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Effect of Polypropylene Fiber on Mechanical Behaviour of Expansive Soils

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ABSTRACT

This paper presents an experimental study evaluating the effect of polypropylene fiber on mechanical behaviour of expansive soils. The initial phase of the experimental program includes the study of the effect of polypropylene fiber on maximum dry density and optimum moisture content with different fiber inclusions. Dynamic compaction tests have been conducted on an expansive soil sample with 0%, 0.5%, 0.75%, and 1% polypropylene fiber additions (by dry weight of the soil) and samples have been prepared with the same dry density statically. The second phase of the experimental program focuses on the unconfined compression, tensile and one-dimensional swell behaviour of the unreinforced and reinforced soil samples. Finally it is concluded that mitigation of expansive soils using polypropylene fiber might be an effective method in enhancing the physical and mechanical properties of subsoils on which roads and light buildings are constructed.

KEYWORDS: swelling clays, polypropylene fiber, unconfined compression, tensile strength.

INTRODUCTION

Expansive soils are the main cause of damages to many civil engineering structures such as spread footings, roads, highways, airport runways, and earth dams constructed with dispersive soils (Abduljauwad 1993). Stabilization by chemical additives, pre-wetting, squeezing control, overloading, water content prevention are general ground improvement methods that are used to mitigate swelling problems (Guney, et al., 2007). There has been a growing interest in recent years in the influence of chemical modification of soils which upgrades and enhances the engineering properties. The transformation of soil index properties by adding chemicals such as cement, fly ash, lime, or combination of these, often alter the physical and chemical properties of soils including the cementation of the soil particles. Especially use of lime admixture has proved to have a great potential as an economical method for improving the geotechnical properties of expansive soils (Bilsel and Oncu, 2005; Nalbantoglu and Tuncer, 2001; Basma and Tuncer, 1991; Leroueil and Vaughan, 1990). Rao and Shivananda (2005) have examined the compressibility behavior of lime-stabilized soils. According to McKeen (1976) cement and lime show different behavior in soil stabilization. Cement contains the necessary ingredients for the pozzolanic reactions, whereas lime can be effective only if there are reactants in the soil. Recently there is a growing attention to soil reinforcement with different types of fiber. According to Heineck et al. (2005) experimental results gathered over the past years show the potential of different types of fiber in reinforcing problematic soils. In order to understand completely the strength behaviour of unreinforced and reinforced soils, Prabakar and Sridhar (2002) carried out a series of experiments on a non-expansive soil and assessed the suitability of sisal fibre as a reinforcement material, and concluded that a significant improvement in the failure deviator stress, and shear strength parameters (c and φ) are achieved . Freilich and Zornberg (2010) observed an increase of shear strength of soils with the presence of randomly distributed polypropylene fibers. Therefore, polypropylene fiber appears to be a great potential for reducing the detrimental effects on buildings, earth retaining structures and roadways induced by expansive soils (Loehr, 2000). However, there is limited research done on fiber reinforcement of fine grained soils, particularly its effect on compaction characteristics, strength and hydromechanical properties.

In this experimental investigation, the aim was to study the effect of polypropylene fiber reinforcement on the improvement of physical and mechanical properties of a clay sample obtained from an expansive clay deposit in Famagusta, North Cyprus. The experimental program was carried out on compacted soil specimens with 0%, 0.5%, 0.75%, and 1% polypropylene fiber additives, and the results of compaction, unconfined compression, tensile strength and one-dimensional swell tests on 0%, 0.5%, 1% fiber are discussed. Despite the difficulties encountered in representative specimen preparation due to random distribution of fiber filaments, it is observed that there is a future prospect in the use of this environmental friendly additive for soil mitigation.

MATERIALS

Soil

The soil used in this study has been obtained from the campus of Eastern Mediterranean University in North Cyprus. The physical properties of the soils are as depicted in Table I. According to Nelson and Miller (1992) high plasticity index indicates high swell potential, the most problematic soil type under light structures.

Table 1: Physical properties of the studied soil

Property	
Specific Gravity	2.56
Sand (%)	8
Silt (%)	40
Clay (%)	52
Liquid limit (%)	57
Plastic limit (%)	28
Plasticity index (%)	29
Linear shrinkage (%)	20
Optimum moisture content (%)	24
Maximum dry density (kg/m^3)	1497
Soil classification (USCS)	CH

Polypropylene

The most commonly used synthetic material, polypropylene fiber is used in this study. This material has been chosen due to its low cost and hydrophobic and chemically inert nature which does not absorb or react with soil moisture or leachate. The high melting point of 160°C, low thermal and electrical conductivities, and high ignition point of 590°C are other properties. The Propylene fiber used in this study has physical properties such as specific gravity of 0.91, and an average diameter and length of 0.06 mm and 20 mm respectively.

