Research Article

Impact of Carbon Fibre on Mechanical Characteristics of Clayey Soil Under Several Normal Stress

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Abstract
Geotechnical engineering requires the use of ecologically acceptable, long-lasting, and effective solutions to fortify clayey soil. The mechanical behavior of clayey soil strengthened with carbon fibres (CFs) was studied in this work. Soil specimens were subjected to uniaxial compression strength tests at their optimal moisture content (OMC). The impacts of CFs length and percentage on the strengthened soil specimens' shear resistance, and stress-strain curve behavior were investigated. The effect of CFs on specimen cohesiveness and angles of internal friction was also investigated. The results showed that adding CFs to clayey soil can increase its shear resistance and cohesiveness greatly. Because the fibres can be spread easily in soil samples and had a suitable length that can generate an interlaced network among soil grains that restricted soil movement once exposed to external stresses, it is presumed that utilizing three percent of CFs weight content had six millimeters length could indeed give the highest impact on resistance development among all the specimens.

Keywords: Clayey Soil, Carbon Fibres, Uniaxial Compression Strength, Shear Resistance, Mechanism of Failure, Angles of Internal Friction.

1. Introduction
During the building of foundations, road pavements, and slopes on softly clayey soil, many challenges such as excessive or uneven settling and inadequacy of load capacity might arise. Soil strengthening is a geotechnical engineering technique used to enhance the performance of dumpsite covers, heal shallow slope failures, and reinforce roadbeds, and similar. Cement, asphalt, lime, chemicals, and recycled materials have been once routinely used to enhance the mechanical behavior of softly soil. These admixtures, on the other hand, have been deemed to be both ecologically beneficial and long-lasting. (Terashi, 1980) investigated the behavior of cement-treated soil pile, and their findings revealed that the cement's reinforcing effectiveness degraded with time. (Quang and Chai, 2015) conducted permeability and consolidation tests on clayey samples treated with cement and lime. The findings revealed that adding a particular quantity of cement to the soil could increase the production of cementation products that plug the interaggregate gaps, lowering soil porosity. Low porosity, on the other hand, may delay the release of excess pore pressure held in the soil, resulting in local shear failure and jeopardizing the structure's integrity, particularly under cyclic stress circumstances. As a result, geotechnical engineers must devise new and more effective ways to fortify clayey soil. Many investigations on fibre-strengthened soil have been conducted (Consoli et al, 2013; Li et al, 2018; Liu et al, 2020) because the interface friction among fibre and

soil could enhance the mechanical characteristics of soil. (Mirzababaei et al, 2020) used a sophisticated X-Ray CT facility to explore the process of fibre re-orientation, locative, deformation, and tortuosity in a randomly fibre -strengthened clayey soil at diverse phases of stress. Their findings revealed a significant amount of anisotropic fibre arrangement (both in spatial position and angles in the XZ&XY directions), which is amplified by stress. Fibre parameters such as sort, incorporation percentage, length, length/diameter ratio, young's modulus, and direction are major influencing elements for soil strengthening (Hejazi et al, 2012; Amir-Faryar and Aggour, 2012; Yoo et al,2017; Boz and Sezer, 2018). Carbon fibres (CFs) has a higher tensile resistance and young's modulus than traditional fibres like polypropylene (Pp). It also has high durability and a moderate biodegradation rate, making it ideal for soil strengthening. Carbon fibres have recently gained increased interest in civil engineering due to its extraordinary resistance, relatively wide length/diameter ratio and very good natural resistance to degradation. Nevertheless, the majority of research to date have mostly focused on the use of CFs in cement or concrete elements. Only a few researches have been published on the use of CFs for soil enhancement. Previous research revealed that randomly dispersed short CFs could efficiently strengthen non-cohesive soil (Cui et al, 2018). Finer soil grains, according to (Ranjan et al,1996), could establish stronger interfacial adhesion with fibres due to a lower likelihood of slip failure than coarser soil grains. As a result, clayey soil expected to be able to form strong links with carbon fibres. Furthermore, because carbon fibres (CFs) have a smaller diameter (seven micron) than polypropylene fibres (PpFs), the length/diameter ratio of CFs is substantially greater. CFs are selected to strengthen soil since it has been claimed that the value of strengthened specimens rises gradually with increasing fibre length/diameter ratio for a particular fibre volume fraction (Yoo et al, 2017; ASTM Committee D2487-17 on Soil and Rock, 2017). Although PpFs is often less expensive than CFs, CFs is thought to be more effective since a tiny amount of CFs can result in significant soil improvement (Cui et al, 2018). As a result, the overall expense is not large when compared to the lower dose required for soil stabilization. Additionally, as fabrication technology improves, the cost of CFs is likely to decrease.

