

Study on the impact of a biopolymer-fiber combination on soil reinforcement

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Abstract. Due to environmental concerns, the search for eco-friendly and efficient soil reinforcement has become urgent in recent. In this paper, the low-carbon and environment-friendly materials biopolymer and fibers were used for soil reinforcement. Direct shear tests were carried out to determine the reinforcement effect, results show that the shear strength of soil increases first and then decreases with the increase of fiber content, it reaches to the peak value at the content of 0.5%. Biopolymer increases soil shear strength and 0.5% content presents most effective strengthening effect. When biopolymer and fibers are mixed into soil, it shows better reinforced effect than the sum of individual efforts.

Keywords: component; fiber; biopolymer; multiplying effect; soil reinforcement

1. Introduction

In geotechnical engineering, it is unavoidable to encounter some soil that cannot match the requirements for building. Thus, the searching of suitable soil stabilization method is necessary. Traditional soil reinforcement technology mainly includes physical and chemical reinforcement methods [1]. The physical methods can increase the compactness and friction of soil [2-4], while the chemical methods use chemical additives such as cement and lime to stabilize soil. Chemical additives can improve soil particle interaction through a sequence of chemical processes that boost soil aggregation and cementation. However, the extensive use of cement and lime will cause damage to the surrounding environment. Meanwhile, the production of cement consumes a lot of energy, emits greenhouse gases, and produces dust, sulphide and other toxic compounds [5]. With the national goal of carbon neutrality and carbon peaking, it is urgent to find a low-carbon and environmentally friendly for soil reinforcement.

In recent years, many researchers try to replace traditional chemical additives with biological materials such as enzymes, microorganisms, resins, acids and biopolymers [6]. Biopolymers are high-molecular chain polysaccharide polymers produced by algae, bacteria, and fungi consuming carbon dioxide during the cultivation process. Biopolymer xanthan gum can significantly improve the shear strength and unconfined compressive strength of soil through agglomeration and adsorption, while reducing the collapsible potential of soil [7, 8]; β -1,3/1,6-glucan biopolymer greatly improves the compressive strength of soil by forming ionic bonds with clay particles [9]. Biopolymers show impressive strength in improving soil engineering properties [10-12]. However, the biopolymer reinforced soil commonly exhibits brittle behavior [13, 14]. At the same time, the fiber reinforcement methods have attracted the attention of researchers for its little impact on the environment, the advantages of low cost and convenient construction [15, 16]. Adding fiber into soil can increase the stiffness, peak strength and residual strength of soil, improve the brittle failure behavior of soil and enhance its ductility [17-19].

In this research, the high modulus and flexible fibers are mixed with biopolymer to reinforce soil. A series of direct shear tests were conducted to explore the shear strength of fiber reinforced soil, biopolymer reinforced soil and fiber-biopolymer reinforced soil. Besides the reinforced effect of these three methods were compared and analyzed.

2. Materials and methods

2.1 Materials

The sandy soil used in this test is a well-graded and commonly used type of sand taken from a construction site in Wuhan, The basic properties of the soil are tested according to the ASTM D2487, the results are shown in Table 1 and Figure 1.

The biopolymer used in this test is xanthan gum, it is a kind of polysaccharide produced by the bacterium *Xanthomonas* [20]. It has been proved to be a good cement material for soil stabilization [21].

The fibers are polypropylene fibers with a diameter of 20 μm and a length of 12 mm. Tensile tests are carried out according to the ASTM D7556-10. The results show that the tensile strength of polypropylene fibers is 500 MPa, the elastic modulus is 4000 MPa, and the elongation is 25%. The picture of sandy soil, polypropylene fibers and biopolymer xanthan gum used in this experiment are shown in figure 2.

