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COMPRESSIBILITY AND STRENGTH DEVELOPMENT OF SOFT SOIL BY POLYPROPYLENE FIBER

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ABSTRACT: In recent years, there has been an increasing interest in the impact of chemical soil modification on the engineering qualities of soils. The addition of chemicals such as cement, fly ash, lime, polymers, or a mixture of these to soil index characteristics alters the physical and chemical properties of soils, including the cementation of soil particles. Polymers have been documented to enhance a substantial improvement in strength in clayey soils due to the formation of bonds among clay minerals and polar end groups of the polymer. The main aim of this study is to highlight the issue by investigating the suitability of a small number of polypropylene fibers of different proportions as soil reinforcement. Experiments were conducted on clay soil containing various amounts of polypropylene fiber, ranging from 0.5 to 1.5 percent. When polypropylene fiber is combined with soil at 0.5, 1.0, and 1.5 percent, the liquid and plastic limits, as well as the unconfined compressive strength increased. When 1 percent polypropylene is added to the soil, the compressibility of the soil drops dramatically. The compression index falls by 69 percent, and the swelling index falls by 78 percent. The specific gravity and maximum dry unit weight decrease with the increase in the percentage of polypropylene fiber.

Keywords: Soft clay, Polypropylene fiber, Compressibility, Strength, Improvement, Atterberg limits

1. INTRODUCTION

Clay consistency can be classified qualitatively as very soft, soft, or stiff. Clayey soils are classed in terms of consistency according to the British Standard (C.P. 8004, 1986). Such categorization is dependent on the term "undrained shear strength," which tends to show that fragile soft clay has a low shear strength that varies from 20 to 40 kPa, with particularly soft clay having a shear strength of less than 20 kPa [1]. Soft clays have a low bearing capacity, are highly compressible, and take a long time to consolidate. Huat [2] has done an excellent job of covering this subject, with well-documented case studies proving the inherent benefits of soft clay improvement.

Stabilization represents a process of enhancing the engineering features of subsoils earlier to the construction. Such procedure may be finished in a few ways such as pre-loading the ground including the applications of tall vitality impacts, utilizing of sand channels, pre-assembled wick channels, and chemical added substances [1].

Soft clay is soil that contains a considerable sum of water substances. It is also characterized by little shear strength and high compressibility [2]. The distinctive strategies accessible to make strides the load-carrying capacity of destitute soils incorporate; exchange the stack to a steadier soil layer without making strides the properties of the in situ soil; evacuate the delicate soil and supplant it, completely or mostly, with way better quality fill and; progress the in situ soil properties with distinctive methods of ground's enhancement [3].

Occasionally diverse techniques might be combined to provide appropriate foundations to the enforced loading. It was presented by Hebib and Farrell [4] a method for surface stabilizing that was joint with stabilizing cementations columns to support the foundation loads.

Developing any construction project on this soil category is most probably the most challenging. Civil engineering projects located in areas with soft soil are among those that most frequently encounter engineering problems in different world regions. The common technique for stabilizing soft soils has been to take away and replace the soft soils with appropriate material. The large investments of this method have driven research to look for alternative methods.

The already suggested strategies incorporate densification treatment (for example, pre-loading or compacting), pore water weight usage strategies (for example electro-osmosis otherwise de-watering), displacing–replacing (i.e. delicate soil evacuation and substitution with solid soil), arrange to stack, and the application of support materials (for example geotextile), pile-supported dikes, lightweight fill flatboats and profound in situ chemic stabilization [5-9]. The majority of these methods are expensive to apply [10-12]. Nevertheless, stabilizing soils can be taken as the greatest effective and profitable method.

Ground enhancement techniques are methods for altering ground qualities to obtain ideal ground conditions for a specific goal, such as soil densification, accelerated consolidation, or the use of admixture. All of these treatments have the same goal: to stabilize the soil so that it may be used for construction.

To improve the following soil concerns, ground improvement techniques are performed.

- Increase the load-bearing capacity of the soil by making it denser.
- A decrease in soil settling.
- Liquefaction is reduced by earthquake shaking.
- Significantly lowering pore water pressure.
- Keeping shrinkage and expansion to a minimum.
- To avoid liquefaction of the soil (shock-sensitive soils).
- There will be no lowering or excavation of the ground.
- To raise the pH of the soil.

Chemical approaches improve ground quality by reducing the problem by adding various chemical compounds to the soil. To improve the soil chemically, the following approaches are used: Lime, cement, bitumen, fly ash, polymers, silica fume, nanomaterials, and other additives De-salinization is also used to help soils stay stable.

