. Plastic cylinders with diameters of 49.2 mm and heights of 180 mm and 80 mm were used as compaction apparatus. The soil was statically compacted in two layers during sample preparation to achieve homogeneous compaction. Scratches were made between the layers to prevent potential segregation. For each waste filter fiber ratio and optimum moisture content, sample weights were recalculated using the soil's volume-weight relationships and then placed in two layers in the sample container and compacted to the desired density. After the experiment, samples were taken from different specimen locations to check the moisture content.

2.3. Test Method (Test Metodu)

In this study, which investigates the effect of waste vehicle air filter fibers on the shear strength of silty soil, the basic geotechnical properties of the silty soil sample collected from Yukarıbatak Village were first determined, and the fiber addition ratio to be used in the experiments was selected based on the literature [9]. The mixture ratios are presented in Table 2. After preparing the mixtures, a standard compaction test was performed according to ASTM D698 [19] (Figure 3). The optimum moisture content and maximum dry unit weight obtained from the standard compaction test results for the mixtures are shown in Table 3.

When Figure 3 is examined, it is seen that the addition of WAFF significantly affects the compaction properties of the silt soil. While the WAFF additive generally causes a decrease in the dry unit volume weight, it tends to increase the optimum water content. Low-rate WAFF additives (0.25%, 0.50%, 0.75%) exhibit a similar tendency to the compaction curve of the soil, causing a partial decrease in the dry unit volume weight while increasing the optimum water content. Increasing the WAFF ratio to 1.00% and 1.50% significantly increases the optimum water content while creating a more visible decrease in the dry unit volume weight. Especially at WAFF content of 2.00% and above, the dry unit volume weight decrease becomes more pronounced, while a significant increase in the optimum water content is observed. This can be explained by the fact that the fibers prevent homogeneous distribution in the soil matrix, prevent intensive compaction, and create a looser structure. It is observed that the effect of WAFF additive on soil compaction properties varies depending on the additive ratio and causes significant changes at high rates.

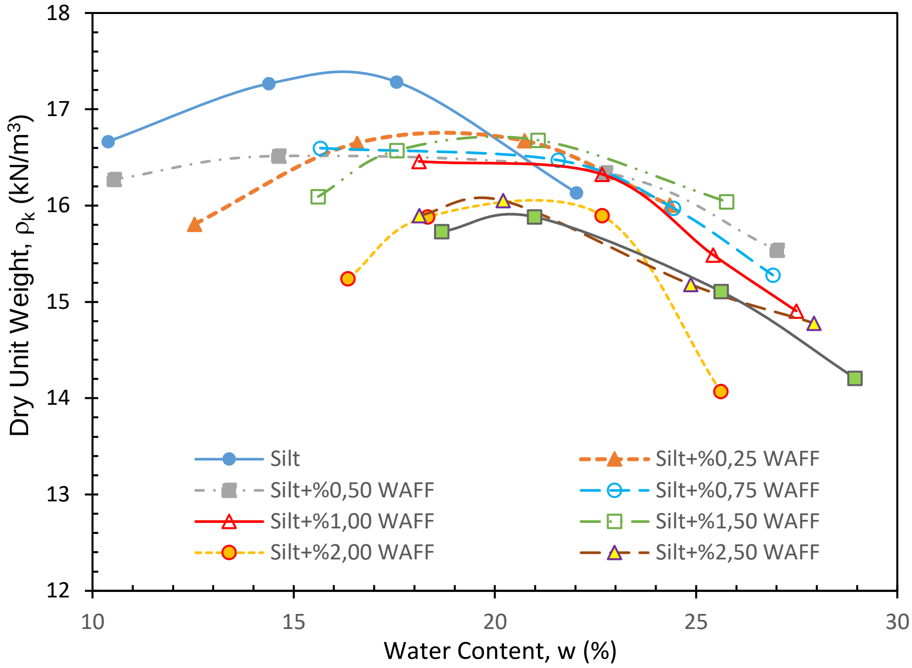

Figure 3. Compaction curves of mixtures (Karışımlara ait kompaksiyon eğrileri)