SAMPLE PREPARATION

All the test specimens were compacted statically by applying the pressure required to achieve maximum dry density at optimum moisture content as obtained from the Standard Proctor compaction test in accordance with ASTM D698-91. The static compaction is applied in a modified CBR instrument. To prepare unreinforced samples, water is added to the soil and mellowed for 24 hours. To obtain reinforced samples, the fiber is added after the mellowing time and blended in a mixer to achieve the best possible distribution. The amount of fiber that should be added to the soil has been calculated according to the dry unit weight of the soil and has been added to the wet soil. To ensure a uniform distribution of the fibers, samples are compacted directly to the size required in special moulds.

EXPERIMENTAL WORK

COMPACTION TESTS

The relationship between dry density and moisture content of samples obtained by Standard Proctor test (ASTM D 698-91) are presented in Figure 1. The test procedure consists of mixing of soil with different water contents and compacting in metal moulds of 101 mm diameter in three layers (25 blows on each layer with thickness of 5-8 cm) using an automatic dynamic compacter with a hammer of 2.5 kg dropping from 305 mm height that produces a compactive effort of 600 kN-m/m. The compaction test has been performed on soils with different fiber contents of 0.5%, 0.75%, and 1 % of dry mass. The compaction curves in Figure 1 indicate that optimum moisture content does not show a significant change by addition of polypropylene fiber, whereas maximum dry density reduces as fiber content increases. This behavior can be attributed to the reduction of average unit weight of solids in the mixture of soil and fiber. Figure 2 shows the dry density versus pressure obtained from static compaction test. This test has been performed using California Bearing Ratio test equipment to find the amount of pressure needed to achieve the maximum dry density at the optimum water content obtained from Standard Proctor test.

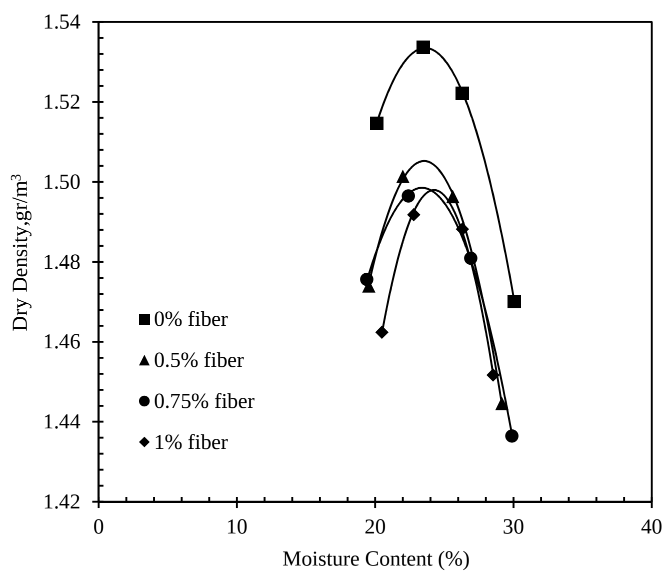

Figure 1: Standard compaction characteristics curve

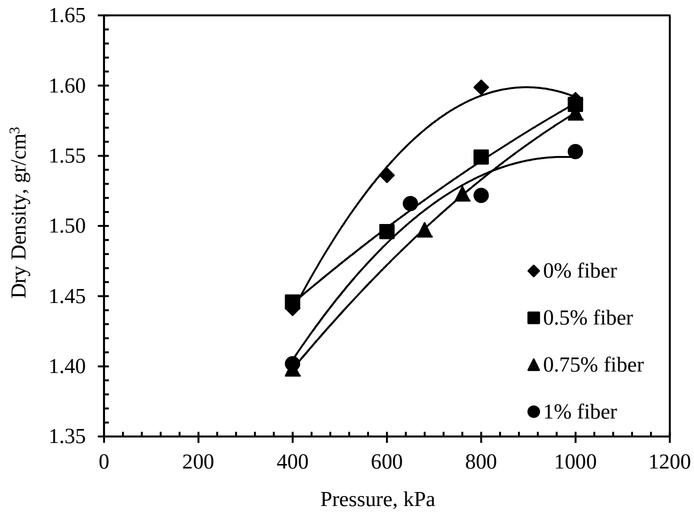

Figure 2: Dry density versus pressure in static compaction

UNCONFINED COMPRESSION TEST

Unconfined compression tests using strain-controlled application of the axial load, are carried out according to the ASTM D2166-06. The unconfined compressive strength is taken as the maximum load attained per unit area or the load per unit area at 15 % axial strain, whichever is secured first during the performance of a test. Samples have been prepared at optimum moisture content and statically compacted directly in the sample preparation mold by CBR instrument to achieve the maximum dry density. Figure 3 demonstrates the stress- strain relationship of fiber reinforced and unreinforced soils where an enhancement in unconfined compressive strength has been observed with an increase in fiber content. It is also observed that the failure of the fiber reinforced specimens occurs in longer time than the original soil, which indicates increase in the ductility of the soil after reinforcement.

