Afyon Kocatepe Üniversitesi Fen ve Mühendislik Bilimleri Dergisi

Afyon Kocatepe University Journal of Science and Engineering

AKÜ FEMÜBİD **21** (2021) 045601 (900-907) AKU J. Sci. Eng. **21** (2021) 045601 (900-907)

DOI: 10.35414/akufemubid.888613

Araştırma Makalesi / Research Article

Shear Strength Parameters of Sand Reinforced with Polypropylene Fiber

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Geliş Tarihi: 01.03.2021 Kabul Tarihi: 14.08.2021

Keywords
Shear box test; Shear strength parameters; Sand; PPF; Standard proctor test

Abstract

Improving the engineering properties of soils is one of the common necessity encountered in geotechnical engineering applications. This article investigates the effect of the addition of polypropylene fiber (PPF) on shear strength parameters of compacted sand. Different percentages of PPF (0.5%, 1.0% and 1.5%) by dry weight of the sand were added. Maximum dry density (MDD) and optimum moisture content (OMC) of sand alone and PPF-reinforced sand were measured by standard Proctor compaction test. Subsequently, shear box test was applied for sand and PPF-reinforced sand under three different normal stresses, samples were prepared under the condition of OMC and MDD. The results showed that when the percentage of PPF reaches 1%, the internal friction angle was at maximum value and cohesion is at the minimum value. With increasing percentage of PPF internal friction angle decreased and cohesion increased.

Polipropilen Elyaf ile Güçlendirilmiş Kumun Kayma Mukavemeti Parametreleri

Anahtar Kelimeler
Kesme kutusu deneyi; Kayma mukavemeti parametreleri; Kum; Polipropilen elyaf; Standart proktor deneyi

Öz

Zeminlerin mühendislik özelliklerinin iyileştirilmesi, geoteknik mühendisliği uygulamalarında sıklıkla karşılaşılan gerekliliklerden biridir. Bu çalışmada, polipropilen elyaf (PPF) ilavesinin sıkıştırılmış bir kumun kayma mukavemeti parametreleri üzerindeki etkisi araştırılmıştır. Kuru kuma ağırlıkça farklı yüzdelerde (%0.5,%1.0 ve %1.5) PPF ilave edilmiştir. Katkısız kumun ve PPF ile güçlendirilmiş kumun maksimum kuru birim hacim ağırlıkları (MDD) ve optimum su muhtevaları (OMC) standart Proktor deneyi ile belirlenmiştir. OMC ve MDD şartlarında hazırlanan katkısız kum ve PPF takviyeli kum numuneler üzerinde üç farklı normal gerilme altında kesme kutusu deneyi yapılmıştır. Elde edilen sonuçlar, PPF yüzdesi % 1 olduğunda, içsel sürtünme açısının maksimum ve kohezyonun ise minimum değere ulaştığını göstermiştir. Artan PPF yüzdesi ile içsel sürtünme açısı azalmış ve kohezyon artmıştır.

1. Introduction

Soil stabilization is a method for alteration or preserving the engineering properties of soil with the aim of improving the shear strength properties soils. The materials which will be used in soil stabilization should be very cheap and durable to the harsh environmental situations. From the aspect of view, usage of PPF is such convenient for soil stabilization. Due to durability, low cost (1.87-2.85 $/kg), and their availability, the application of PPF can be taken as an effective solution for so many geotechnical engineering problems (Prabakar and Sridhar 2002).

The key point of soil stabilization is the consideration of environmental pollution as there are so many materials which have a significant effect on strengthening the soil, but they have a negative effect on soil underground water pollution. That means the selected materials for soil stabilization should not have an effect on environment pollution. The PPF is easily recyclable, ecologically friendly material. In addition, among all types of fibers, polypropylene is the lightest, it is lighter than polyester and nylon by 34% and 20% respectively. PPF has a lower specific gravity ($G_s \cong 0.91$) compared to the other type of fibers, thus giving the greatest volume for a given weight and this high yield of PPF means that it offers good volume and good coverage while being lighter. It is more important to take care of the selected materials to have resistance to bacteria and microorganisms in order to maintain its nature for a long period of time. Fortunately, PPF are not attacked by bacteria or microorganisms like synthetic fibers of nylon, acrylic and polyester. The other reason for choosing polypropylene is the effect of temperature changes, it remains flexible at temperatures around -55°C. PPF has low water absorption, it is about 0.3% by weight when immersed in water for about 24 hours. It has excellent resistance to acids and alkalis with the exception of chlorosulfonic acid and concentrated sulfuric acid and some oxidizing agents of the alkali family. (Net. Ref.1).