Table 2. Mixture properties and experimental design (Karışım oranları ve deneysel tasarım)

Mix ID	1	2	3	4	5	6	7	8	9
WAFF %	0	0,25	0,50	0,75	1,0	1,5	2,0	2,5	3,0

Measuring water absorption rate requires an evaluation based on capillary rise and saturation times. The water absorption rate in concrete and mortar is measured according to ASTM C1585 [17]. ASTM C1585 focuses on capillary absorption and can be adapted for use with air filters. In this context, the WAFF was placed in a porous container with its bottom side in contact with water. The weight change was measured at specific intervals. In this study, the water absorption rate (WA) was calculated as the ratio of the mass of absorbed water to the dry mass of the WAFF (Eq. 1).

$$\%WA = (m_w/m_f)x100 \qquad \textbf{(1)}$$

Here, WA is the water absorption rate , m_w is the mass of water absorbed by the WAFF, and m_f is the dry mass of the WAFF.

Table 3. Standard compaction test results (Standart kompaksiyon deney sonuçları)

Mixture ID	Dry Unit Weight kN/m^3	Water Content %
Silt	17,34	16,19
Silt+%0,25 WAFF	16,87	18,84
Silt+%0,50 WAFF	16,80	17,92
Silt+%0,75 WAFF	16,75	18,01
Silt+%1,0 WAFF	16,73	19,93
Silt+%1,50 WAFF	16,71	19,69
Silt+%2,0 WAFF	16,21	19,83
Silt+%2,50 WAFF	16,06	20,02
Silt+%3,0 WAFF	15,89	20,21

Unconfined compressive strength (UCS) testing is a fundamental laboratory method used to evaluate the mechanical behavior of soils and predict their performance under loading conditions. This test is critical in geotechnical engineering as it provides vital information on soil materials' shear strength and stiffness. In this study, UCS tests were conducted to evaluate the mechanical properties of silty soil samples reinforced with WAFF. UCS tests were performed by ASTM D2166 (2016). Prepared soil samples with a standard cylindrical shape of 50 mm in diameter and 100 mm in height were subjected to axial loading using a universal testing machine. The loading rate was set at 0.80 mm per minute to ensure uniform deformation and allow accurate stress-strain measurements. Tests continued until the samples showed visible failure or significant reduction in load-carrying capacity, indicating the ultimate compressive strength of the soil-fiber mixtures. Critical parameters such as peak compressive strength, axial stress at failure, and post-peak behavior were recorded and analyzed during the testing process. The effect of different WAFF contents on UCS values was systematically studied to determine the optimum fiber dosage for maximum strength increase. The results obtained from these tests provide valuable data on the reinforcing effect of WAFF in soil stabilization and its potential as an alternative to traditional fiber reinforcement materials.

3.RESULTS (BULGULAR)

To evaluate the effect of the moisture content and water absorption time of the waste vehicle air filter fiber (WAFF) on the water absorption rate, a water absorption test was conducted on the WAFF. Samples with a natural air-dried moisture content of 5.74% were used. For every 100 g of dry mass, the WAFF was placed in a porous container that allowed water absorption from distilled water. Measurements were taken at intervals of 1, 10, 30, 60, 720, and 1440 minutes. After the water absorption process, the excess water was removed, and the mass of the WAFF was measured. The amount of water absorbed over time was plotted in a graph (Figure 4).