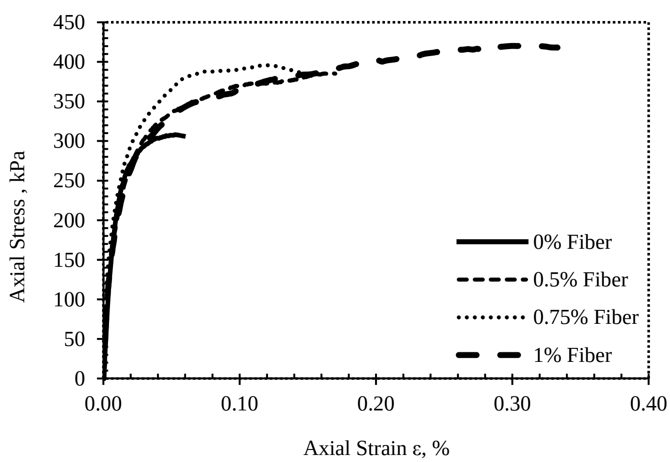

Figure 3: Stress-Strain relationship of original and fiber reinforced soils

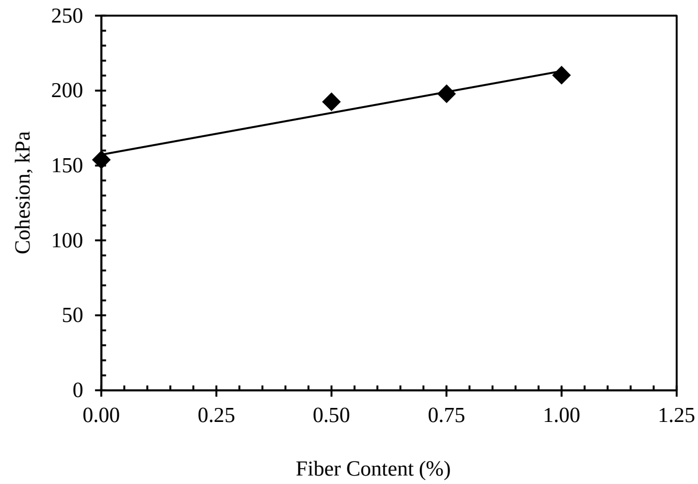

Figure 4: Cohesion versus fiber content

Furthermore, the test results indicate that the unconfined compressive strength, and hence the cohesion increase with increasing fiber content, the highest values being noted for samples with 1% fiber inclusion. The cohesion values with respect to fiber contents are depicted in Figure 4.

SPLIT TENSILE STRENGTH TESTS

Split tensile strength is a method to measure the tensile strength of concrete. This method has been used according to the ASTM D3967-08 to measure the tensile strength of reinforced and unreinforced soil specimens. Samples of 50 mm diameter and 100 mm height have been prepared and tested in the split tensile strength equipment. Since the testing method is developed for tensile strength measurement of concrete, when used for soils there is need for applying a correction factor to account for the reduction of cross-sectional area under compression. This study is aimed to show the tendency of increasing tensile strength with fiber additions, presenting the results in Figure 5. The ratios of unconfined compressive strength to split tensile strength with respect to fiber contents are given in Figure 6, which indicate that fiber reinforcement is more effective in improving tensile strength than the compressive strength.

