Compressive Behavior of Composite Soils Reinforced with Polypropylene Fiber and Polyvinyl Acetate Resin

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Abstract

With the reduction of available land resources, more and more construction of civil engineering structures is carried out over weak or soft soil, which leads to the establishment and development of various ground improvement techniques such as soil stabilization and reinforcement. Several reinforcement methods are available for stabilizing expansive soils. These methods comprise stabilization with chemical additives, rewetting, soil replacement, compaction control, moisture control, surcharge loading, and thermal methods. Recently, for a second time, one of the early methods has been introduced to civil projects, i.e. random fiber reinforcement. However, very limited information has been reported on the use of randomly distributed discrete fibers for soil reinforcement. In this paper, a novel method of soil reinforcement using a mixture of discrete polypropylene (PP) fibers with poly vinyl acetate (PVAc) was introduced. Fibers can perform superior at fully wet conditions in soil compared to ordinary chemical resins. That is why the combination of PP fiber and PVAc resin was used in this study. For this purpose, four percentages of PP fibers (12 mm length) including 0%, 0.05%, 0.1% and 0.15% were mixed with 0% and/or 0.6% PVAc to prepare different treatments. CBR test at both dry and soaked methods was chosen to evaluate the compressive behavior of soil composites. The results showed that the combination of 0.1% PP fibers with 0.6% PVAc resin presents the best CBR values at both dry and saturated conditions compared to resin modified and/or fiber reinforced soil samples.

Key words: Soil Stabilization, Soil Reinforcement, Poly Propylene Fibers, Poly Vinyl Acetate.

1. Introduction

With the reduction of available land resources, more and more construction of civil engineering structures is carried out over weak or soft soil, which leads to the establishment and development of various ground improvement techniques such as soil stabilization and reinforcement. Therefore; application of stabilizing agents on soils has a long history. When stabilizing agents are added to soils, a series of reactions will take place. Soil may be stabilized to increase strength and durability or to prevent erosion and dust generation on unpaved roads. These processes strengthen the linking between grains and fill up the voids in soils, which improves the engineering properties of soils. Several reinforcement methods are available for stabilizing expansive soils. These methods comprise stabilization with chemical additives, rewetting, soil replacement, compaction control, moisture control, surcharge loading, and thermal methods. All these methods may have the disadvantages of being ineffective and expensive.

Fundamentally chemical stabilization by cement or lime is a proven technique for improving the performance (strength and stabilization) of soil (Ismail et al (2002) and Basha et al (2005)). However, these chemical additives usually result in a high stiffness and brittle behavior (Basha et al (2005)). Incorporating reinforcement inclusions within soil is also an effective and reliable technique in order to improve the engineering properties of soil. In comparison with conventional geosynthetics (strips, geotextile, geogrid, etc.), there are some advantages in using randomly distributed fibre as reinforcement. First, the discrete fibres are simply added and mixed randomly with soil, in much the same way as cement, lime, or other additives. Second, randomly distributed fibres limit potential planes of weakness that can develop parallel to oriented reinforcement. Therefore, it has become a focus of interest in recent years.

However, very limited information has been reported on the use of randomly distributed discrete fibres for soil reinforcement. Only recently, the natural fibres have tried in the field of soil projects (Gavami et al (1999) and Prabakar and Sridhar (2002)) due to their affordable cost, strength, friendly environmental nature and bulk availability. In addition, some investigators found that the use of discrete fibre increased significantly the toughness and led to further improvement of the strength behavior of cement. (Savastano et al (2003) and Li et al (1995).