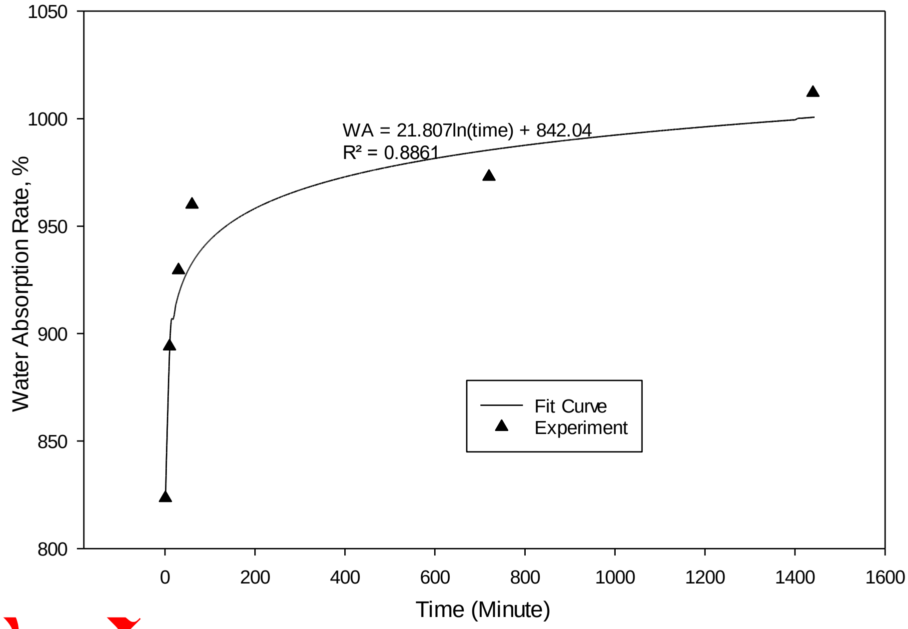

Figure 4. Water absorption of WAFF (Atık araç hava filtresinin su emmesi)

The results of the water absorption test are shown in Table 4. It was found that the WAFF used in this study had a very high water absorption rate, ranging from 823.5% to 1012%. Focusing on the water absorption time, a difference in the absorption rate was observed between 1 minute and 30 minutes, while no difference was found between 30 minutes and 1440 minutes. It can be concluded that the high water absorption capacity of the WAFF is due to the material used and its porosity. Based on this result, it is suggested that the improvement effect would be greater in soils with high water content (e.g., at the bottom of embankments).

A total of 18 unconfined compressive (UC) tests were performed on the samples obtained by static compaction. When classified according to the mixture properties and experimental design, the average values of two similar samples from 9 different scenarios are shown in Table 5.

The unconfined compressive strength test results of the samples are shown in the graphs in Figure 5 and Figure 6.

Table 4. Results of water absorption test of WAFF (Atık araç hava filtresinin su emme sonuçları)

Initial Water Content in WAFF (%)	Time (minute)	Water Absorption %
%10	1	823.5
	10	894
	20	929.5
	60	960
	720	973
	1440	1012

Table 5. Unconfined compressive strength test results (Serbest basınç deney sonuçları)

Mix ID	qu (kPa)	Load (N)	Peak Strain %
1	1346.88	280.38	2.30
2	1649.88	335.51	1.92
3	1719.87	362.96	3.06
4	1934.14	406.65	3.58
5	1689.28	355.24	3.93
6	1599.93	336.97	4.21
7	1663.15	346.50	4.54
8	1640.81	337.16	5.55
9	1703.35	353.29	6.11

Figure 6 shows the unconfined compressive strength (UCS) values of silty soil with the addition of WAFF at weight percentages of 0.25, 0.50, 0.75, 1.0, 1.50, 2.0, 2.5, and 3.0. According to the results, the average UCS of the natural silty soil (reference sample) was measured to be 1346.88 kPa. The average UCS values for the WAFF-added samples were measured as 1639.64, 1719.87, 1934.14, 1689.28, 1599.93, 1663.15, 1640.81, and 1703.35 kPa, respectively.

The percentage changes in unconfined compressive strength (UCS) values of the mixtures, relative to the reference sample, based on the WAFF addition ratio, are shown in Figure 7. The UCS increase percentages for the WAFF-added samples compared to the reference sample were 21.74%, 27.69%, 43.60%, 25.42%, 18.79%, 23.48%, 21.82%, and 26.27%, respectively.