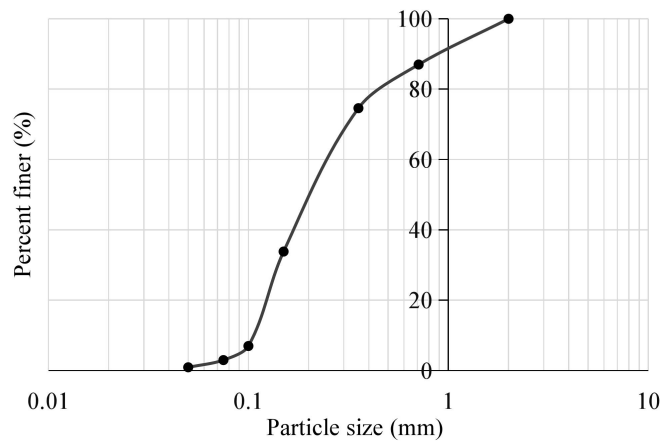


Fig 1. The grain size distribution curve of the soil.

Table 1. The basic properties indices of soil.

Property	value
Specific gravity	2.51
Maximum dry unit weight (kN/m^3)	17.56
Optimum moisture content (%)	12.14

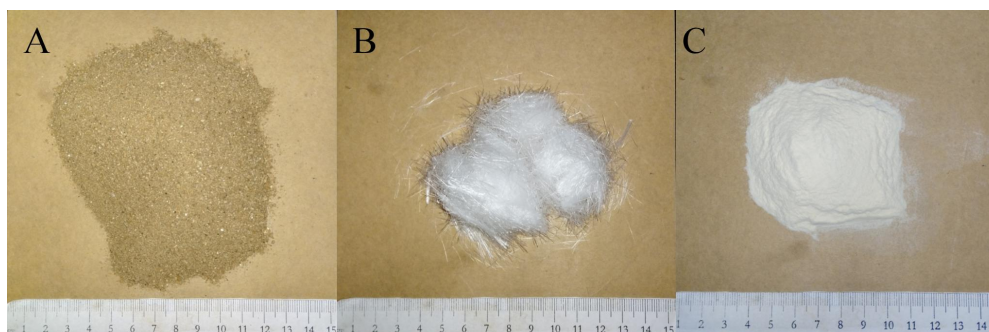


Fig 2. The (A) Sand, (B) Polypropylene fibers, (C) Biopolymer xanthan gum, used in this test.

2.2 Sample preparation and direct shearing test

The shear strength of plain soil, fiber reinforced soil, biopolymer reinforced soil and biopolymer-fiber reinforced soil were tested and compared in this research. The dried sandy soil

was mixed with the designed content of polypropylene fibers (0.25%, 0.5%, 1%, respectively) and biopolymer (0.25%, 0.5%, 1%, respectively), and then water was added to the optimum moisture content (12%). For the homogeneous mixing of these materials in soil, samples were cured in room condition for 12 hours. The samples were made at a compaction degree of 95% when the dry density of the samples was 1.58 g/cm³. After sample preparation, they were placed in a 60° oven for 12 hours. And then the specimens were subjected to direct shear tests under normal stresses of 50, 100, and 200 kPa, respectively. According to ASTM D5321, the shear rate was set at 0.8 mm/min. Three parallel specimens were prepared for each group of samples.

3. Results and discussions

Direct shear tests results of fiber reinforced soil are shown in figure 3A. The shear strength of fiber reinforced soil increases with the increase of fiber content. When the fiber content increases to 0.5%, the shear strength reaches the peak value, and then it decreases. At the fiber content of 0.5%, the fiber reinforced soil shows its best reinforcement effect, thus 0.5% is the optimal fiber content.

Direct shear test results of biopolymer reinforced soil with different biopolymer contents are shown in figure 3B. The shear strength of biopolymer reinforced soil increases with the increase of biopolymer content under the vertical loads of 50, 100, and 200 kPa. When the biopolymer content exceeds 0.5%, the improvement effect in shear strength slows down, and the strength curve turns to an inflection point. For economical consideration, 0.5% is generally used as the effective addition amount of biopolymer.