Li et al (1995) reported that there were notable increases in shear strength, toughness and plasticity of a cohesive soil after reinforcement with discrete Poly Propylene (PP) fibre. It seems that Polypropylene fibres were employed to soil improvement because of its excellent acid and alkali resistance. Park and Tan (2005) studied the effects of short fibre (60 mm) reinforcement on the performance of soil wall. Miller and Rifai (2004), based on their test results, indicated that fibre inclusion increased the crack reduction and hydraulic conductivity of compacted clay soil. Tang and his colleagues (2007) determined the strength and mechanical behavior of randomly distributed short PP-fibre (12mm long) reinforced un-cemented soil and cemented soil. Thus it was found that the inclusion of fibre reinforcement within un-cemented and cemented soil caused an increase in the unconfined compressive strength (UCS), shear strength and axial strain at failure. Increasing fibre content could increase the peak axial stress and decreases the stiffness and the loss of post-peak strength, weakens the brittle behavior of cemented soil. Abtahi et al (2008) investigated the performance of Polypropylene fibres (6, 12 and 19 mm) blended with lime to stabilize soil samples. They also extended the equilibrium cross-section theory to analyze experimental results.

So this paper is going to introduce a novel method of soil reinforcement using PP fibers with Poly Vinyl Acetate (PVAc). PVAc was chosen from our previous work (Abtahi et al (2009)). Thus it had been found that PVAc would be a suitable binder of soil particles. Since, water does not considerably change the properties of fiber-composites, fibers can perform superior at fully wet conditions in soil compared to ordinary chemical resins. That is why the combination of PP fiber and PVAc resin was used in this study.

2. Data and Material

A local soil was tested and used in the experimental investigation. The soil was sieved through ASTM10 and washed through ASTM200. After that the soil sample was classified based on the Unified Soil Classification System (ASTM D 422-87) as sandy silt, SM, (AASHTO A-2-4). The properties of the sandy silt (SM) used are shown in Table 1:

Property	Value
Specific gravity (gr/cm$^{3)}$	2.940
Liquid limit (%)	34.67
Plastic limit (%)	27.04
Plasticity Index	7.63
Optimum moisture content (OMC, %)	13.70
Dry California Bearing Ratio (CBR, %)	1.63

Table 1. Properties of soil used in this study

As it can be seen from Table 1, the value of CBR (California Bearing Ratio) is approximately 1.63%, which is smaller than the requested CBR value of 3–4% for highway subgrade.

Resin-Fiber modified soil samples were fabricated with different conditions. **Four percentages of PP fibers (12 mm length) including 0%, 0.05%, 0.1% and 0.15% were mixed with 0% and/or 0.6% PVAc to prepare different treatments.** 0.6% resin content and PP fibers of 12 mm were the optimized values derived from our previous work (Abtahi et al (2009)). The chemical formulation of PVAc is shown in Fig. 1 while some physical and mechanical properties of PP fibers are presented in Table 2.

Characteristic	**Value**	**Standard**
Homogeneity	100%	-
Color	Transparent	-
Length mm	12	
Melting Point ^0C	160	-
Specific Gravity gr/ cm^3	910	ASTM D 792

Fire Point ^0C	590	-
Tensile Strength CN	17.341	ASTM D 638
Elongation at rupture	118.5	ASTM D 638
Tensile Modulus MPa	6840	ASTM D 638

Table 2. Some physical and Mechanical Properties of PP fibers

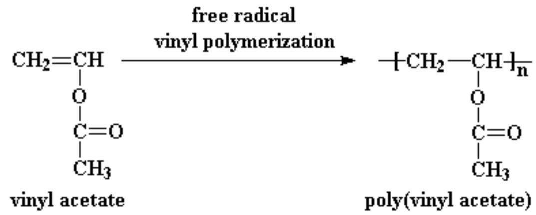

Fig 1. Chemical formulation of PVAc

All soil treatments had been kept 48 hour at the isolated chamber to let the PVAc to cure before CBR tests were began. The isolated chamber included the CBR mold covered with a polyethylene sheet.

3. Research Methodology

The second stage of the test procedure was the strength testing. The specimens were compacted into the CBR molds for testing per AASHTO T-193 and ASTM D-1883 procedures. Each soil specimen was compacted in three layers, at 56 blows, to achieve a compaction of approximately 100% of the maximum dry density. Once the specimens were allowed to cure and soak, depending on the test condition, the specimens underwent the strength tests.