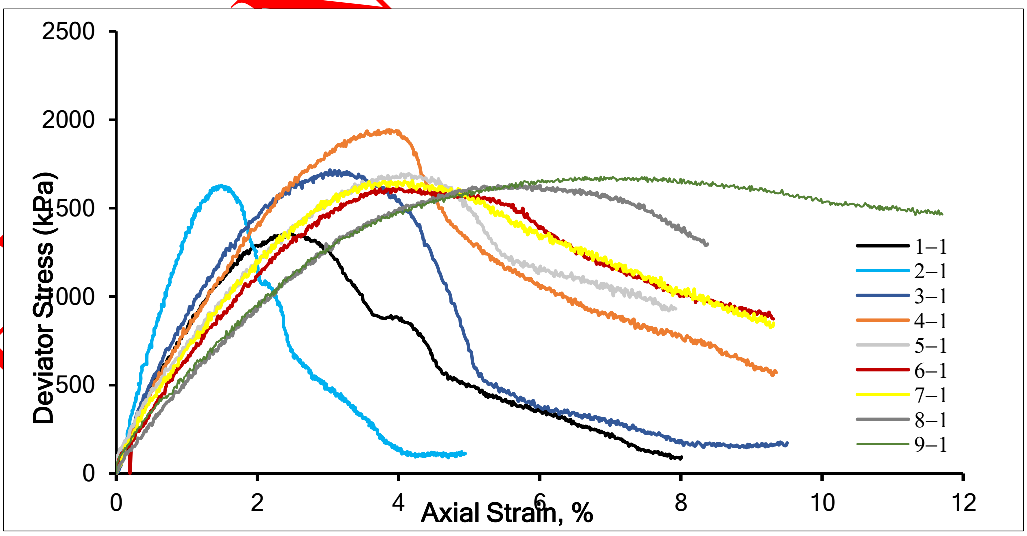

Figure 5. Unconfined compressive strength results of the first samples of the mixtures (Her karışımın ilk numunelerine ait serbest basınç deney sonuçları)

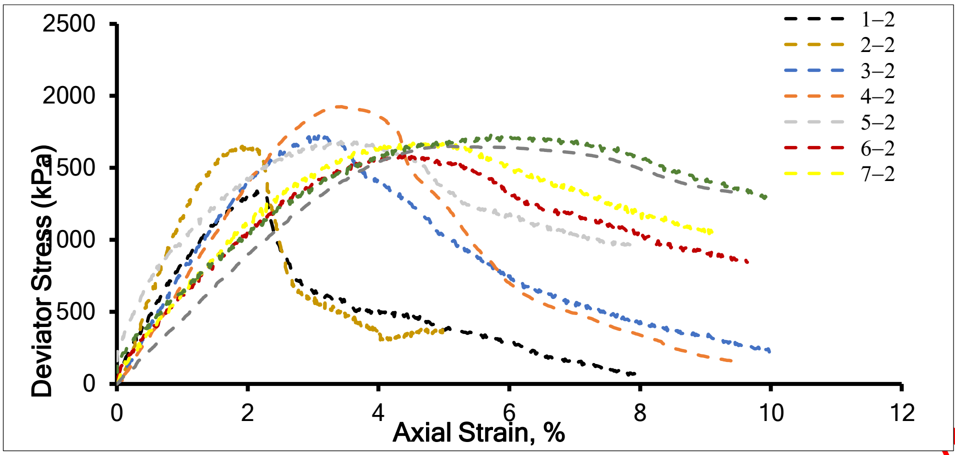

Figure 6. Unconfined compressive strength results of the second samples of the mixtures (Her karışımın ikinci numunesine ait serbest basınç deney sonuçları)