Behzad and Arun [13], carried out a study to stabilize peat soils utilizing cement to be a binding material as well as polypropylene fiber to be an additive. Because of the significant contents of naturalistic waters for peat soils, the stabilized peat soil tests had been left at a typical temperature of a room with relative humidity to be cured by air for 90 days. It was found that the results of the CBR test revealed an increment by a factor of more than 22 regarding the un-soaked situation while 15 regarding the soaked situation for the stabilized specimens. Adding the polypropylene fiber along with cementitious materials to the stabilized peat soils enhanced the quality of the stabilized peat soils and contributed a significant sum of consistency and intactness to specimens of the stabilized peat soils. It was additionally noticed that as the timing of curing for the stabilized peat soils preceded during 180 days, the dampness substance also kept on diminishing.

Al-Neami et al. [14] employed Polypropylene fiber PPF instead of traditional soil stabilization fibers to try to improve cohesive soil. As a test, three different fiber ratios (0.25 percent, 0.5 percent, and 0.75 percent by dry weight of soil) and lengths (6, 12, and 18) mm were mixed with cohesion to improve specific clay qualities. The results of soil samples prepared at three different water conditions at a dry density (optimal contents of waters, dried plus wet sides of the compaction curve) showed that the ratios', as well as length increasing for polypropylene fibers, causes a decrease in the maximum dry density of soils. The cohesion of soil increases with the inclusion content of PPF up to 0.5%, then decreases. The size of polypropylene fibers possesses a large influence upon the soil's cohesion and adding 0.5% polypropylene fiber with an 18 mm length for the soil represented the optimal mixture for design to enhance the soils.

Abdulrahman et al. [15] used one of the strategies to recycle plastic to enhance gypseous soil by mixing in 1 percent plastic fiber to boost "shear strength" and decrease soil collapsibility at saturation or soil wetness. The soil utilized was classed as SW-SM, with a 39 percent gypsum concentration and a relative density of 73 percent. The soil was subjected to a variety of tests, including a collapse test, a direct shear test, and a model loading test before and after mixing with fiber plastic. The value of soil cohesiveness steadily increases from 2 MPa in natural soil to 11 MPa when mixing with 1% plastic fibers, according to the findings.

On clay-silt soils, Ajayi-Majebi et al. [16] investigated the effects of an epoxy resin (bisphenol A/epichlorohydrin) and a polyamide hardener. In their investigation, unsoaked California Bearing Ratio (CBR) increased significantly in 3-day cured stabilized soil samples with 4% additions. Lignosulfonate and synthetic polymers were found to be beneficial in enhancing the unconfined compression strength of both lean and fat clay soils by Tang et al. [17]. Spraying poly (vinyl alcohol) to prevent the formation of crust and increase the durability of clay soils under the effect of simulated heavy rain provided a significant advantage, according to Page [18].

Mirzababaei et al. [19] dealt with the influence of two polymers on the free swell potential of three fat clay soils, namely 3 to 10% poly (methyl methacrylate) and 1 to 3% poly (vinyl acetate). They discovered a significant drop in free-swell potential and the production of aggregated clay-granular matrices after adding polymers.

2. RESEARCH SIGNIFICANCE

The main aim of this study is to highlight the issue by investigating the suitability of a small number of polypropylene fibers of different proportions (0.5%, 1%, and 1.5% by soil dry weight) to be used as soil reinforcement. These ratios were selected with these values after several experiments while mixing at different rates higher than what is stated, and then this ratio was selected. The paper submits an economical method for the treatment of clayey soil using environmentally friendly material.

3. MATERIAL AND EXPERIMENTAL MODEL

3.1 Soil

To examine the influence of polypropylene fiber on the soil's properties, clayey soil was used in this research. Table 1 illustrates the physical features of the clay while Fig. 1 presents the grain size distribution. Index properties were determined for the clay soils. The soil is classified as low plasticity clay CL according to the "Unified Soil Classification System".

Table 1. Physical properties of the soil used.

Test	Results	Specification
Specific gravity	2.66	ASTM D 854 [20]
Gravel %	0	ASTM D 422 [21]
Sand %	4%	
Fines % (Clay and Silt)	96%	
Liquid limit (%)	32	ASTM D 4318 [22]
Plastic limit (%)	17	

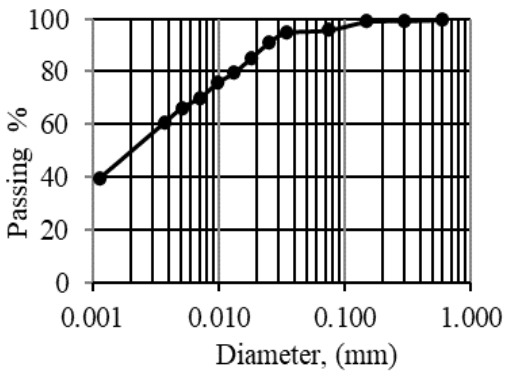

Fig. 1 Particle size distribution curve of the clay.