The purpose of this work is to see how CFs affects the mechanical characteristics of clayey soil. The impact of fibre lengths (three, six, and ten millimeters) and volume fractions (one, , and two three percentage by weight as a replacement of soil) on the mechanical behavior of soil samples was investigated using a set of direct-shear tests and uniaxial-compression tests. The mechanism of failure, ultimate resistance, and stress-strain curve behavior of the CFs strengthened soil samples were all thoroughly investigated and discussed.

2. Experimental Work

2.1 Materials and Method

The essential objective of this work is to assess the strengthening impacts of CFs of several lengths and volume fractions on mechanical features of clayey soil. Several experimental tests have been conducted which could be categorized into three categories:

• first category: water content & density relation test, direct-shear test under one hundred, two hundred, three hundred, and four hundred kilopascal standard stress and uniaxial compression test have been implemented on plane soil samples as reference samples.

• Second category: water content & density relation test, direct-shear test has been implemented on strengthened soil samples with several volume fractions of CFs (one, two, and three percent) and lengths (three, six, and ten millimeters) under one hundred, two hundred, three hundred, and four hundred kilopascal standard stress.

• Third category: uniaxial compression test implemented on strengthened soil samples with different volume fractions of CFs (one, two, and three percent). In this category, the utilized fiber length were only six millimeters.

2.1.1 Carbon Fibres (CFs)

China-made and locally available synthetic carbon fibres have been utilized as a strengthening material in the current experimental study (Figure 1). It has a diameter of seven micron and three different lengths (three, six, and ten millimeters). The tensile resistance is 4900 MPa, while its elongation, Young's modulus, and density are 2.1%, 230000 MPa, and 1.8 g/cm3, consecutively. According to the above excellent features, a small proportion of CFs was expected to efficiently improve the characteristic of soil.

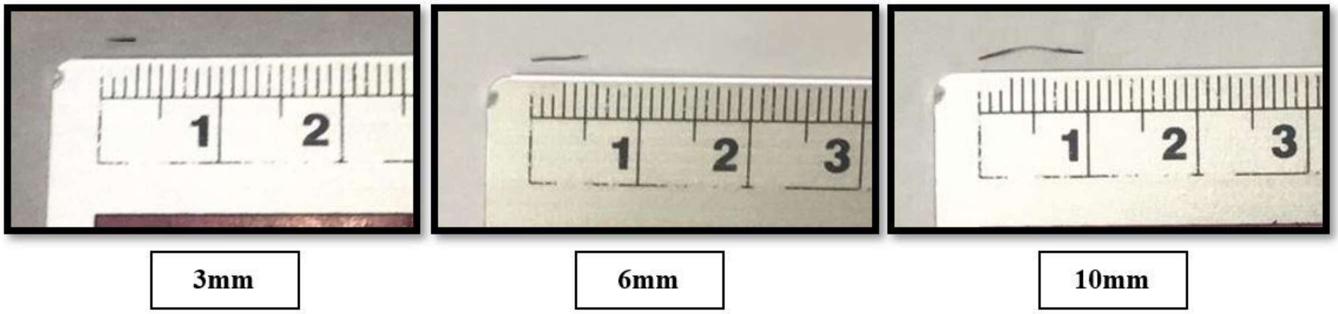

Figure 1. Scale of Utilized Carbon Fibers.

2.1.2 Clayey Soil Samples

The soil employed in this work taken from Raparin excavation site, in the Sulaymaniyah governorate of the Kurdistan region of Iraq. The soil specimens have been collected from a depth of two meter below the level of natural ground and wrapped in plastic bags to prevent water evaporation while transporting to the laboratory for exanimating. Table 1 demonstrates the main features of the collected soil samples and the corresponding specifications that were adopted in the evaluation of the features. According to the unified soil classification system (ASTM, D2487, 2017) and the distribution curve of grain size (ASTM, D422, 2007), which is demonstrated in Figure 2, the soil could be classified as clayey soil. Figure 3 demonstrates the relation between water content and density, and it could be seen from the relation that the OWC equal to 27% with the corresponding MDD of 1510 kg/m3.

