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Strength properties of soft clay treated with mixture of nano-SiO_2 and recycled polyester fiber

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ABSTRACT

This paper investigates the effect of recycled polyester fiber, produced from polyethylene (PET) bottles, in combination with nano-SiO_2 as a new stabilizer to improve the mechanical properties of soils. We intend to study the effect of adding nano-SiO_2 and recycled polyester fiber on soil engineering properties, especially the shear strength and unconfined compressive strength (UCS), using clayey soil with low liquid limit. Three different combinations of fiber-soil ratios ranging between 0.1% and 0.5% as well as three different combinations of nano-soil ratios ranging between 0.5% and 1% are used. The shear strength and UCS of treated specimens are obtained from direct shear test and unconfined compression test, respectively. Results of this study show that the addition of recycled polyester fiber and nano-SiO_2 increases the strength of soil specimens. Both the shear strength and UCS are improved by increasing the contents of recycled polyester fiber and nano-SiO_2 in the soil mixture. The increase in the nano-SiO_2 content leads to a reduction in failure strain, but the increase in the content of recycled polyester fiber leads to an increase in failure strain. The increase in the contents of recycled polyester fiber and nano-SiO_2 leads to an increase in elastic modulus of soils. Based on the test results, the addition of recycled polyester fiber improves the mechanical properties of soils stabilized with nano-SiO_2 as well as the recycled polyester fiber has a positive effect on soil behaviors.

1. Introduction

The purpose of soil stabilization is to increase the strength properties and reduce the settlement. The recycled materials in geotechnical engineering have many economic and environmental benefits for the nature. This approach reduces the cost of engineering projects. Thus, several studies have been conducted to investigate the use of recycled materials as a new stabilizer in soil stabilization projects.

For soil stabilization, fiber, cement and different materials were used to increase the strength parameters of soils. The work of Hamidi and Hooresfand (2013) indicated that the addition of polypropylene fiber leads to increases in shear strength parameters and failure stress of cemented soils. Park (2009) studied the influence of polyvinyl alcohol (PVA) fiber on compressive strength of cemented sand, and reported that the 1% fiber makes the axial strain of cemented sand two times larger than that of normal sand.

Mirzababaei et al. (2013) conducted a compaction test on clayey soils containing carpet wastage fiber, and concluded that the addition of fiber decreases the maximum dry unit weight of clay and also increases its optimum moisture, and these two parameters decrease the swelling pressure of clay. Park (2013) carried out a series of tests on the cemented sand reinforced by PVA, and found that the unconfined compressive strength (UCS) of sand with 2% cement and 1% fiber becomes 3.5 times that of non-reinforcement soil. In a study conducted by Mohamed (2013), the addition of 1% dry straw decreases the maximum dry unit weight and shrinkage limit of clay. Estabragh et al. (2013) pointed out that, based on the total and effective stresses, the increase in the content of nylon fiber leads to an increase in shear strength parameters of clay. Zulkifley et al. (2013) believed that the addition of cement and sodium bentonite results in significant reductions in liquid limit, plastic limit and plasticity index of clay.

Several studies have been conducted on the stabilization of soft clay using different materials, such as recycled materials, natural fiber, and chemical materials. However, over the last twenty years, nanotechnology has evolved as an interdisciplinary area, which has attracted great interest. Pham and Nguyen (2014) carried out a series of tests on the clayey soils by adding nano-SiO_2, and found that the addition of nano-SiO_2 leads to a reduction in the swelling index of clay. In a study conducted by Mohammadi and Niazian (2013), adding nano-clay increases the liquid and plastic limits of

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soil and also increases the shear strength parameters of treated specimens. The research conducted by Noll et al. (1992), Yonekura and Miwa (1993), and Zhang et al. (2004) indicated that the addition of nano-SiO_2 increases the strength and the Atterberg limits of clay and also decreases its permeability. Niroumand et al. (2013) studied the influence of nano-clay on compressive strength of earth bricks as sustainable materials, and found that the nano-clay makes the compressive strength of earth bricks 4.8 times larger than that of normal earth bricks. Taha and Taha (2012) carried out numerous tests on clay behavior by adding nano-particles. They concluded that the addition of nano-Al_2O_3 to the soil decreases both the values of expansive and shrinkage strains. In a study conducted by Luo et al. (2012), the addition of nano-Al_2O_3 to the soil reduces the maximum dry unit weight and increases the optimum moisture content, and the addition of different amounts of nano-Al_2O_3 to treated soil reduces the plasticity index values.

In the studies conducted by above-mentioned investigators, the recycled materials were used alone. In this condition, the recycled materials result in improvement of some engineering properties and deterioration of other properties of soils. Moreover, few previous papers have computed the influence of mixture of recycled polyester fiber and nano-SiO_2 on the strength properties of clay. Hence, the aim of this study is to investigate and evaluate the feasibility of using recycled polyester fiber in combination with nano-SiO_2 as a new stabilizer to improve the mechanical properties of soft clay.

