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Effect of waste tire cord reinforcement on unconfined compressive strength of lime stabilized clayey soil under freeze–thaw condition

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ABSTRACT

Mechanical properties of fine grained soils, which are subjected to freeze–thaw condition, often change considerably, so when these soils are used as a part of a structure or as an infrastructure, determining a proper solution is necessary. In this paper, stabilization and fiber reinforcement are simultaneously examined as a soil modification method. A series of unconfined compression tests was carried out to investigate the effects of tire cord waste products on mechanical characteristics of a lime stabilized and unstabilized clayey soil subjected to freezing and thawing cycles. Several specimens were prepared at three percentages of lime (i.e. 0%, 4%, and 8%) and four percentages of discrete short nylon fiber (i.e. 0%, 0.5%, 1%, and 1.5%) by weight of dry soil. The samples were saturated and exposed to one up to three freeze–thaw cycles before testing. The results indicated that the compressive strength and stress–strain behavior of specimens depend considerably on the amounts of both fiber and lime. For stabilized specimens, the reinforcement effect of fiber was more than unstabilized ones and also, by inclusion of fiber, 4% lime stabilized specimens indicated more strength in comparison to the untreated and 8% lime stabilized specimens. Furthermore, the contribution of fiber in the strength of samples increased as the number of freeze–thaw cycles was increased.

1. Introduction

Inferior soils are usually an unavoidable problem due to the extension of constructing projects and lack of desirable grounds, so civil engineers employ several techniques to amend them. Soil stabilizing by adding chemical materials is one of the most common methods for treating fine grained soils. Lime has been used to improve some mechanical and plastic properties of fine grained soils since many years ago. Some of the useful effects of lime on engineering parameters of soils are increase in strength, durability, and decrease in plasticity (Akinlabi ola, 1977; Al-Rawas et al., 2005; Bell, 1993; Guney et al., 2007; Sherwood, 1993). However, occurrence of some unfavorable phenomena such as reduction in failure strain, residual strength, and toughness of soil has been reported due to lime application (Abdi and Khayyat-Baharlooyi, 2010; Cai et al., 2006; Clare and Cruchley, 1957).

Soil reinforcing with discrete fibers has been developed as another soil improving method in recent years. Ghavami et al. (1999) explained that inclusion of natural fibers like sisal and coconut fiber provides ductility as well as increase in strength of soil. Similar results about reinforcing soils with natural fibers have been reported by other researchers (Ahmad et al., 2010; Bouhicha et al., 2005; Prabakar and Sridhar, 2002; Zhang et al., 2010). Furthermore, desirable efficiency of synthetic fibers like polypropylene, polyamide, and polyester fibers in improving mechanical properties and failure characteristics of soils has been confirmed (Diambra et al., 2009; Hataf and Rahimi, 2006; Ibraim and Fourmont, 2006; Kumar et al., 2006; Michalowski and Cermak, 2002; Park and Tan, 2005; Viswanadham et al., 2009; Yetimoglu and Salbas, 2003; Yetimoglu et al., 2005). Some researchers utilized advantages of fiber reinforcing by use of waste or byproduct materials as an economical and eco friendly solution for improving engineering properties of weak soils. Hataf and Rahimi (2006) and Yoon et al. (2006) mixed scrap tire rubber with sand. Cetin et al. (2006) and Akbulut et al. (2007) mixed waste rubber with clayey soil and also, Kim et al. (2009) reinforced light weight soil with waste fishing net. These researchers reported that fiber reinforcing causes increasing in unconfined compressive strength, ductility and toughness of soil samples.

Few studies have been carried out on effects of fiber inclusion on mechanical behavior of stabilized soil, as an idea to employ the positive effects of randomly oriented fiber reinforcing to eliminate brittleness of stabilized materials. Cai et al. (2006) conducted some unconfined compressive, direct shear, swelling, and shrinkage tests on polypropylene fiber reinforced lime stabilized clayey soil. While lime stabilized samples showed a brittle failure pattern, fiber–lime specimens showed strain-softening ductile failure. Also, inclusion of fiber with cement stabilized soil has shown increase in strength as well as rise in ductility and reduction in brittleness of stabilized material (Chauhan et al., 2008; Consoli et al., 2009; Park, 2009; Tang et al., 2007).

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Seasonal freeze–thaw cycles are an important problem that specially affects mechanical properties of fine grained soils. In the temperature below 0° Celsius, water in pores turns to ice. This process, which is also known as soil freezing, causes many of lands to be exposed to freeze–thaw condition (Watanabe, 1999). In such regions, pavements are subjected to freezing and frosting heave in the winters, and thaw settlement and weakening in the springs. This cycle imposes enormous loss on cold region countries annually. For example, during 1994 thaw period of spring, 25% of national road network of Sweden tolerated traffic restriction and reconstruction of destructed roads consisted 25% of entire road maintenance budget of that country (Simonsen and Isacsson, 1999). Several researchers described the destructive effects of freeze–thaw cycles on soil engineering properties (Hohmann-Porebska, 2002; Qi et al., 2008; Qin et al., 2010; Sheng et al., 1995; Shoop et al., 2008; Simonsen and Isacsson, 1999; Wang et al., 2007; Zhang et al., 2004).