Table 1. Physical Features of Collected Plain Soil Samples.

Features		Values	Specifications
MDD		1510 kg/m3	ASTM D 698
OMC		27%	ASTM D 698
Gs		2.6	ASTM D 854
Atterberg limits	LL	63.48%	ASTM D 4318
	PL	29.13%	
	PI	34.35%	

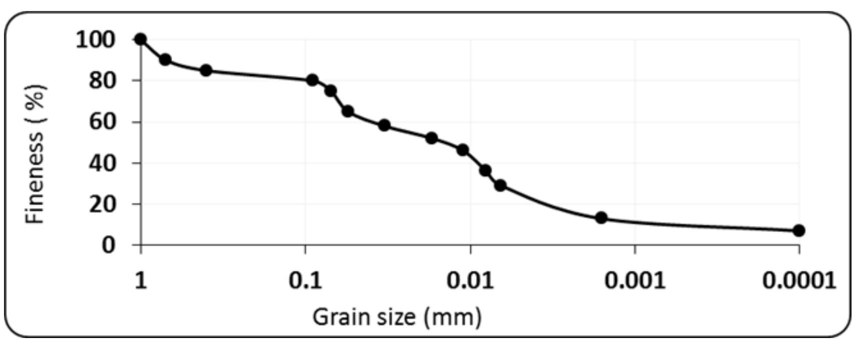

Figure 2. Grain size distribution of utilized soil.

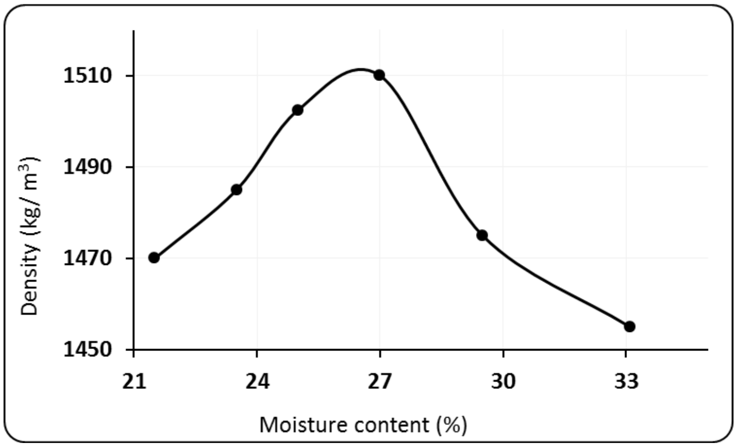

Figure 3. Relation Between Moisture Content & Density of Utilized Soil.

2.1.3 Preparation of Samples

The samples could be taken in their natural moisture content (MC) However, the natural MC is typically low, which might lead to low soil plasticity, which prevents the homogeneous dispersion of fibres in the soil. The following procedure was used to solve this problem. The CFs have been blended with dry soil in a pan after being disseminated in deionized water (DI water). Considerable care has been given to assure that the CFs have been evenly dispersed throughout the mixture of soil. After that, the combination has been dried for twenty-four hours at one hundred and five degrees Celsius in an oven. Once done, the combination was crushed into powder and then whiskered with DI water (decided by the ideal moisture content) and maintained in a closed plastic bag for twenty-four hours to ensure that the moisture has been evenly distributed throughout the samples. Subsequently, the direct shear and uniaxial compression tests have been conducted according to ASTM D3080/D3080M and ASTM D2166/D2166M, consecutively, at a loading rate of 0.8 millimeters per minute.

3 Result and Discussion

3.1. Impact of Carbon Fibres Length and Volume Fraction on Shear Resistance Parameters

In comparison to the reference sample (natural plain soil sample), Figure 4 demonstrates the association between shear resistance and normal stress for samples with varying contents of three millimeters of CFs (volume fractions evaluated as a percentage by weight). The shear resistance appears to grow as the CFs concentration increases but begins to drop when more than two percent of CFs are applied, as shown in the graph. The samples with three percent of CFs had the maximum shear resistance among the three millimeters CFs samples. When exposed to normal stresses of one hundred, two hundred, three hundred, and four hundred kilopascals, their ultimate shear resistances were 85, 125, 170, and 214 kilopascals, consecutively. The impact of CFs on the resistance parameters is seen in Figure 5. The cohesiveness of samples containing two percent of CFs reached 41.1 kilopascals, which is 105.5 percent greater than the reference sample.