3.2 Polypropylene Fiber (PPF)

The properties of polypropylene fiber used in this study such as fiber kind, length, and diameter are listed in Table 2 and Fig. 2 depicts the features as well as fiber's shape utilized within the current work. The beneficial lifespan of such fiber might last for 5 years at a temperature of 121° C, for 10 years at a temperature of 110° C, and 20 years at a temperature of 99° C. Special stabilization grades are Underwriters Lab-rated at a temperature of 120° C for ongoing services [17].

3.3 Soil Samples Preparation and Test Procedures

The preparation of soil specimens was done utilizing the mixing technique. A 12 mm polypropylene fiber (PPF) was used for the current work, as shown in Fig. 2. It is added to the soil in three proportions (0.5, 1, and 1.5) %. The fiber weight supplied to the soil could be determined via the coming expression [23]:

Table 2. Polypropylene fiber specification [17].

Fiber Properties	Values
Fiber kind	Single fiber
Length, mm	12
Diameter, mm	0.034
Density, g/cm^3	0.91
Tensile strength, MPa	350
Modulus of elasticity, MPa	3500
Fusion point, °C	165
The burning point, °C	590° C
Surface area, m^2/kg	250
Elongation, %	24.4
Water absorption	Nil
Dispensability	Excellent
Acid and alkali resistance	Very good

Fig 2. Soil with polypropylene fiber

$$\rho f = \frac{Wf}{W} x\, 100 \quad (1)$$

where Pf = ratio of fiber content, Wf = weight of the fiber, and W = weight of the soil dried in air.

Then mixing the soil with a specific quantity of fiber in a good manner utilizing the mixing machines. Subsequently, mixing the soil was done with a specific quantity of fiber in a manner via utilizing the type of mixer machines, as illustrated in Fig. 3. Laboratory tests were performed on the samples as follows:

i. Conducting compaction test according to ASTM D1557[24] to study the influence of adding PPF on optimum moisture content and the maximum dry density of the studied soil. For modified pressure, three percentages (0, 0.5, and 1) % were used. These tests show that adding PPF reduces the maximum dried density for the soils since such kind of additive possesses a little particular weight.

ii. Carrying out testing to examine the PPF effect upon the "unconfined compressive strength" of soils prepared at the maxi dried density as well as optimal contents of water using the addition of (0, 0.5, and 1) %.

iii. A one-dimensional consolidation test was conducted according to ASTM D2435 [25] on three samples to examine the PPF's influence upon the Cc (compressing index), Cr (recompressing index), and Cv (coefficient of consolidation).

Fig 3. Mixer type for soil sample preparation.

4. PRESENTATION AND DISCUSSION OF TEST RESULTS

The current section introduces the testing results conducted via utilizing three ratios of polypropylene (0.5, 1, and 1.5%) by the way of dried weight mixture plus the untreated soil as illustrated to examine the conduct of soft clayey soil stabilized with polypropylene.

4.1. Effect of PPF on the specific gravity

Specific gravity (Gs) of three samples for the soil with different percentages of polypropylene was determined and the results are plotted in Fig. 4. The figure shows a decrease in specific gravity with added polypropylene. Due to the low unit weight of the polypropylene fiber, the specific gravity of the stabilized soil decreased slightly.

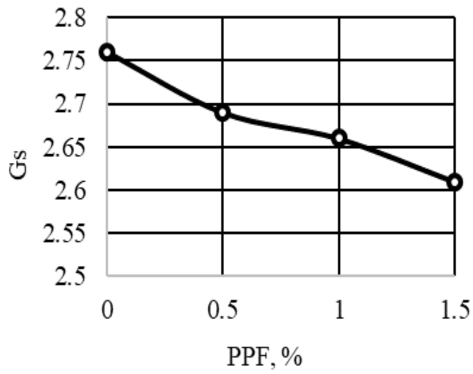

Fig 4. Specific gravity for soft clay with different polypropylene fiber percentages.

4.2 Consistency Limits Results

For such a series, testing the specimens was done to examine the addition effect of polypropylene for the clay. Figure 5 shows consistency limits (Atterberg limits) for clay with different percentages of polypropylene, while Fig.6 illustrates the influence of polypropylene on the plasticity index of the soft clay.

