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Research paper

Preparation of scrap tire rubber fiber–silica fume mixtures for modification of clayey soils

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ABSTRACT

This experimental work was performed to investigate the influence of silica fume–scrap tire rubber fiber mixture inclusion on the geotechnical properties of clayey soils. The natural and modified clayey soil samples were subjected to the unconfined compression, the shear box, the odometer and the falling-head permeability tests after compaction at optimum moisture content. The results of experimental research indicated that silica fume, fiber and silica fume–fiber mixture modification enhanced both the unconfined compression strength and strength parameters. Although, the fiber modification increased in the hydraulic conductivity, it decreased in the swelling pressure. It was observed also that the silica fume and silica fume–fiber modification decreased both the hydraulic conductivity and swelling pressure. Consequently, it is concluded that the silica fume–fiber mixture materials can be successfully used for the modifications of clayey soils in the geotechnical applications.

1. Introduction

Construction of buildings and other civil engineering structures on weak or soft soil is highly risky because such soil is susceptible to differential settlements due to its poor shear strength and high compressibility. Improvement of certain desired properties like bearing capacity, shear strength parameters and permeability characteristics of soil can be undertaken by a variety of round improvement techniques such as the use of prefabricated vertical drains or soil stabilization (Abuel-Naga et al., 2006; Chu et al., 2006; Tang et al., 2007).

The concept of earth modification is an ancient technique and demonstrated abundantly in nature by animals, birds and the action of tree roots (Prabakar and Sridhar, 2002). Constructions using these techniques are known to have existed in the fifth and fourth millennium BC (Jones, 1985). Randomly distributed fiber-modified soils have recently attracted increasing attention in geotechnical engineering (Yetimoglu and Salbas, 2003). Vidal (1969) firstly developed the concept of soil modification and he demonstrated that the introduction of modification elements in a soil mass increases the shear resistance of the medium. The primary purpose of modifying soil mass is to improve its stability, increase its bearing capacity, and reduce settlements and lateral deformation (Akbulut et al, 2007; Hausmann, 1990; Kalkan, 2012; Prabakar and Sridhar, 2002; Yarbasi et al., 2007).

Several soil modification methods are available for modifying clayey soils. These methods include modification with chemical additives, rewetting, soil replacement, compaction control, moisture control, surcharge loading, and thermal methods (Chen, 1988; Nelson and Miller, 1992; Steinberg, 1998). All these methods may have the disadvantages of being ineffective and expensive. Therefore, new methods are still being researched to increase the strength properties and to reduce the swell behaviors of clayey soils (Puppala and Musenda, 2002). Many investigators have experienced on natural, fabricated, and by-product materials to use them as additive materials for the modification of clayey soils (Aitcin et al., 1984; Akbulut et al., 2004; Akbulut et al., 2007; Asavasipit et al., 2001; Cetin et al., 2006; Kalkan and Akbulut, 2004; Kalkan, 2006; Kayabali, 1997; Prabakar et al., 2004; Sandra and Jeffrey, 1992).

Recently, there have been many experimental researches on the reinforcement of soils with randomly disturbed natural and synthetic fiber materials (Akbulut et al., 2007; Cetin et al., 2006; Charan, 1995; Gray and Ohashi, 1983; Kaniraj and Havanagi, 2001; Maher and Gray, 1990; Nataraj and McManis, 1997; Park and Tan, 2005; Pierce and Blackwell, 2003; Prabakar and Sridhar, 2002; Ranjan et al., 1996; Santoni et al., 2001; Tang et al., 2007, 2010). These previous investigations indicate that strength properties of fiber-reinforced soils consisting of randomly distributed fibers are a function of fiber content and fiber–surface friction along with the soil and fiber strength characteristics. The use of fibers in geotechnical design and application is a major focus of several research studies because fiber materials are cost-competitive with other materials (Gregory and Chill, 1998; Musenda, 1999; Puppala and Musenda, 1998). In addition, these fiber materials can be recycled from plastic and rubber waste materials, so the fiber stabilization of soils method can potentially reduce (Akbulut et al., 2007).

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Randomly distributed fibers acting as new modification material have become a focus of intense interest in recent years. In comparison with conventional modification materials, the mixing of discrete fibers with soil mass is simple and quite similar to other admixtures such as cement and lime. One of the primary advantages of randomly distributed fibers is the absence of potential planes of weakness that can develop parallel to oriented modification (Maher and Gray, 1990). Therefore, they have attracted the attention of scientists worldwide, and a number of triaxial tests, unconfined compression tests, California Bearing Ratio tests, direct shear tests on this subject have been conducted (Cai et al., 2006; Consoli et al., 2009; Kaniraj and Havanagi, 2001; Karahan and Atiş, 2011 Latha and Murthy, 2007; Park, 2009; Prabakar and Sridhar, 2002; Ranjan et al.,1996; Santoni et al., 2001; Tang et al., 2007; Yetimoglu and Salbas, 2003; Yetimoglu et al., 2005). Consoli et al. (1998) added the randomly distributed fibers to cemented soil, conducted triaxial compression tests on the mixture, and concluded that the fiber modification increased both the peak and residual strength, and changed the cemented soil's brittle behavior to a more ductile one. The inclusion of fibers significantly changed the failure mechanism by preventing the formation of tension cracks (Consoli et al., 2003). Miller and Rifai (2004) reported that the shrinkage crack reduction and hydraulic conductivity of compacted clay soil increased with an increase in fiber content. All these investigations show that the inclusion of discrete fibers can improve the strength behavior, and significantly enhance the ductility and fracture toughness of soil matrix. It has been proved that discrete fibers can be considered as good earth modification material (Tang et al., 2010).