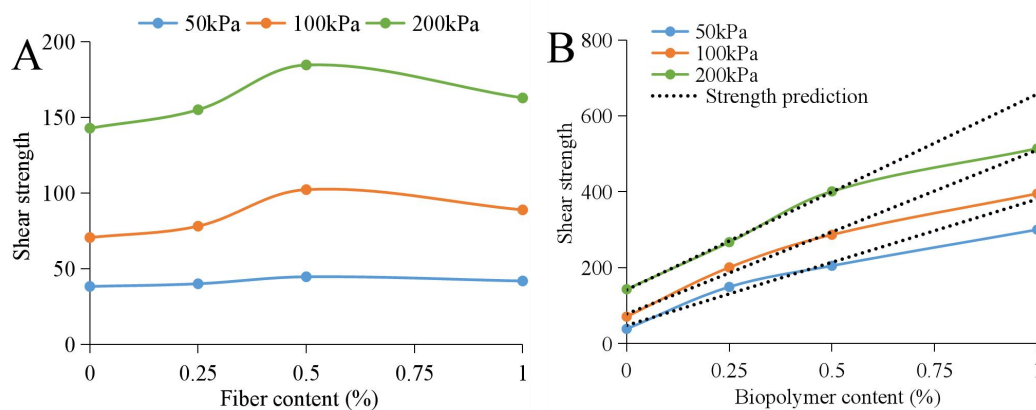


Fig 3. The shear strength of (A) fiber reinforced soil and (B) biopolymer reinforced soil (strength prediction is based on the strength trend at low xanthan gum content)

Table 2. The friction angle (σ) and cohesion (C) of soil.

	Plain soil	Fiber reinforced soil			Biopolymer reinforced soil		
Content		0.25%	0.5%	1%	0.25%	0.5%	1%
Friction angle ($^{\circ}$)	35.03	37.49	42.54	38.56	37.55	52.09	54.32
cohesion (kPa)	2.26	1.68	3.62	5	115.84	147.66	240.51

The friction angle and cohesion of fiber-reinforced soil and biopolymer reinforced soil are shown in Table 2. The addition of fibers increases the friction angle of the soil, while adding biopolymer increases both the friction angle and cohesion of the soil. In the same amount of addition, the biopolymer shows better reinforcement effect on the soil than fibers.

The polypropylene fibers uniformly dispersed in the soil and intertwined with the soil particles to form a spatial network structure. When subjected to external force, the occlusal friction forces and space constraint forces are generated between the soil and the fiber, and the overall joint force is coordinated and deformed [22, 23]. The rough surface soil particles have a strong friction effect with the polypropylene fiber surface, which increases the friction angle of the soil effectively. With the increase of fiber content, the contact area between fibers and soil particles increases, and the

reinforcement effect of fibers increases significantly. But excessive fibers will be entangled into agglomerates, which reduces the denseness of soil and leads to strength reduction instead [24].

Biopolymers can form high viscosity hydrogels when dissolved in water [11, 25]. With the dehydration and shrinkage of the hydrogel, it fills the pores between the soil particles and connects the soil particles, improving the mechanical properties of the matrix, which leads to the increase of friction angle and cohesion of biopolymer reinforced soil [26, 27]. As the increase of biopolymer content, the filling effect to soil matrix pores and the connection effect of soil particles are enhanced, thus increase the reinforcement effecf of biopolymer. At the conditon of high biopolymer content, the distribution of hydrogels in soil becomes nonuniformity. This cause the decrease of biopolymer's enhancing efficiency in soil strength.