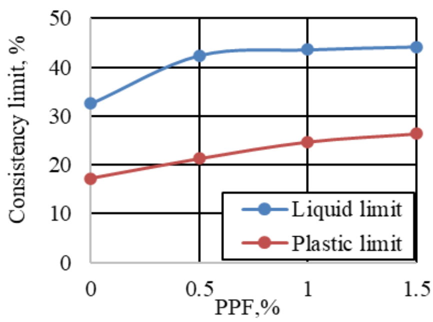

Fig 5. Consistency limits with different polypropylene fiber percentages.

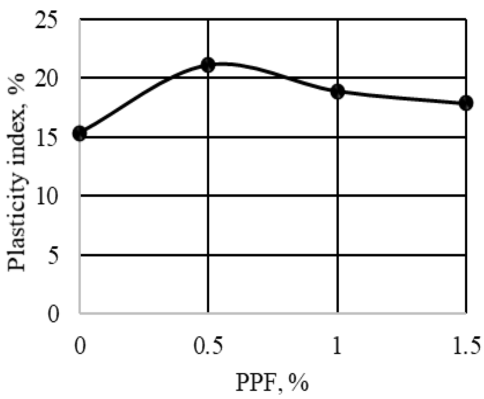

Fig 6. Plasticity index with different polypropylene fiber percentages.

One could observe be the existence of an increase within liquid as well as plastic limits while there is a decrease in the plasticity index with an increase in the percentage of polypropylene. The addition of polypropylene at the maximum value of 1% results in an increase in the liquid limit to (44), the plastic limit increased by about 5%. Hence, the plasticity index decreased by about 15%. The increment within the clayey liquid limits can be associated with the affinity's development for the clayey surface over the waters; this alteration can be attributed to titanium chloride present as a catalyst in the propylene product. Nevertheless, the last outcome within all fettles represents a decrease within the plasticity index. Accordingly, the soils get transformed into more practical materials. Moreover, there is a reduction in the sensitive feature of soils' strength to dampness. The overall increase within the plastic limits for soils can be attributed to water-absorbing that happens once polypropylene was added to the clay. Polypropylene functioned as a drying factor, thus adding more water was required for making the soil's sample roll into a thread of (3 mm) diameter until appearing the crack can be considered as a sign of attaining the plastic limit.

4.3 Compaction Test

From Figure 7, one can observe that the maximum dry unit weight decreases when there is an increase in polypropylene fiber ratio. The maximum dry unit weight displayed a reduction of about 2.5 % plus 13.6 % correspondingly, for 0.5, 1, and 1.5 % adding of polypropylene fiber to the soil. This can be mostly attributed to the low value of particular gravity for polypropylene fiber compared to the high value of particular gravity (2.66) for soils, while the optimum moisture content values continually increase when there is an increase in the ratio of polypropylene fiber as shown in Fig. 8. This makes the stabilization using this material efficient in the construction of roads and lightweight embankments. The optimum moisture content displayed an increasing about 1.52 plus 2.07 times than the virgin soils' value. Such conduct is because of the reduction within the typical unit weight for solid contents within the mixes of soils as well as fiber.

Polypropylene fiber has a small tendency to absorb water so that as this material occupies a volume within the soil, it acts at decreasing the water kept within the soil voids and hence decreasing the liquid limit. For 0.5,1 and 1.5 % of fiber adding, both contents of fiber display a narrow tendency whereas the maximum dry unit weight values are almost the same. This corresponds to what was found by Soundara and Senthil [26].

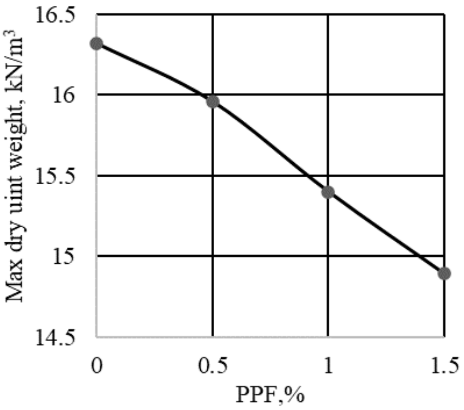

Fig 7. Relationship between maximum dry unit weight and percent Polypropylene fiber.

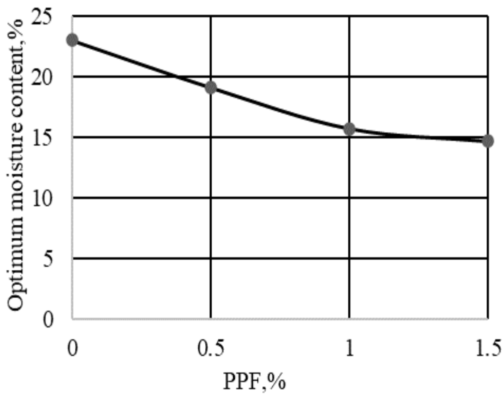

Fig 8. Relationship between the optimum moisture content and percent polypropylene fiber.