The effect of CFs on angles of internal friction, on the other hand, was not substantial, with just a twenty percent enhancement was observed compared with the reference sample. When the samples were strengthened with more than two percent of CFs, both the cohesiveness and the angles of internal friction declined significantly. In most cases, adding CFs of three millimeters length to the soil sample would not result in a substantial improvement in tensile resistance.

The shear resistance of samples improved with increasing CFs concentration when CFs of six millimeters length was utilized, as illustrated in Figure 6 The higher amount of CFs which has length of six millimeter in the sample, the better the reinforcing impact on shear resistance appears to be (which is similar behavior in the case for CFs which has length of three millimeter). The impact of six millimeters of CFs on shear resistance and resistance characteristics is often greater than that of three millimeters of CFs. The angles of internal friction of samples with three percent content of CFs which has length of six millimeter was 24.6, exhibiting a 25.5 percent growth over reference samples, as illustrated in Figure 7. Their cohesiveness also improved dramatically, from twenty kilopascal to ninety-six kilopascal (an increase of three hundred and eighty percent). Both Figure 5 and 6 show that when the CFs proportion is increased from two percent to three percent, the reinforcing effect is stronger than when the proportion is altered from one percent to two percent.

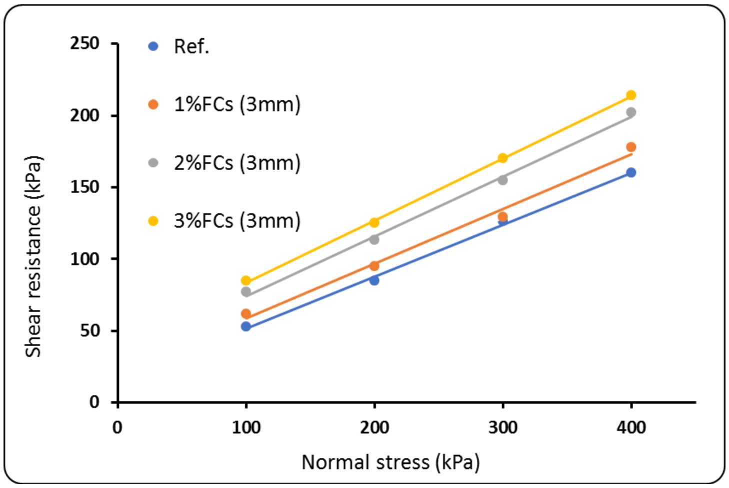

Figure 4. Association Between Shear Resistance and Normal Stress for Samples with Varying Contents of Three Millimeters of CFs.

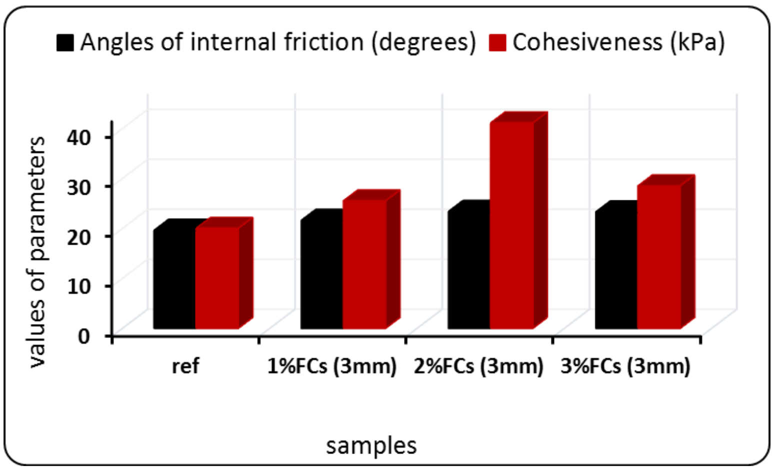

Figure 5. Impact of Three Millimeters of CFs on Angles of Internal Friction & Cohesiveness.