Randomly distributed PPF in the soil cause to increase the ductility of reinforced soil compared to unreinforced, and by adding the fiber content in the soil, the tensile force in the soil matrix is increased. The most popular applications of the PPF in the geotechnical engineering are in the construction of embankment, backfill, foundation, sub-base and slope stability problems (J Li and Ding 2002, Tang *et al.* 2007, Unnikrishnan *et al.* 2002). Ibraim and Fourmont (2007) used direct shear and compaction tests to investigate the effect of the addition of PPF on the shear strength properties of very fine sand. To this end, they added various percentages of PPF to the fine sand, and tests were performed with different relative densities of sand and PPF-reinforced sand. They found that the strain which is needed to reach the peak was increased, as well as the maximum shear strength of the PPF-reinforced sand increased. Attom and Al-Tamimi (2010) reported the effect of two types of PPF on shear strength of sandy soil at four various PPF content (0%, 1%, 2%, 3% and 4%) and researchers changed length of the fiber, thickness of the fiber and (L_f/D_f) ratio. The outcomes of the experimental study indicated that when the greater aspect ratio of the two types of PPF is used, the shear strength characteristics of PPF-reinforced soil gets improved well. The effect of short discrete PPF on soil properties was investigated by Jiang *et al.* (2010), according to their results, they stated, the cohesion intercept and internal friction angle of unreinforced soil are lower than PPF-reinforced soil. Anagnostopoulos *et al.* (2013) executed several shear box tests to examine the influence of PPF inclusions on the shear stress-strain behavior of sand for different PPF content, different sand grain size and relative densities. According to their experimental results, they noticed that the relative density, the percentage of fineness, and the PPF content have a considerable impact on the improvement of peak and residual shear strength of PPF-reinforced sandy soil. Hamidi and Hooresfand (2013) implemented a conventional triaxial test to study the influence of PPF on the behavior of cement-treated sand. It has been found that the inclusion of PPF changes the brittle behavior of cement-treated sand to ductile, moreover, its peak and residual shear strength increase. Noorzad and Zarinkolaei (2015) used several shear box tests and unconsolidated undrained triaxial tests to explore the influence of PPF on the shear strength characteristics of sand. The percentages of PPF and fiber length used in the study were (0%, 0.25%, 0.5% and 1%) and (6.0, 12.0 and 18.0) mm respectively. They discovered that by increasing the PPF content and fibers length, shear strength of the sand increased. They found the optimum percentage of PPF content to be 1% of dry weight of the sand and the fiber length to be 18 mm. Babu *et al.* (2016) performed shear box test on reinforced sand with PPF, based off of the experimental results, they revealed that the shear resistance of the sand reached the maximum value at 0.75% PPF content. Liu *et al.* (2017) investigated sandy soil reinforced with a different mixing ratio of PPF, Based on the results, they stated the inclusion of PPF improves shear strength and dilation. Darvishi and Erken (2018) studied the influence of the inclusion of PPF on shear resistance parameters of sand using the shear box test with various percentages of PPF, samples were prepared at a relative density of 65%. The experimental outcomes presented that the addition of PPF has an influence on the properties of shear resistance of the sand. A significant improvement was observed in the growth of sand resistance parameters with increasing of PPF content in the soil matrix. Kaushik and Sharma (2019) carried out several cyclic CBR tests to study the effect of waste PPF on the resilient modulus of clay. The results showed that reinforcing clay with PPF increased its resilient modulus. It has been found that the optimum content of waste PPF to be 0.4% by dry weight of soil. Rosman and Chan (2020) studied the impact of the inclusion of PPF on the consolidation and compressibility properties of dredged sea soil. As a consequence, they suggested that 0.5% of PPF by dry weight of the soil can be used for improving the compressibility of this kind of soil.