2. Materials and methods

2.1. Materials used

The expansive soil used was sampled from the Behbahan suburbs in Iran. The soil contains clay and sand. Nano-SiO_2 used was purchased from Nanosany Company in Iran, and recycled polyester fiber used was purchased from Fiberarjan Company in Iran.

According to the unified soil classification system, the soil used is classified as clayey soil with low liquid limit. The liquid and plastic limits of soil are estimated to be 30 and 22, respectively. The grain size distribution curve of soil is illustrated in Fig. 1. From this figure, it can be observed that the soil contains 22% fine sand, 29% silt, and 49% clay. The maximum dry density of soil is 16.4 kN/m^3 and the optimum moisture content of soil is 15%. Recycled polyester fiber, as shown in Fig. 2, was used for reinforcement. Fiber used is made of the bottles waste by chopping them into small length with almost the same minimal diameter of 20 μm. The length of recycled polyester fiber is 20 mm. The physical properties of recycled polyester fiber are presented in Table 1. The physical properties and chemical composition of nano-SiO_2 are presented in Tables 2 and 3, respectively.

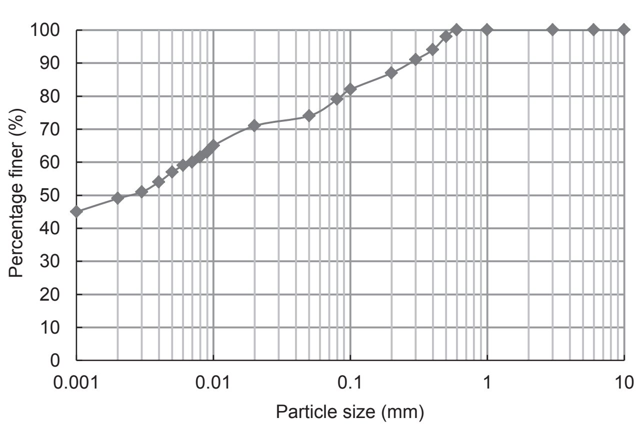

Fig. 1. Grain size distribution curve of soil.

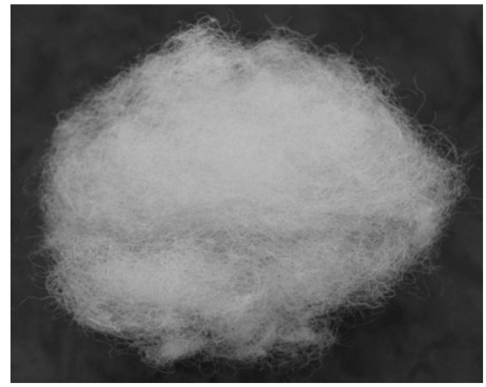

Fig. 2. Picture of recycled polyester fiber.

Table 1
Properties of recycled polyester fiber.

Specific gravity	Moisture content (%)	Tensile strength (MPa)	Color
1.22	0.4	200–400	Colorless

2.2. Test methods

In order to evaluate the effect of nano-SiO_2 and random inclusion of fiber on strength parameters of the specimens, twelve groups of specimens, including one group of natural specimens, one group of specimens reinforced with recycled polyester fiber, one group of specimens stabilized with nano-SiO_2, and nine groups of specimens treated with fiber-nano-SiO_2, were used in two tests, i.e. unconfined compression test and direct shear test. To evaluate the shear parameters of mixture, the direct shear tests were carried out in three normal stresses: 100 kPa, 200 kPa, and 300 kPa. To investigate the increase in UCS due to addition of recycled polyester fiber and nano-SiO_2, a series of unconfined compression tests was conducted on clay treated with recycled polyester fiber and nano-SiO_2 and natural specimens. The laboratory tests were carried out with different contents of recycled polyester fiber (0.1%, 0.3%, and 0.5% of soil dry weight) and different contents of nano-SiO_2 (0.5%, 0.7%, and 1% of soil dry weight).

2.2.1. Sample preparation

In this study, three various contents of nano-SiO_2 (i.e. 0.5%, 0.7%, and 1% of soil dry weight) were selected. In the laboratory, the soil was crashed by a hammer and then screened through sieves. In order to prepare specimens stabilized with nano-SiO_2 and recycled polyester fiber, the soil was divided into five layers and each layer was sprayed with the prescribed amount of nano-SiO_2. Each layer was mixed alone by horizontally cylindrical mixer for at least 1 h. This procedure is the best method to obtain homogeneous samples (To et al., 2011). Because of the fact that the tests were performed under constant moisture content and due to the absorption of

Table 2
Physical properties of nano-SiO_2.

Purity (%)	Average particle size (nm)	Specific surface area (m^2 g^{-1})	Bulk density (g cm^{-3})	Real density (g cm^{-3})	Color
99	11–13	600–785	0.1	2.4	White