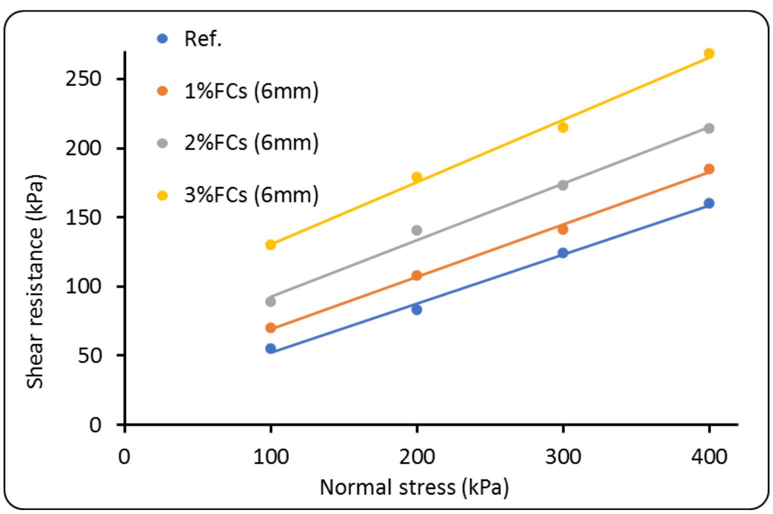

Figure 6. Association Between Shear Resistance and Normal Stress for Samples with Varying Contents of Six Millimeters of CFs.

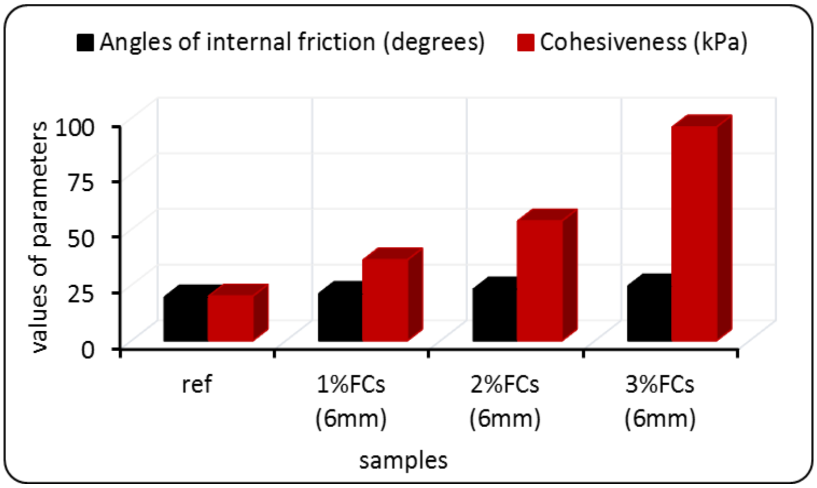

Figure 7. Impact of Six Millimeters of CFs on Angles of Internal Friction & Cohesiveness.

This is in contrast to what was seen with three millimeters of CFs, where the resistance tended to diminish as the CFs concentration increased to three percent.

The impact of ten millimeters of CFs on shear resistance is comparable to that of six millimeters of CFs. The shear resistance of samples rose as the CFs concentration increased, as illustrated in Figure 8. Figure 9 shows the influence of ten millimeters of CFs on angles of internal friction and cohesiveness. In the case of samples with three percent of CFs, the greatest cohesiveness measured was 64.9 kilopascal. Despite the lesser improvement as compared to samples with six millimeters of CFs of the same content, a significant increase in cohesiveness was obtained, with a 224.5 percent growth when compared to reference sample.

The length and amount of CFs would, in general, have a significant impact on the mechanical characteristics of soil samples. The sample with a three percent content of six millimeters CFs had the greatest shear resistance values of all the samples examined, followed by the sample with a three percent content of ten millimeters CFs, and finally the sample with a two percent content of three millimeters CFs.(Kumar et al, 2006) observed comparable findings when soil samples were fortified in different ways employing varied quantities (0–2 percent) of three millimeters, six millimeters, and twelve millimeters polyester fibres (PLFs). Because of the fibre-soil contact friction, CFs was shown to be helpful in increasing angles of internal friction and cohesiveness. CFs is thought to generate mutual friction between the soil and the dense network structure, improving soil cohesiveness dramatically. As a result of the improved angles of internal friction and internal cohesiveness, soil shear resistance may be increased even more. Short-FCs strengthening, on the other hand, could fill part of the voids and also provide interconnecting impacts when dispersed equally in soil. The soil stiffness could also be improved by using short-CFs. CFs, which can inhibit the growth of stress fractures and soil deformation, may be responsible for the enhanced stiffness.