4.4 Unconfined Compressive Strength

Chemical stabilization is a technique that involves adding a binder to the soil to enhance the geotechnical characteristics of soft clay, such as mechanical and chemical properties. The most popular and versatile way of testing the strength of stabilized soil is to use the unconfined compressive strength UCS value of compacted soil. It is the primary test that is recommended for determining the amount of additive that should be used in soil stabilization.

Figure 9 shows the relationship between deviator stress and axial strain for soil tested in the unconfined compression machine conducted according to ASTM D2166 [27] with the addition of polypropylene. It is noticed that the unconfined compressive strength UCS increases from 149.15 kPa to 185.35 kPa for soil with increasing polypropylene content from 0% to 1.5 %. This increase is due to the that the titanium chloride reactions from polypropylene interact with the Ca++ from the soil to form cementations' components calcium silicate hydrate (CSH)), within the polypropylene-soil mixture and resulting in strength gain. It can be noticed that there is a decrease in the UCS due to an increase in the number of clay particles (including Na-montmorillonite), these particles will be able for adsorbing a lot of water. Henceforth, making the clay-water framework will tend to be weak. Finally, results of the UCS tests for soil confirmed that considering the general relationship between unconfined compressive strength and the quality of the subgrade soils used in pavement applications, the results of q_u for 1.5% polypropylene addition consider both soils as very stiff subgrade materials, while they are considered as medium soil. Based upon the aforementioned results, one could conclude that 1% addition of polypropylene fiber to the soil can produce an optimal mixture for designing goals to enhance soils since this addition provides a maxi cohesive value once provided to soils.

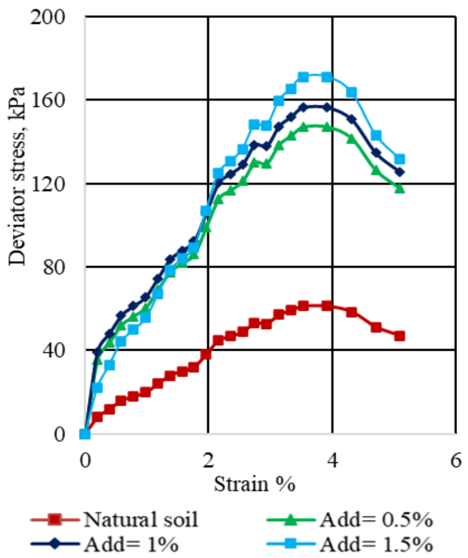

Fig 9. Deviator Stress-Strain relationship for soil at different percentage polypropylene.

4.5 Consolidation Test

A consolidation test was carried out for soil specimens (unreinforced as well as reinforced soils by 0.5, 1 plus 1.5 % of polypropylene fiber) to investigate the polypropylene influence upon “compression index” (C_c), “swelling index” (C_s), and the “coefficient of volume change” (m_v). The results are shown in Table 3. There is a decrease in C_c, C_s, mv, and C_v with the addition of PPF.

The compression index (Cc) is a key metric in geotechnical engineering since it relates to the degree of expected consolidation settlement that a soil stratum would undergo when subjected to loads larger than those previously encountered. The Cc denotes the slope of the linear component of the e-log P’ curve.

Table 3. Consolidation test.

Index Properties	Untreated soil	Index value: Treated soil, % 0.5	1	1.5
Initial void ratio (e_o)	0.658	0.36	0.22	0.217
Compression index (Cc)	0.196	0.097	0.059	0.048
Swelling index (Cs)	0.099	0.051	0.021	0.018
Coefficient of volume compressibility (av)*10^{-3} (m^2/kN)	0.62	0.59	0.18	0.165
Coefficient of volume change (mv)*10^{-3}(m^2/kN) at a pressure of 200 kPa	0.373	0.432	0.147	0.147

5. CONCLUSIONS

The current work concentrated on the influence of polypropylene fiber on clay soils stabilizing. The work revealed an encouraging usage of polypropylene materials for soils; in light of this work the coming findings could be concluded from the study:

1. The specific gravity and maximum dry unit weight decrease with the increase in the percentage of polypropylene fiber.
2. The liquid and plastic limits and the unconfined compressive strength increase when polypropylene fiber is mixed with soil at different percentages.
3. The soil compressibility decreases considerably when the soil is mixed with 1.5 % of polypropylene. The compression index decreases by 69% while the swelling index decreases by 78%.

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