The main objective of this paper is to investigate the use of waste materials such as silica fume and scrap tire rubber fiber in geotechnical applications and to evaluate the effects of scrap tire rubber fiber and scrap tire rubber fiber–silica fume mixture on the unconfined compressive strength (UCS) and strength parameters such as cohesion and internal friction angle, hydraulic conductivity and swelling pressure of clayey soils. The data of UCS were obtained from the compression tests, strength parameters from the shear box tests, swelling pressure from odometer tests and hydraulic conductivity from the falling-head permeability tests under laboratory conditions.

2. Materials

2.1. Clayey soil

The clayey soil was supplied from the clay deposits of Oltu Oligocene sedimentary basin, Erzurum, Northeast Turkey. It consists of montmorillonite and quartz and calcite non-clay minerals. According to the United Soil Classification System, this soil is inorganic clay of high plasticity (CH) and highly compressible inorganic silt and organic clay (MH) (Kalkan, 2003; Kalkan and Bayraktutan, 2008). The grain-size distribution and XRD pattern of clayey soil are given in Figs. 1 and 2. Its chemical composition and engineering properties are summarized in Tables 1 and 2, respectively.

2.2. Silica fume

Silica fume used in this experimental study has been supplied from Ferro-Chromate Factory in Antalya (Turkey). Silica fume, a very fine solid material generated during silicon metal production, has historically been considered a waste product. It is a by-product of producing silicon metal or ferrosilicon alloys. Although the silica fume is a waste of industrial materials, it has become the most valuable by-product pozzolanic materials due to its very active and high pozzolanic property. One of the most beneficial uses for silica fume is in concrete. Because of its chemical and physical properties, it is a very reactive pozzolan (Atis et al., 2005; Kalkan and Akbulut, 2004). The grain-size distribution of silica fume is shown in Fig. 1. Its chemical composition and index properties are summarized in Tables 1 and 2, respectively.

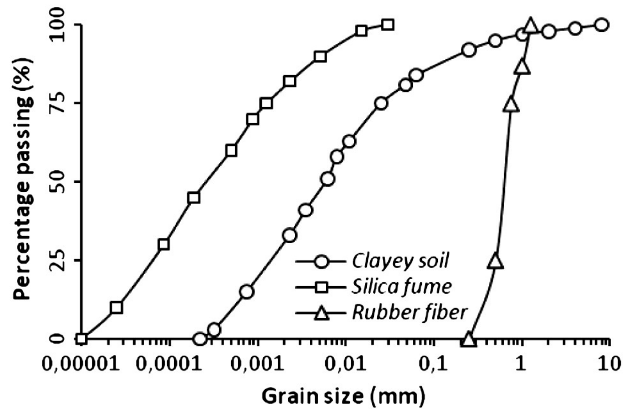

Fig. 1. The grain-size distributions of clayey soil, silica fume and scrap tire rubber fiber.

2.3. Scrap tire rubber fiber

The scrap tire rubber fibers were supplied from local recapping truck tire producers in Erzurum, Northeast Turkey. When the tread on truck tires are down, it is more economical to stave off the old tread and replace it than to purchase brand new tires. The tire is shaved off into 150 mm length and smaller strips using a sharp rotating disc. These strips are then ground into scrap rubber (Akbulut et al., 2007; Pierce and Blackwell, 2003). The scrap tire rubber fibers were sieved to remove finer and coarse fiber particles. They had length ranging from 5 to 10 mm, thickness ranging from 0.25 to 0.50 mm and width ranging from 0.25 to 1.25 mm. The grain-size distribution was determined by using fiber width. The grain-size distribution and engineering properties of scrap tire rubber fiber used in this study are summarized in Fig. 1 and Table 3, respectively.

3. Experimental study

3.1. Preparation of mixtures

The clayey soil used in this study has been dried in an oven at approximately 65 °C and then ground before using the mixtures. First, the required amounts of clayey soils, silica fume and scrap tire rubber fiber have been blended together under dry conditions. The contents of silica fume are 10 and 20% by the total weight of mixtures. In the same way, the contents of scrap tire rubber fiber were chosen as 1, 2, 3 and 4% by total weight of mixtures. As the fibers tended to lump together, considerable care and time were spent to get a homogeneous distribution of the fibers in the mixtures. Then the prepared

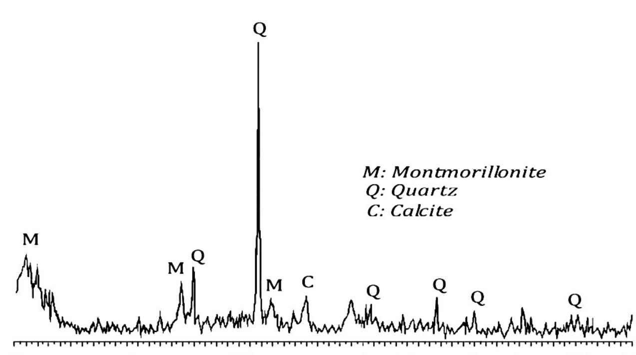

Fig. 2. XRD pattern of clayey soil.