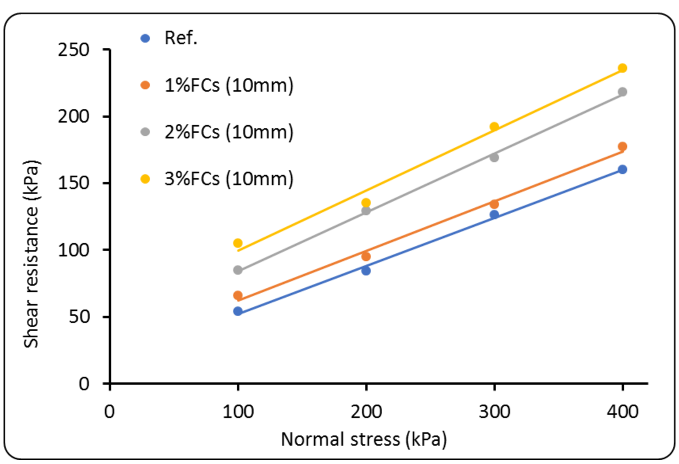

Figure 8. Association Between Shear Resistance and Normal Stress for Samples with Varying Contents of Ten Millimeters of CFs.

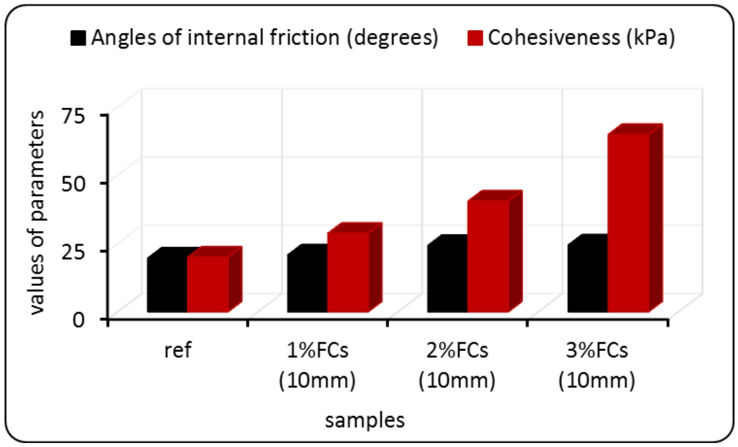

Figure 9. Impact of Ten Millimeters of CFs on Angles of Internal Friction & Cohesiveness.

3.2. Uniaxial Compression Resistance

The connections between Uniaxial Compression resistance and axial strain for soil samples strengthened with various amounts of six millimeters of CFs are shown in Figure 10. The addition of CFs enhanced not only the ultimate shear resistance but also the post-peak residual resistances, as shown by the stress–strain relation. Before the ultimate point, the CFs enhanced the stiffness of the samples. The reference sample and the sample of one percent of CFs of six millimeters length both showed strain hardening behaviour, as shown in Figure 10. The stress-strain graphs of samples containing two and three percent of CFs of six millimeters length, on the other hand, showed quick hardening up to the maximum and subsequently softening after the maximum. The strengthened sample exhibited ductility when the CFs concentration was raised from two percent to three percent. As shown in Table 2, the young's modulus of the sample with three percent of CFs of six millimeters length was 5.29 MPa, which is 108.3 percent greater than the reference sample. As demonstrated in Figure 11, the resistance of samples appeared to rise as the concentration of CFs of six millimeters length increased. Maximum shear resistances of samples which contained one, two, and three percent of CFs of six millimeters length have been found to be greater than the reference sample by about 29.0 percent, 80.8 percent, and 122.8 percent. (Ding et al, 2018) showed similar enhancement rates when soil samples have been supplemented with twelve percent from total weight of cement. It's worth mentioning that raising the amounts of CFs can shift the stress-strain correlations of samples from strain hardening to hardening-softening behaviour. It could be concluded that CFs can enhance the connection between sand grains and restrict movement when the soil is affected by external stresses in the same way that cement can.