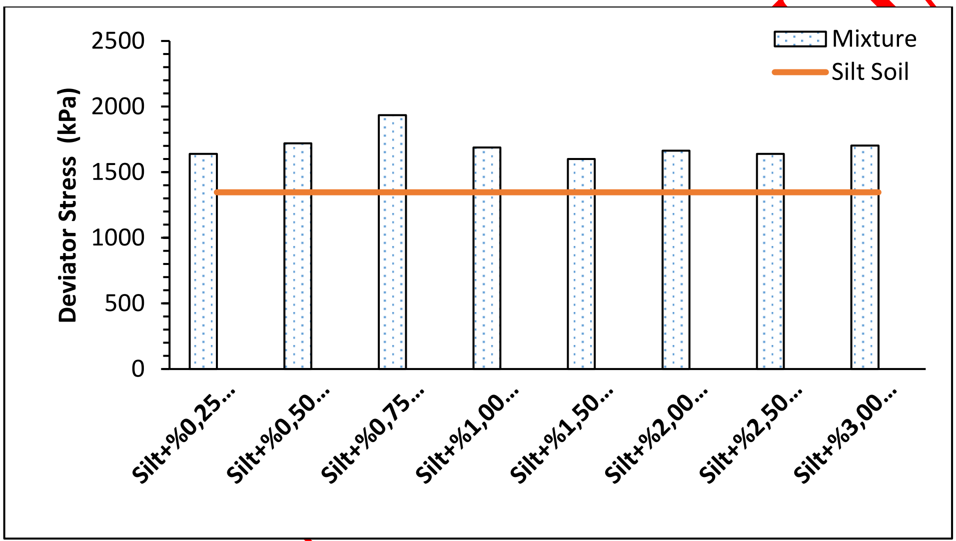

Figure 7. Unconfined compression stress test results of samples (Numunelerin serbest basınç deney sonuçları)

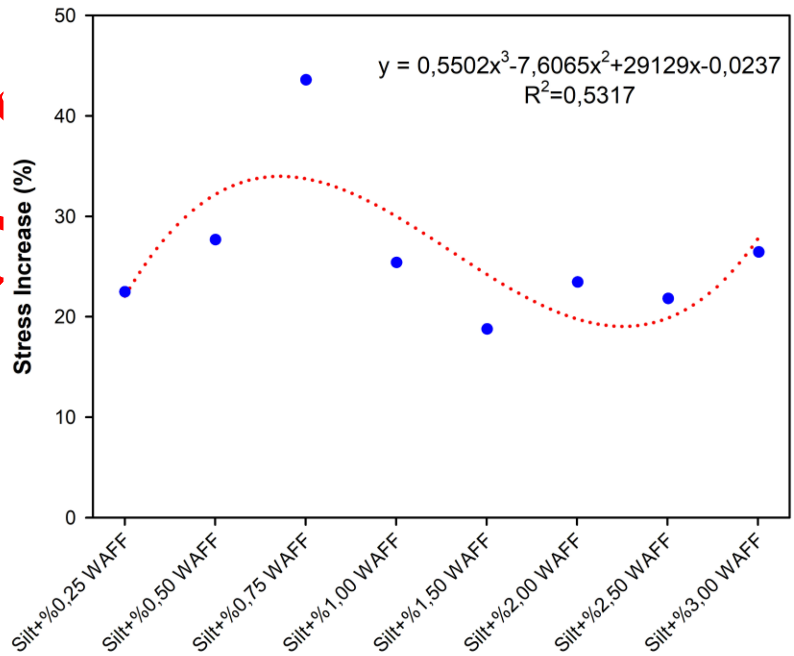

Figure 8. UCS value increase of WAFF additive samples compared to reference sample (Atık araç hava filtresi lif katkılarının referans numuneye kıyasla serbest basinç dayanımı artışı)