Figs 2-7 show the CBR values for different treatments performed at both soaked and dry conditions.

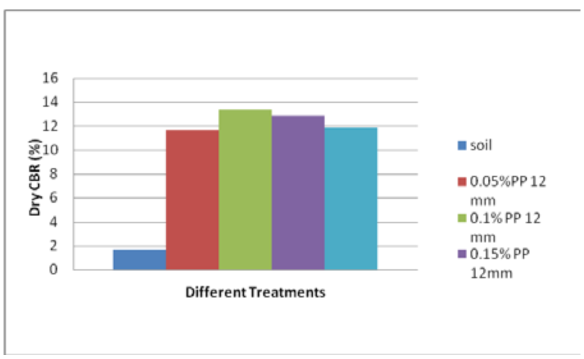

Fig 2. Effect of fiber content on dry CBR

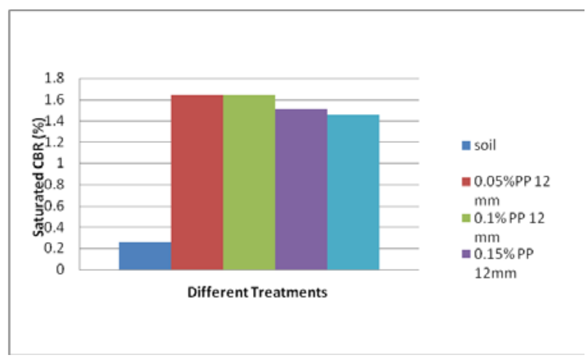

Fig 3. Effect of fiber content on soaked CBR

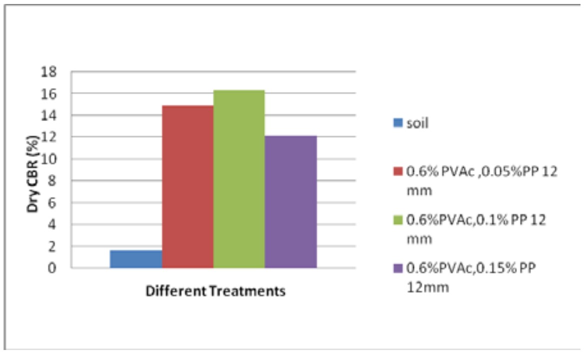

Fig 4. Effect of fiber content on dry CBR at resin-fiber modified treatments

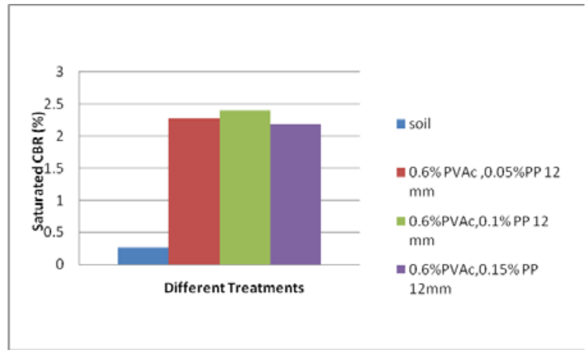

Fig 5. Effect of fiber content on soaked CBR at resin-fiber modified treatments

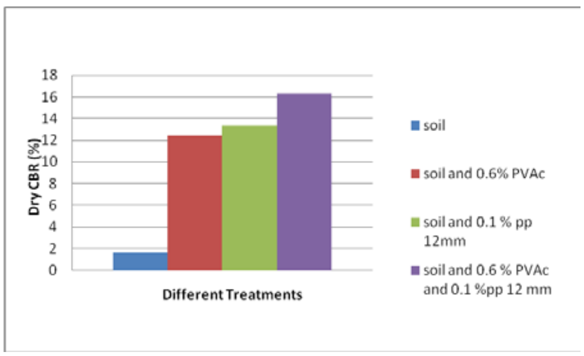

Fig 6. Comparison of optimized treatments and dry CBR results

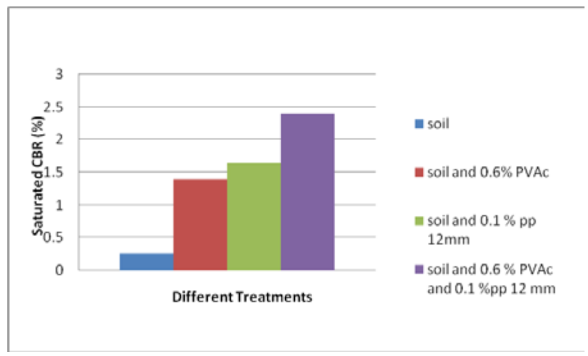

Fig 7. Comparison of optimized treatments and soaked CBR results

4. Results and Analysis

Figs 2 and 3 state that fibers increase the CBR value compared to the neat soil. The maximum value of CBR is related to the sample modified with 0.1% of PP fibers at both dry and soaked conditions. It seems that the "lubricating concept of fibers", i.e. interaction of fiber-to-fiber instead of fiber-to-soil, dominates to the reinforcing performance of fibers deceasing the CBR value as the fibers content increases. From Figs 4-7 it can be concluded that the combination of fibers and PVAc resin improves CBR values at both soaked and dry conditions compared to fiber and/or resin modified samples. Figs 4 and 5 satisfy that 0.1% of PP fibers present the best CBR value among the resin-fiber modified treatments at both dry and soaked conditions. Fig 7 illustrates that the combination of fiber and resin presents superior CBR values at soaked condition compared to PVAc modified sample. It means that PP fibers keep the integrity of the soil-composite at fully wet conditions, i.e. soaked situation. This phenomenon is due to the fact that water can not alter any unfavorable effect on synthetic fibers such as polypropylene. Generally, synthetic fibers have a smooth