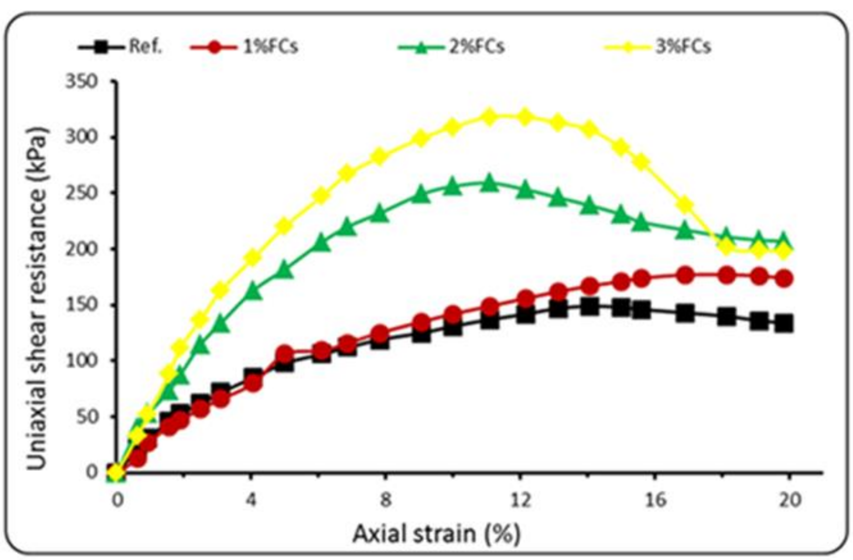

Figure 10. Association Between Uniaxial Shear Resistance and Axial Strain for Samples with Varying Contents of Six Millimeters of CFs.

Table 2. The percent of increment of maximum resistance and young's modulus for samples with varying contents of six millimeters of CFs.

sample	Maximum resistance (kPa)/ increment (%)	young's modulus (MPa)/ increment (%)
Ref.	142.5/ 0	2.55/ 0
1% FCs (6 mm)	171.41/ 28.95	2.90/ 14.5
2% FCs (6 mm)	257.55/ 80.76	4.78/ 87.8
3% FCs (6 mm)	317.42/ 122.8	5.29/ 108.3

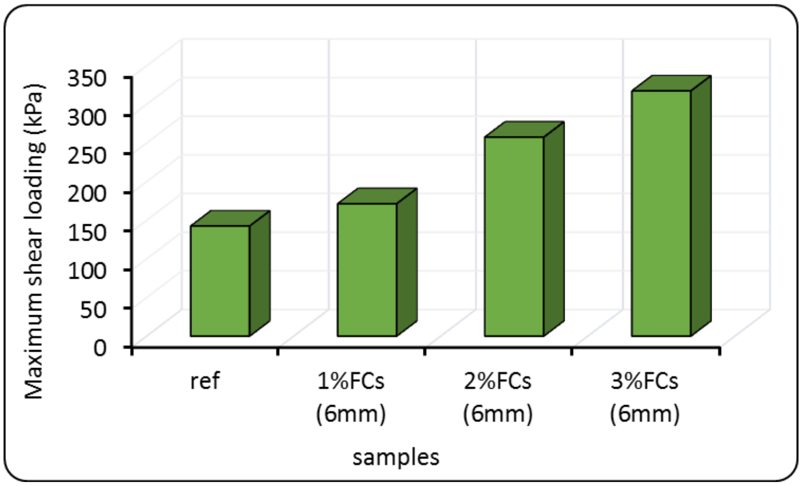

Figure 11. Impact of Six Millimeters of CFs Content on Uniaxial Maximum Shear Loading.

4 Conclusions

The impacts of CFs volume fraction and length on features of clayey soil under series tests including direct shear test, uniaxial compression test have been investigated. The following conclusions can be drawn from this research:

1) With increased fibre percentage, the MDD and OMC both fell significantly. Adding CFs to soil samples can considerably increase their resilience.
2) The amount of resistance improvement is proportional to the length of CFs. Short fibres, such as CFs of three millimeters length, could not provide a substantial increase in resistance because there was little contact surface to connect with the sand grains, and the short fibres were quickly pulled out under shear loading.
3) Increased fibre percentage enhanced the uniaxial compression resistance of soil sample substantially. The samples with the highest failure resistance were those strengthened with three percent of FCs of six millimeters length.
4) Soil samples which strengthened with three millimeters, six millimeters, and ten millimeters of CFs enhanced their cohesiveness by 105.5 percent, 380 percent, and 224.5 percent, consecutively.
5) The percentage of CFs has a big impact on the resistance improvement. It would be challenging to homogeneously scatter the fibres in the soil sample when a high CFs percentage has been introduced, leading in cluster formation. The interfacial link would be weakened as a result of fibre aggregation, lowering shear resistance.