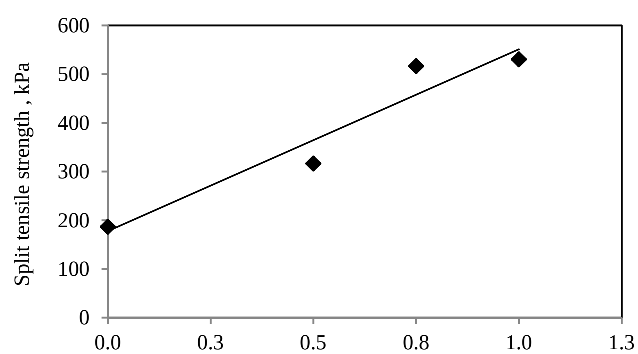

Figure 5: Split tensile strength versus fiber content

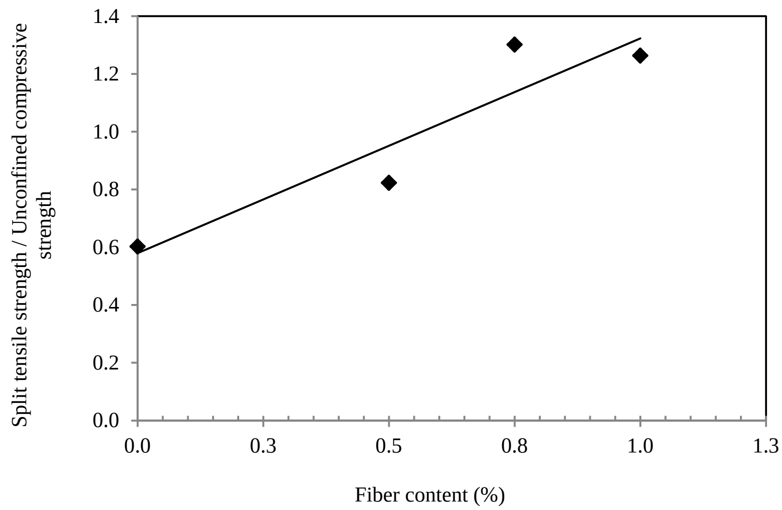

Figure 6: Split tensile strength/unconfined compressive strength versus fiber contents

SWELL

To investigate the swelling characteristics of unreinforced and fiber reinforced specimens,one- dimensional swell tests were carried out. Samples were statically compacted in consolidation rings at optimum moisture content in consolidation rings of 50 mm inner diameter and 19 mm of height. The samples were left under a low surcharge of 7 kPa and full swell was measured. Specimens of different fiber inclusions have been swelled until the increase in free swell with time became marginal. Figure 7 presents the free swell response in percent swell (ΔH/H0) with respect to time in minutes for different fiber percentages. The results show an increase of swell with 0.5% and 0.75% fiber contents and a sudden reduction with 1% fiber content. According to Ghazavi and Roustaie (2009), a reduction in swell percentage has been obtained with 3% of polypropylene fiber and an enhancement of swell percent with 1% and 2% of polypropylene fiber. Sample size is a factor which can influence the swell percentage of the soil samples.

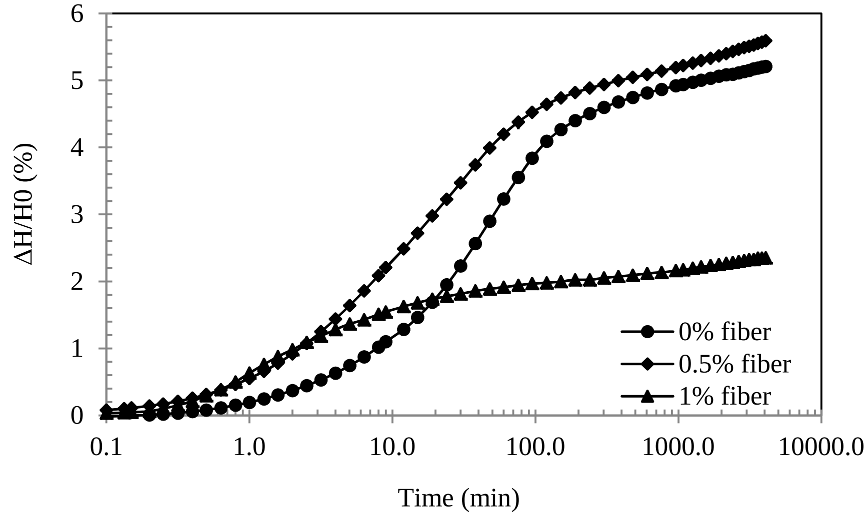

Figure 7: Percent swell of unreinforced and reinforced soil specimens versus time

As Loehr et. al (2000) pointed out, samples of 10.2 cm showed reduction in swell percentage versus time with the increase of fiber content and the same soils tested with 6.4 cm diameter samples indicated an increase in swell percentage.

CONCLUSIONS

Based on this experimental study, optimum water content is not influenced by polypropylene fiber inclusion, whereas maximum dry density has been reduced. This can be attributed to the reduction of average unit weight of solids in the soil-fiber mixture. Studying the influence of polypropylene fiber on swell characteristics, the overall conclusion is that one-dimensional swell decreases considerably with 1% fiber addition. Unconfined compressive strength increases with polypropylene fiber inclusions. Maximum value of cohesion can be observed with 1% fiber content which is approximately 1.5 times of the unreinforced soil. From the analysis of split tensile strength test, it is observed that the maximum value of the tensile strength obtained for 1% fiber inclusion is 2.7 times of the unreinforced soil. Increase in the ratio of tensile strength to compressive strength indicates that polypropylene fiber reinforcement is more effective in improving tensile than the compressive strength. Thus fiber enhances the ductile behavior of soils, reducing shrinkage settlements during desiccation, hence detrimental damages to structures, such as roads and pavements may be prevented.

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