Different techniques have been proposed to provide more durability for freeze–thaw exposed soils. Shoop et al. (2003) examined some rapid stabilizers for thawing soils. Yarbasi et al. (2007) used waste materials such as silica fume, fly ash, and red mud for modifying granular soils against harmful impacts of freeze–thaw cycles. Results showed that waste additives could improve the compressive strength and CBR values of stabilized soil and also, they can increase durability versus freeze–thaw cycles. They reported that after 60 cycles of freeze–thaw, for unstabilized specimens compressive strength decreased 77.1% while this value was 15.6% for treated soil with waste materials. Also, after the cycles, CBR values of unstabilized specimens decreased from 68% to 56%, but it varied from 250% to 233% for stabilized specimens. Kalkan (2009) added silica fume to fine grained soil used in landfill system and showed that increase in number of freeze–thaw cycles reduced strength and increased permeability of soil, but addition of silica fume to soil as a stabilizer showed favorable results by increasing strength and declining permeability. Some chemical stabilizers have been examined by other researchers to improve durability of soils (Altun et al., 2009; Liu et al., 2010).

A new approach for improving soil characteristics against freeze–thaw condition is reinforcing soil with randomly oriented discrete fibers. Zaimoglu (2010) studied freezing–thawing behavior of reinforced soil by unconfined compressive tests. His experiments disclosed efficacy of fiber reinforcing in increasing of strength and durability of fine grained soils. Some recent studies have confirmed effectiveness of fiber reinforcing against freeze–thaw deterioration in soils (Ghazavi and Roustaie, 2010; Gullu and Hazirbaba, 2010).

In spite of the mentioned studies, synergic effects of stabilization and fiber reinforcement on mechanical properties of soils under freeze–thaw condition have not been investigated yet. Furthermore, previous investigations have not considered the behavior of reinforced soil under condition of absorbing water during thaw period. In the present study, effect of stabilization by lime and reinforcing with waste tire cord on freeze–thaw subjected kaolinite is studied by conducting several unconfined compression tests. The employed fiber is the waste product of tire cord factories and its application as reinforcing elements can solve the problem of disposing as well as supplying an economic material for soil improvement.

2. Materials and experimental procedure

2.1. Soil and lime

A homogenous Zonouz kaolinite soil from East Azerbayjan's mines, which is classified as CL according to the Unified Soil Classification System (USCS), was selected for this study. The particle size distribution curve and the engineering properties of the clay are shown in Fig. 1 and Table 1 respectively. Industrial hydrated lime was used for soil stabilization. Table 2 presents some physical properties and chemical compositions of the employed lime.

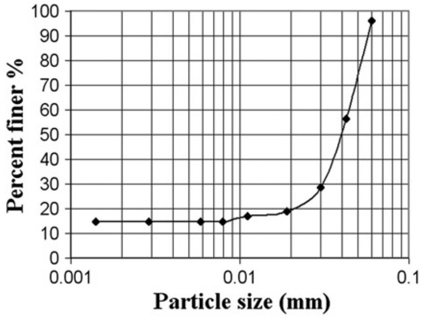

Fig. 1. Grain size distribution of Zonouz clay.

2.2. Fiber

The fiber is derived from waste material of tire cord factory products. The main constitutive substance of this fiber is nylon 6–6. High resistance against heat, fatigue, impact, and sunlight, and high resilience are some of the valuable characteristics of this fiber, which is usually used in tire and seat belt of vehicles, fishnet, reinforced hoses, and so on. In tire cord company, quality control unit regularly tests samples of productions based on tensile strength, tensile strain at failure point, H-adhesion test, absorption percentage of resorcinol formaldehyde latex (RFL) which is used for adhesion between the interface of fiber and rubber, and hot air thermal shrinkage. The products which do not satisfy particular standards and also, some fibers which become torn in tire production process are discarded as waste products. Usually 10% of nominal production capacity of tire cord factories is waste material. Fig. 2 shows tire cord with 20 mm length and its properties are given in Table 3.

2.3. Sample preparation and test procedures

According to requirements of ASTM D5102, cylindrical specimen with 57 mm diameter and 120 mm height was selected for unconfined compressive test. Based on pre-test results, the lime contents of 0%, 4%, and 8% and fiber contents of 0%, 0.5%, 1%, and 1.5% by weight of dry soil were selected for examining the behavior of fiber in different matrix (i.e. 0% lime for unstabilized soil matrix, 4% for well stabilized soil matrix, and 8% for a matrix soil with extra lime).

For every combination, weight of each material was determined exactly based on the optimum moisture content and maximum dry density which is obtained from the standard Proctor compaction test. Clay and lime were mixed in dry condition properly. Then, water was added gradually and mixture was pushed to pass from sieve No. 10 for pulverizing crumbs. Afterwards, fiber was mixed until a uniform mixture was formed. The uniformity of distribution was checked by eye observation.

For exchanging moisture among particles and forming homogenous blend, the mixtures were kept in plastic bags for 24 h. Weight of each specimen was determined in accordance with given specimen volume and obtained maximum dry density from compaction tests. This weight was divided into four portions and each portion was

Table 1
Properties of Zonouz clay.

Soil properties	Values
Specific gravity	2.69
Liquid limit	41.3%
Plastic limit	25.2%
Plasticity index	16.1%
USCS classification	CL
Optimum moisture	25.15%
Maximum dry density	15.06 kN/m^3
PH	9.69