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Mechanical properties of soil reinforced with both lime and four kinds of fiber

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HIGHLIGHTS

- Plant fibers and polypropylene fiber are suitable as reinforcement materials.
- The optimal fiber content and fiber length are drawn by means of UCS.
- Reinforcement increases the cohesion and the internal friction angle of lime-soil.
- The triaxial compressive test is carried out in terms of four reinforcement zones.

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ABSTRACT

Soil was solidified with both lime and fibers to investigate the mechanical properties of the soil. Wheat straw, rice straw, jute and polypropylene fiber was added to the soil and lime-soil respectively. Unconfined compressive test of the fiber-soil was conducted to confirm the optimal fiber content and optimal fiber length. Triaxial compressive test of fiber-lime-soil was carried out to study the shear strength, deviatoric stress-strain properties and sample failure pattern. The results are as follows: Optimal fiber content was 0.2% or 0.25%, and the optimal fiber length was 30% or 40% of the sample diameter. Reinforcement significantly increased the cohesion and lightly improved the internal friction angle. The cohesion increments of polypropylene fiber-lime-soil, jute-lime-soil, rice straw-lime-soil and wheat straw-lime-soil were decreased in turn. The four kinds of fiber may all improve the strength and deviatoric stress-strain properties of soil and lime-soil, in which polypropylene fiber for reinforcement is the best.

1. Introduction

Soil is traditionally solidified with lime. Lime-soil has better properties in improving the strength [1–3], but it is characterized with poor tensile strength and strong cracking. As a further improvement, fibers are added into lime-soil to enhance the mechanical properties, and to reduce the vertical and lateral deformation [4–6]. Fiber-soil has been attracting attention in geotechnical engineering [7].

Fiber is generally divided into two categories: one is the plant fiber like wheat straw, coir, bagasse, sisal, and jute, etc. because they have the advantages of availability and low cost [8–10]. Others are synthetic fibers, such as polypropylene fiber, polyvinyl alcohol fiber, nylon fiber, etc. They have higher tensile strength, better corrosion resistance and durability [11–13].

The fibers may enhance the mechanical properties of soil by the means of interface friction between fibers and soil particles and the spatial confined effect of fibers [14,15]. The addition of less fiber could not create significant friction effect, whereas those excess fibers had an adverse impact on the strength and deformation resistance of soil [16–18]. Hence, the fiber content and fiber length are the key parameter associated with the mechanical properties of the fiber-soil.

The unconfined compressive test results of sisal-black cotton soil showed that the strength and deformation resistance of soil increased with the increase of sisal content and sisal length and had an optimal fiber content and fiber length. At the same time, the addition of fiber decreased the maximum dry density and optimal moisture content of the soil [19]. The coir fiber was added to the fly ash-soil, the coir content of 0.25%, 0.5%, 0.75% and 1% by dry weight of soil, the shear strength of coir-fly ash-soil increased

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with the increase of fiber content [20]. The addition of polypropylene fiber (0.05%, 0.15% and 0.25% by dry weight of soil) restricted soil particles slide and enhanced the unconfined compressive strength (UCS), shear strength and residual strength, and decreased the brittleness of cement-soil [21–23].

Tajdini et al. conducted the unconfined compressive test and tensile test of soil reinforced with jute, polypropylene fiber and steel fiber, the results indicated that adding fibers to cement-soil dramatically improved the compressive strength, tensile strength and flexural strength of cement-soil, and fibers played an important role in changing the behavior of the fiber-cement-soil from brittle to ductile [24].

In this study, wheat straw, rice straw, jute and polypropylene fiber was used to reinforce soil and lime-soil respectively. The surface of wheat straw is smooth, that of rice straw and jute is rough, and polypropylene fiber has the characteristics of smooth surface and high tensile strength [18,25]. The unconfined compressive test of fiber-soil and the triaxial compressive test of fiber-lime-soil were carried out.

2. Materials and testing methods

2.1. Test plan

The tests were conducted in two stages. The first stage was the unconfined compressive test of soil and fiber-soil. It is convenient to prepare a series of samples at some fiber contents and the fiber lengths in order to determine the optimal fiber content and the optimal fiber length.