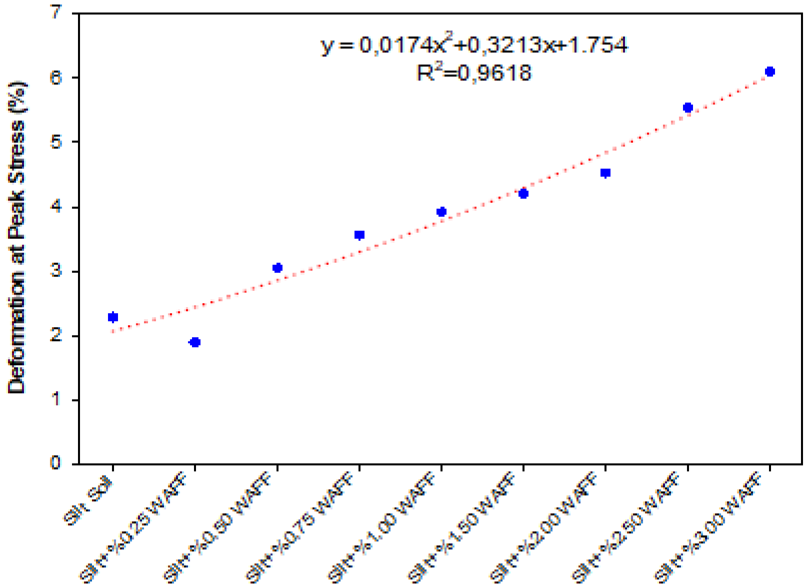

Figure 9. Deformation changes of the samples at peak stress (Numunelerin pik gerilmedeki deformasyon değişimleri)