The objective of this article is to study the shear strength parameters of high friction sand after the addition of different percentages of PPF. For this purpose, a set of shear box tests were carried out on the sand alone and PPF-reinforced sand with various percentages of PPF (0.0%, 0.5%, 1.0%, and 1.5%) by dry weight of sand, and the average fiber length used in this study was about 18 mm. Samples for the shear box test were prepared under conditions of MDD and OMC.

2. Materials and Method

The soil which used in the experiments was river sand with uniform gradation taken from the Murat River in Elazığ at Turkey. The PPF were provided by the geotechnical staff of Firat University. In Figure 1 the sand and PPF can be seen. The sand has a high friction angle, its angle of repose is 35° as shown in Figure 2. The gradation of sand had been obtained through a sieve test that was carried out according to ASTM D422-63, Figure 3 illustrate the grain size distribution curve of the sand. According to the sieve analysis results, the percentage of fine is 4.69%, sand fraction 89.60% and gravel fraction 5.71%. The specific gravity of sand was determined in the laboratory based on ASTM D854-14. The maximum and the minimum dry densities for sand were measured by experiment in agreement with ASTM D4254-91. The measured index parameters of the sand are listed in **Hata! Başvuru kaynağı bulunamadı.** According to the unified soil classification system (USCS), the sandy soil used in this study was grouped as being well-graded sand (SW). The physical properties of PPF are also summarized in **Hata! Başvuru kaynağı bulunamadı.**

Table 1. Index properties of the sand

Property	Value
D_{10}, D_{30},D_{50}, D_{60} (mm)	0.19, 0.5, 0.9, 1.2
Uniformity Coefficient (C_u)	6.315
Curvature Coefficient (C_c)	1.096
(USCS)	SW
Specific Gravity (G_s)	2.74
MDD, ρ_{dmax} (gr/cm^3)	2.03
Min. dry density, γ_{kmin} (gr/cm^3)	1.49
Maximum void ratio (e_{max})	0.839
Minimum void ratio (e_{min})	0.350

Standard Proctor test was applied according to ASTM D-698 to find MDD and OMC of sand and PPF-reinforced with percentages introduced previously. The shear box test according to ASTM D-3080 was carried out on the samples of sand and PPF-reinforced sand to determine their shear strength parameters. Specimens for the shear box test with dimensions 6.0x6.0x2.0cm were organized under conditions of MDD and OMC. All tests were performed with strain-controlled shear box test machine with constant shearing rate 1.0 mm/min. The shear stress and horizontal displacement were recorded.

(a)

(b)

Figure 1. (a) Sandy soil, (b) polypropylene fiber.

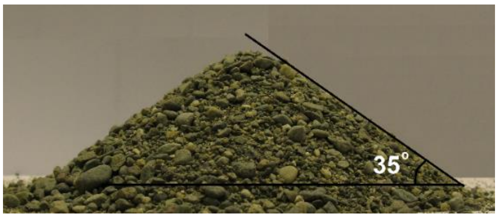

Figure 2. The angle of repose of the sand.

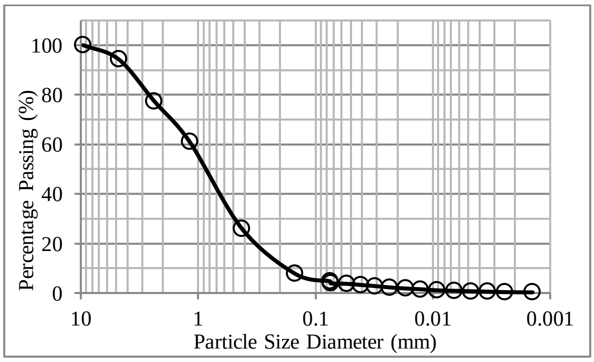

Figure 3. The grain size distribution curve of the sand.