Based on previous research results [26,27], the fiber content was 0.1%, 0.15%, 0.2%, 0.25% and 0.3% in this paper. In view of the sample diameter was 61.8 mm, the fiber length should be less than half of the sample diameter to prevent the fibers from folding, so the fiber length was 6, 12, 19, 25 and 31 mm. The samples were non-reinforced soil, wheat straw-soil(WS-S), rice straw-soil(RS-S), jute-soil(J-S) and Polypropylene fiber-soil(PP-S).

In the engineering, the soil is mainly shear failure in the condition of three-dimensional stress, and fiber-soil cannot meet the requirements on strength and deformation of embankment and foundation. Therefore, the second stage was the triaxial compressive test of fiber-lime-soil in order to study the shear strength and deviatoric stress-strain properties. The samples were lime-soil, wheat straw-lime-soil(WS-L-S), rice straw-lime-soil (RS-L-S), jute-lime-soil(J-L-S) and polypropylene fiber-lime-soil(PP-L-S). The samples were prepared in the condition of three fiber contents, three fiber lengths and four reinforcement zones (reinforcement in the whole zone, the upper zone, the lower zone and the middle zone of the sample).

The purpose for addition of part of the soil sample is to adapt to several conditions of embankment so as to reduce construction cost. (1) The embankment is higher, the load is smaller on road, the reinforcement only in the upper zone of the embankment is enough to meet the requirement on the strength and deformation of soil. (2) The ground surface soil is soft. It is necessary to enhance the strength and deformation resistance of the soil of the lower embankment so as to coordinate the deformation of the embankment. (3) In order to compare with the reinforcement effect of the whole zone, the upper zone and the lower zone respectively, the reinforcement sample of middle zone was prepared.

2.2. Materials

2.2.1. Soil

The soil, a salt content of 2.64%, was collected from coastal area in Tianjin, China, and was air dried and sieved (2 mm). The physical properties indices of soil are presented in Table 1.

Table 1
Physical properties indices of soil.

Properties	Value
Specific gravity	2.72
Grain size distribution	
Gravel (%)	0
Sand (%)	2.2
Silt (%)	62.6
Clay (%)	35.2
Atterberg limits	
Liquid limit (%)	32.6
Plastic limit (%)	16.8
Plasticity index	15.8
Optimal moisture content (%)	18
Maximum dry density (g/m^3)	1.81

2.2.2. Fiber

(1) Wheat straw

The outer epidermis of wheat straw is very dense, and its inner structure is relatively loose. As shown in Fig. 1(a), cross section of wheat straw is honeycomb, and it is easy to decay in humid environment, so anticorrosion of the plant fibers is very important. The wheat straw was immersed in the SH agent (modified polyvinyl, in the form of liquid, made in Lanzhou University, China.) for 3 days and then air dried, which reduced its water absorption performance and enhanced its tensile ability [28]. The physical and mechanical properties of natural wheat straw and wheat straw immersed in SH agent for 3 days are reported in Table 2.

(2) Rice straw

As shown in Fig. 1(b), the outer epidermis of rice straw is rough, its middle and inner layer is loose, and the cross section is of multilayer and tubular with large pores. The physical and mechanical properties of natural rice straw and rice straw immersed SH agent are presented in Table 2. The tensile strength and elongation of rice straw is slightly better than that of wheat straw.

(3) Jute

As presented in Fig. 1(c), the cross section of jute is an irregular polygon with large pore. The physical and mechanical properties are summarized in Table 2. The tensile strength is greater than that of wheat straw and rice straw. Its surface roughness is superior to that of wheat straw and inferior to that of rice straw.

(4) Polypropylene fiber

Polypropylene fiber is one of the most common synthetic materials used for reinforcing soil due to its nontoxicity, corrosion resistance and high tensile strength. The physical and mechanical properties are presented in Table 2.

2.2.3. Lime

Lime is sieved (2 mm), and the properties of lime are shown in Table 3.

2.3. Testing methods

2.3.1. Prepared sample

The sample, moisture content of 18%, dry density of 1.74 g/cm^3, was 61.8 mm in diameter and 125 mm in height. Lime content was 8% of dry weight of soil [29]. The curing room is relative humidity of 95%, the temperature of 20 °C, and the curing age of 28 d.