morphological surface, i.e. there is no porous on the fiber structure. Consequently, synthetic fibers absorb physically a little water and/or humidity. The chemical water-absorption is also neglectable. Polypropylene fibers belong to the synthetic fibers family. Fig 8 shows SEM image of electro-spun polypropylene fibers.

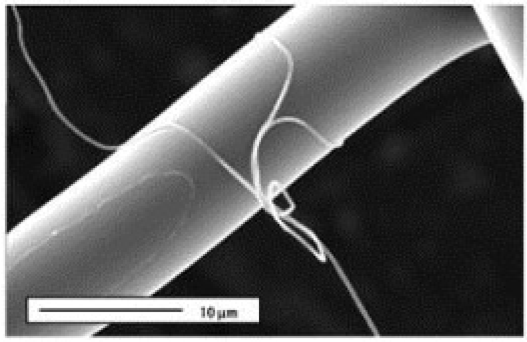

Fig 8. SEM image of electro-spun polypropylene fibers

The smooth morphological surface of polypropylene fibers can be seen from the figure. That is why PP fibers can perform suitable at fully-wet conditions. So, this paper opens a new window to the application of fibers in composite-soil, i.e. the resistance of fibers at soaked conditions.

5. Conclusions

In this paper, a novel method of soil reinforcement using a mixture of discrete polypropylene (PP) fibers with poly vinyl acetate (PVAc) was introduced. Chemical resins, e.g. PVAc, are considered as easy-to-use and rapid-to-perform used for soil modification. However, low water-resistance of ordinary chemical resins decreases their technical and economical benefits. On the other hand, fibers can perform superior at fully wet conditions in soil compared to ordinary chemical resins. That is why the combination of PP fiber and PVAc resin was used in this study. CBR test at both dry and soaked methods was chosen to evaluate the compressive behavior of soil composites. The results showed that the combination of 0.1% PP fibers with 0.6% PVAc resin presents the best CBR values at both dry and saturated conditions compared to resin modified and/or fiber reinforced soil samples. This phenomenon is due to the fact that water can not alter any unfavorable effect on synthetic fibers such as polypropylene. So, this paper opens a new window to the application of fibers in composite-soil, i.e. the resistance of fibers at soaked conditions.

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