Table 2. Physical properties of the PPF (Li *et al.* 2014)

G_s	0.91
Length of the fiber, L_f (mm)	18
Thickness or diameter of fiber, D_f (mm)	0.03
Aspect Ratio (L_f/D_f)	600
Density (kN/m^3)	8.927
Tensile strength (MPa)	350
Elasticity modulus (MPa)	3500
Fusion point (°)	165

3. Results and Discussion

From the Proctor compaction tests, the OMC and MDD of sand and PPF-reinforced sand mixtures were measured and are given in Figure 4 and 5. it was noticed that by increasing the content of PPF, the MDD decreases while the OMC increases.

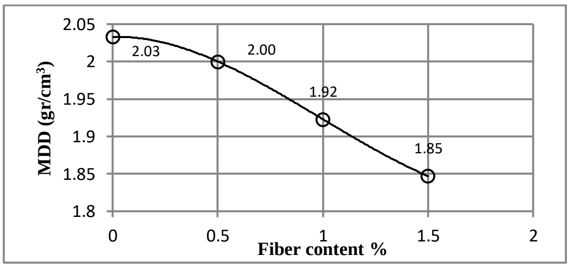

Figure 4. Maximum dry density versus fiber content.

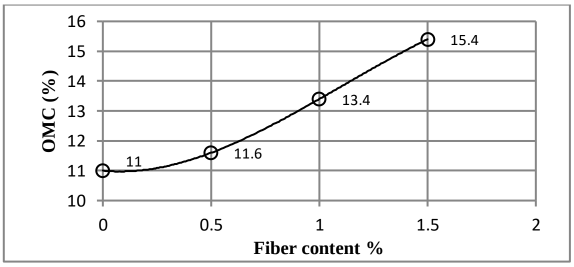

Figure 5. Optimum moisture content versus fiber content.

The relationships between the shear stress corresponding to the horizontal displacement for three different axial stresses for sand and PPF-reinforced sand with different percentages of PPF are given in Figure 6. through Figure 8. It can be seen that by adding more PPF content, the ductility of the PPF-reinforced sand increases. In addition, the variation of the peak shear stress corresponding to the different axial stresses for different PPF content is shown in Figure 9. It can be concluded that by adding the PPF content, the slope between shear stress and axial stress becomes steeper until the percentage of PPF reaches 1%. Thus, the value of the internal friction angle of PPF-reinforced sand gets higher while the cohesion intercept reduces. Moreover, when the percentage of PPF becomes more than 1%, the slope of shear stress and axial stress changes to gentle. Consequently, the value of the internal friction angle of PPF-reinforced sand gets lower while the cohesion intercept increases slightly.

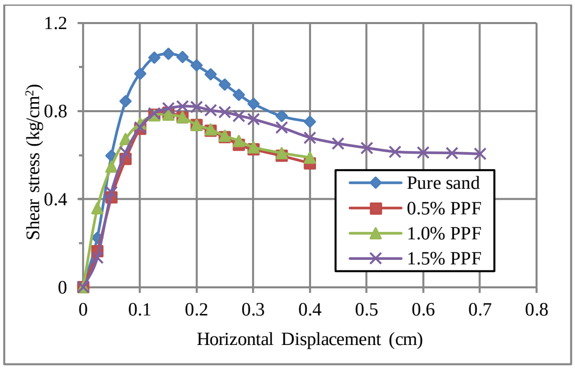

Figure 6. Shear box test results for sand and PPF-reinforced sand at a normal stress of 0.556 kg/cm2.

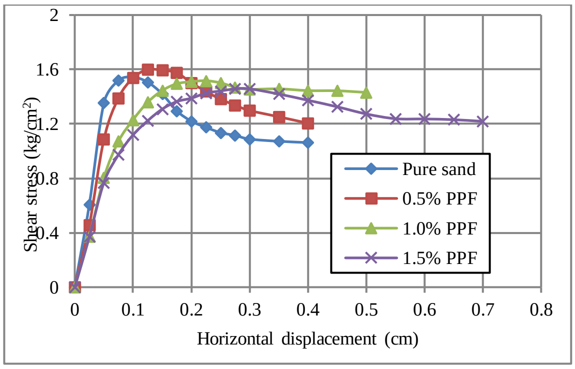

Figure 7. Shear box test results for sand and PPF-reinforced sand at normal stress of 1.111 kg/cm^2.