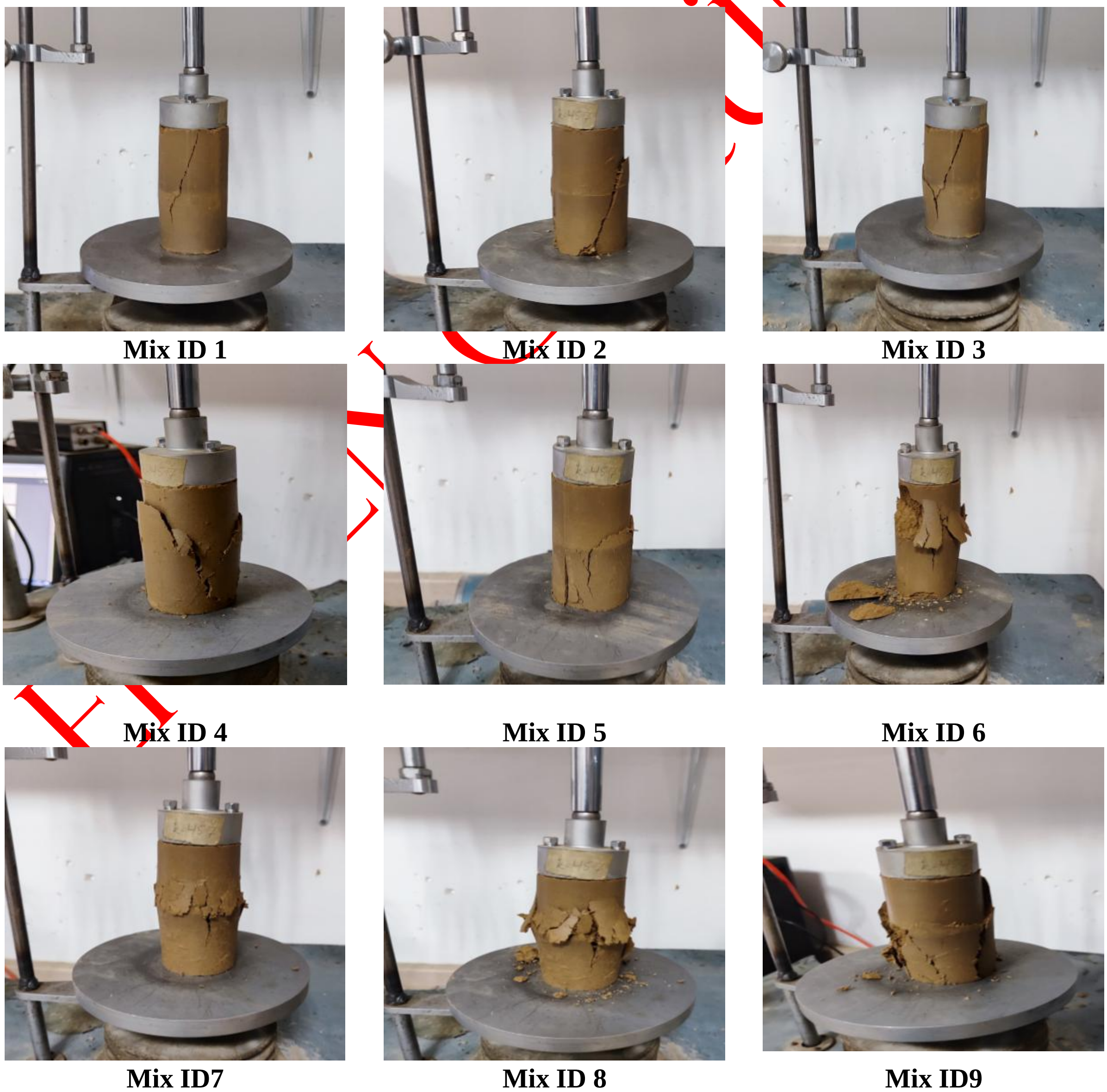

Figure 10. UCS test of samples (Numunelerin serbest basınç dayanım deneyi görüntüleri)

4.CONCLUSIONS (SONUÇLAR)

This study investigates the effects of adding fibers obtained from waste vehicle air filters (at varying rates from 0.25% to 3.00%) on the strength of silty soils. According to the experimental results, the fiber addition significantly increased the unconfined compressive strength of the soils. The maximum strength increase of 43.60% was achieved with a 0.75% fiber content, while the lowest increase of 18.79% occurred with a 1.50% fiber content. The optimum fiber content was determined to be 0.75%, which provided the maximum stability improvement. It was also observed that the fiber addition increased the ductility of the soils and altered their fracture behavior.

The literature states that the optimum usage rate of PP fibers is in the range of 0.4–0.6% and provides an increase in soil strength of 80–150% at these rates. In contrast, the optimum rate for WAFF in this study was determined to be 0.75%, and a maximum strength increase of 43.6% was obtained. In this direction, PP fibers exhibit higher performance in terms of strength increase, and the improvement provided by WAFF is also acceptable in engineering applications.

The waste fibers used in this study offer both environmental and economic benefits. The evaluation of waste vehicle air filters in this way presents a sustainable alternative to synthetic materials, such as polypropylene, which have a high carbon footprint. The use of waste air filters as an environmentally friendly soil improvement additive contributes to both the recycling of industrial waste and the improvement of soil mechanical properties. This method has been shown to be a low-cost and environmentally sustainable approach to soil improvement.

This study has demonstrated the potential of fibers obtained from waste vehicle air filters as a soil improvement additive. Future studies could extend this method to a broader range of applications by evaluating different types of waste materials (e.g., textiles, plastics, or rubber) in a similar manner. Additionally, evaluating the performance of fiber additives in different soil types (e.g., sandy or clayey soils) would enhance the general applicability of the method. Supporting the laboratory experiments with field applications is crucial for testing the practicality of this method in real-world projects. Research on long-term performance, durability, and environmental impacts will also provide more comprehensive information on the sustainability of this method.

DECLARATION OF ETHICAL STANDARDS (ETİK STANDARTLARIN BEYANI)

The author of this article declares that the materials and methods they use in their work do not require ethical committee approval and/or legal-specific permission.

Bu makalenin yazarı çalışmalarında kullandıkları materyal ve yöntemlerin etik kurul izni ve/veya yasal-özel bir izin gerektirmediğini beyan ederler.

AUTHORS' CONTRIBUTIONS (YAZARLARIN KATKILARI)

Mehmet Uğur YILMAZOĞLU: He conducted the experiments, analyzed the results and performed the writing process.

Deneyleri yürüttü, sonuçları analiz etti ve yazım sürecini gerçekleştirdi.

CONFLICT OF INTEREST (ÇIKAR ÇATIŞMASI)

There is no conflict of interest in this study.

Bu çalışmada herhangi bir çıkar çatışması yoktur.

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