Nevertheless, additional study is needed to fully comprehend the reinforcing process of CFs on clayey soil, as well as its mechanical characteristics under saturated circumstances. Other significant clayey soil qualities, including permeability, time-based deformation, durability, and stability under various stress regimes, should also be addressed.

Reference

Amir-Faryar, B. and Aggour, M. S. (2012). Determination of optimum fiber content in a fiber-reinforced clay. *Journal of Testing and Evaluation*, 40(2), 334-337.

ASTM Committee D-18 on Soil and Rock (2010). Standard test methods for liquid limit, plastic limit, and plasticity index of soils. ASTM international.

ASTM Committee D-18 on Soil and Rock (2017). Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) 1. ASTM International.

ASTM Committee D698-18 on Soil and Rock (2018). Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard. American Society for Testing and Materials, West Conshohocken, Pa.

ASTM Committee D854-18 (2018). Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer. ASTM International.

ASTM D2166, A. (2016). Standard test method for unconfined compressive strength of cohesive soil.

ASTM, D. (2007). Standard test method for particle-size analysis of soils.

ASTM, D. 3. 9. (2011). Standard test method for direct shear test of soils under consolidated drained conditions. D3080/D3080M.

Boz, A. and Sezer, A. (2018). Influence of fiber type and content on freeze-thaw resistance of fiber reinforced lime stabilized clay. *Cold Regions Science and Technology*, 151, 359-366.

Consoli, N. C., Consoli, B. S., and Festugato, L. (2013). A practical methodology for the determination of failure envelopes of fiber-reinforced cemented sands. *Geotextiles and Geomembranes*, 41, 50-54.

Cui, H., Jin, Z., Bao, X., Tang, W., and Dong, B. (2018). Effect of carbon fiber and nanosilica on shear properties of silty soil and the mechanisms. *Construction and Building Materials*, 189, 286-295.

Ding, M., Zhang, F., Ling, X., and Lin, B. (2018). Effects of freeze-thaw cycles on mechanical properties of polypropylene fiber and cement stabilized clay. *Cold Regions Science and Technology*, 154, 155-165.

Hejazi, S. M., Sheikhzadeh, M., Abtahi, S. M., and Zadhoush, A. (2012). A simple review of soil reinforcement by using natural and synthetic fibers. *Construction and building materials*, 30, 100-116.

Kumar, A., Walia, B. S., and Mohan, J. (2006). Compressive strength of fiber reinforced highly compressible clay. *Construction and building materials*, 20(10), 1063-1068.

Li, Y., Ling, X., Su, L., An, L., Li, P., and Zhao, Y. (2018). Tensile strength of fiber reinforced soil under freeze-thaw condition. *Cold Regions Science and Technology*, 146, 53-59.

Liu, C., Lv, Y., Yu, X., and Wu, X. (2020). Effects of freeze-thaw cycles on the unconfined compressive strength of straw fiber-reinforced soil. *Geotextiles and Geomembranes*, 48(4), 581-590.

Mirzababaei, M., Anggraini, V., and Haque, A. (2020). X-ray computed tomography imaging of fibre-reinforced clay subjected to triaxial loading. *Geosynthetics International*, 27(6), 635-645.

Quang, N. D. and Chai, J. C. (2015). Permeability of lime-and cement-treated clayey soils. *Canadian Geotechnical Journal*, 52(9), 1221-1227.

Ranjan, G., Vasan, R. M., and Charan, H. D. (1996). Probabilistic analysis of randomly distributed fiber-reinforced soil. *Journal of geotechnical engineering*, 122(6), 419-426.

Terashi, M. (1980). Fundamental properties of lime and cement treated soils. *Report of PHRI*, 19(1), 33-62.

Yoo, D. Y., Kim, S., Park, G. J., Park, J. J., and Kim, S. W. (2017). Effects of fiber shape, aspect ratio, and volume fraction on flexural behavior of ultra-high-performance fiber-reinforced cement composites. *Composite Structures*, 174, 375-388.