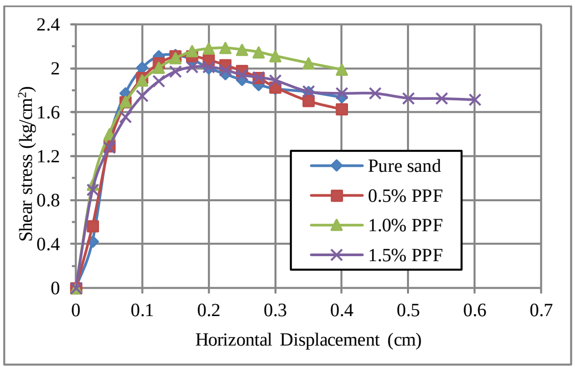

Figure 8. Shear box test results for sand and PPF-reinforced sand at normal stress of 1.667 kg/cm^2.

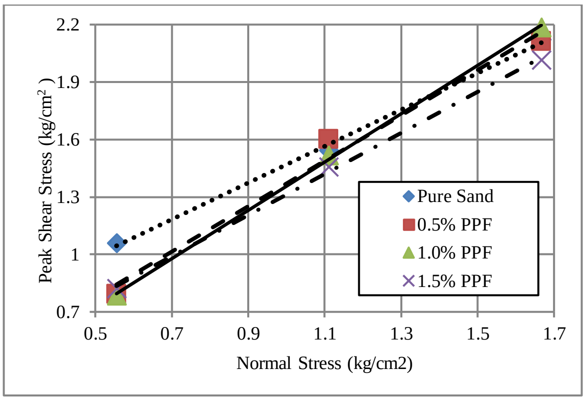

Figure 9. Peak shear stress versus normal stress for different PPF content.

Figure 10. displays the change of the internal friction angle of sand with different percentages of PPF. It can be clearly seen that the angle of internal friction of the PPF-reinforced sand reaches the maximum value when the content of PPF is increased 1.0% by the dry weight of the sand. However, when the percentages of PPF is increased more than 1.0% the internal friction angle starts to reduce. Based on the outcomes of this study, adding a certain amount of PPF can improve the friction angle of the sand. In this study, optimum PPF content was to be 1.0% for the sand which prepared at Proctor density. The cohesion value also changes with increasing PPF content as shown in Figure 11. It is obvious that the cohesion value of the PPD-reinforced sand reduces while the PPF content up to 1.0%. Nevertheless, when the percentages of PPF is increased more than 1.0% the cohesion of the sand begins to get higher slightly. According to the results of this study, it can be said that mixing PPF with the dense sand cannot improve its cohesion value. This decrease of cohesion was also observed by (Anagnostopoulos *et al.* 2013).

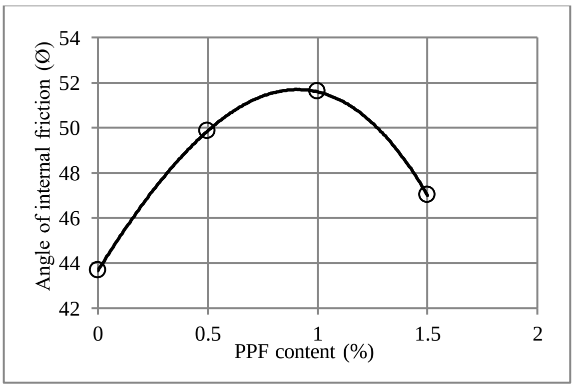

Figure 10. Angle of internal friction versus different PPF content.