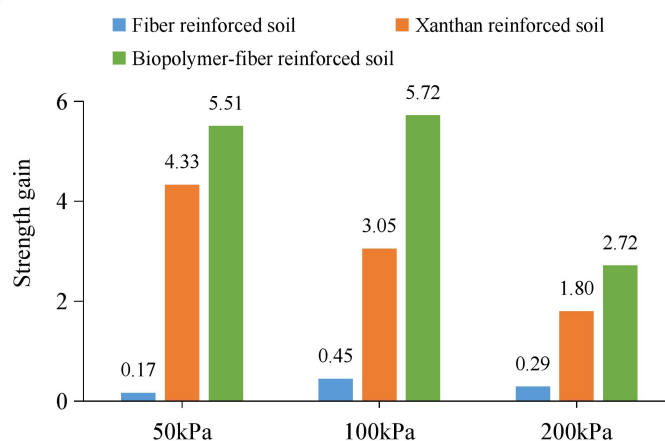


Figure 4. The strength gain of reinforced soil

Fiber affects soil properties through friction and entanglement between reinforcement and soil, while biopolymers significantly enhance the interaction between soil particles. Both of them can effectively enhance the strength of soil. However, there is still a lack of research on combining effect of these two soil reinforcement materials on soil. In this paper, the optimal addition amount of fiber (0.5%) and the effective addition amount of biopolymer (0.5%) were selected to form biopolymer-fiber reinforced soil. In order to compare the reinforcement effect of biopolymer-fiber, biopolymer and fiber directly. The strength of plain soil was taken as the base to calculate the strength gain of reinforced soil under each normal stress

*Strength gain = (reinforced soil strength - plain soil strength) / plain soil strength.

The results are shown in figure 4. Under different normal stresses, the strength gain of the biopolymer-fiber reinforced soil gets greater than the sum of the strength increases of adding biopolymer and fiber separately. Biopolymer attaches to the surface of fibers and soil particles, can not only fill the intergranular pores and improve the microstructure of soil, but also enhance the interaction between soil particles and fibers, thereby improving the mechanical properties of soil. At the same time, the spatial network structure formed by the fibers provides a space skeleton for the biopolymer reinforced soil. When the soil is subjected to external force, the existence of the space skeleton increases the ductility and reduces the brittleness of the soil [28]. Under the coaction of biopolymer and fibers, it shows multiplying effect. The schematic diagram of the interaction among biopolymer, fibers and soil particles is shown in figure 5.

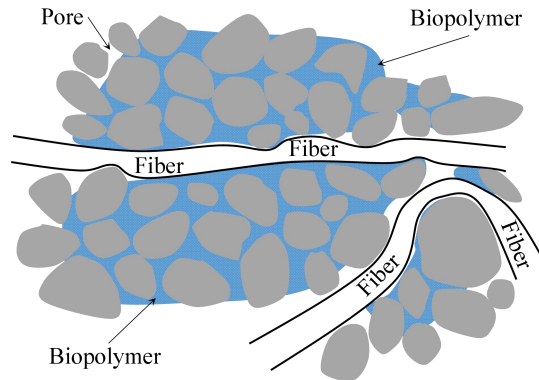


Figure 5. Schematic diagram of the action mechanism of biopolymer-fiber composite soil

4. Conclusion

In this paper, the effects of fiber, biopolymer and their combination on soil strength under different additions were studied through direct shear tests. From the results of this study, the conclusions can be drawn as follows:

- (1) The shear strength of soil increased first and then decreased with the increase of fiber adding content, and the soil strength reached its peak when the fiber content is 0.5%.
- (2) The shear strength of soil increases with the increase of biopolymer content in soil. At high concentration of biopolymer, the increase of soil strength gradually slows down, and the soil strength curve shows an inflection point at 0.5% of biopolymer content.
- (3) Fibers increase the friction angle of soil through friction and entanglement between fiber and soil, while biopolymer increase both the friction angle and cohesion of soil by enhancing the interaction between soil particles. The biopolymer shows a better reinforcement effect on soil than that of fibers. The strength increase of the biopolymer-fiber reinforced soil is greater than the sum of the strength increases when the two are added individually.

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