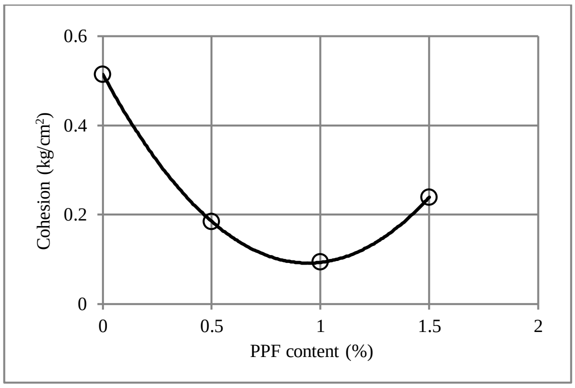

Figure 11. Variation of cohesion intercept versus different PPF content.

Contrary to the results of this study, some researchers have found the optimum percentage of PPF which increases the two parameters of soil shear strength, the angle of internal friction and cohesion (Darvishi and Erken 2018, Jiang *et al.* 2010, Noorzad and Zarinkolaei 2015). Also, different optimum percentages of PPF for improving the internal friction angle and the cohesion of the sand in the literature (Babu *et al.* 2016). It is observed from the published studies that the optimum percentage of PPF for improving the shear resistance of soil relies on many factors like kind of the soil test, soil type, length of PPF, the aspect ratio of PPF, soil particle size distribution and soil relative density. (Anagnostopoulos *et al.* 2013, Attom and Al-Tamimi 2010, Devi and Jempen 2016, Mali and Singh 2014,Noorzad and Zarinkolaei 2015). Presents the results of some studies carried out by different researchers on the impact of the addition of PPF on the shear strength properties of the soil. It can be seen clearly from the table that optimum percentage of PPF is varying from 0.1% to 1%. In this study, optimum PPF percentage also found as 1%. From, it is conspicuous that the results of this study are compatible with the results found by (Noorzad and Zarinkolaei 2015).

Table 3. The optimum percentage of PPF for improving the shear strength properties of the soil found by some researchers.

Reference	Soil type	The optimum Fiber length (mm)	The optimum percentage of PPF (%)	Relative Density of soil (D_r %)	Unreinforced soil		PPF-reinforced soil	
					Internal friction angle (°)	Cohesion (kg/cm²)	Internal friction angle (°)	Cohesion (kg/cm²)
Jiang *et al.* (2010)	Clayey soil	15	0.3% by weight	Dense	27°	0.61	33°	1.15
Anagnostopoulos *et al.* (2013)	Sand	12	0.1% by volume	Very dense	40°	0.24	47°	0.15
Noorzad and Zarinkolaei (2015)	Sand	18	1% by weight	D_r=70%	40°	0	48°	0.19
Liu *et al.* (2017)	Sand	18	0.2% by weight	D_r=70%	30°	0.71	35°	0.82
Darvishi and Erken (2018)	Sand	15	0.5% by weight	Dense	37°	0	41°	0.19
This study	Sand	18	1% by weight	Proctor Density	44°	0.51	52°	0.24

4. Conclusion

A set of standard Proctor compaction tests and shear box tests were implemented to examine the effect of inclusion of PPF on shear resistance properties of dense and high friction sand, the following conclusion can be made:

- ✓ The MDD of PPF-reinforced sand reduces with increasing PPF content, also the OMC of the sand gets higher with an increase in the content of PPF because of an increase in the specific surface area of PPF and it absorbs the portion of water.
- ✓ When the content of PPF reaches 1% by weight, the value of the internal friction angle of PPF-reinforced sand reached maximum, after that it starts to decrease.

- ✓ The cohesion of PPF-reinforced sand decreases until the percentage of PPF reaches 1%, and then increases slightly with increasing PPF content, but it is still lower than that of unreinforced sandy soil. From this study, it appears that PPF cannot improve the cohesion sand. However, the cohesion is not important when sandy soil concern.
- ✓ It is possible to improve the friction angle of the sand by adding a low percentage of PPF, this improvement can be used in the application of geotechnical engineering such as backfill material behind the retaining wall, construction of embankment, sub-base and slope stability etc.

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