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Research on Shear Strength and Permeability Characteristics of Basalt Fiber-Reinforced Tailings

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Abstract. Tailings fiber-reinforcing technology can effectively improve the tailings' property. In order to study the strength and permeability characteristics of basalt fiber-reinforced tailings, a tailings in Yunnan Province is taken as the research object, basalt fiber is reinforced material, The direct shear tests and permeability tests with different fiber lengths and fiber content to tailings by weight were carried out on basalt fiber-reinforced tailings The fiber length of 3mm, 9mm, 12mm and the fiber content percentage by weight to tailings of 0.6%, 0.9%, 1.2% was selected in the experiment. The results show that the basalt fiber can effectively improve the shear strength of the tailings. Under the same fiber length, the shear strength and cohesion of the fiber-reinforced tailings increase with the increase of fiber mass content. The cohesion increases with the fiber getting longer. When the fiber length is 9mm and the ratio to tailings by weight is 1.2%, the cohesion increased by 305.74%, which is maximum. Overall, the internal friction angle does not alter a lot. When the fiber is 12mm or fiber ratio to tailings by weight is 0.6%, the internal friction angle is always less than that of raw tailings regardless of fiber content and length. Permeability coefficient is always greater than that of raw tailings regardless of fiber length on the condition that fiber content is 1.2%. The 12mm long fiber-reinforced tailings' permeability coefficient is always greater than that of 3mm long fiber-reinforced tailings.

1. Introduction

In the process of construction, the construction schedule would usually be hindered if the property of the rock or soil cannot meet the standard requirements, the construction schedule would usually be hindered. Measures must be taken to improve its performance. Fiber-reinforced technology is a helpful way. It is widely used in retaining walls, dams, embankments, slope protection and other projects to improve the performance of the project. Currently, the materials used for reinforcement are mainly natural fibers such as wheat straw fiber [1], coconut shell fiber [2], jute fiber [3], basalt fiber [4-6] et al.; synthetic fiber: polypropylene fiber [7 -8], glass fiber, [9]et al.; and some other materials: bamboo, scrap tires, straw, Set aria [10-13] et al.

Hu Xiaoping, et al. studied polypropylene fiber-reinforced soil and found that the addition of fiber can improve the compressive, shear and deformation characteristics of the soil, fiber can improve the cohesion of the soil, but has little effect on the internal friction angle [14]. The test of basalt fiber-reinforced clay by GAO Lei et al. in reference [4] showed that the internal friction angle of the basalt fiber-reinforced clay did not change much when the fiber content is less than 0.25%. When the content reached 0.35%, the internal friction angle suddenly increased. The interfacial interaction between fiber and soil particles mainly includes gripping effect of single fiber and fiber-net effect. In reference [2], Chang Zhou, et al. found that the influence on permeability coefficient of coconut fiber and double polyethylene material's content is clear. WANG De-yin, et al. based on the SEM analysis, concluded that the 1D reinforcing effect of a single fiber and the 3D reinforcing effect of fiber mesh are the dominant mechanisms of fiber-reinforced soils, which are conditioned by the interfacial mechanical interactions between fiber and soil particles. Fibers on the shear surface may be either pulled out or broken during shear [15]. BAI Japing, et al. studied the influence of georgic and geotextile on the permeability coefficient of tailing sand under different rein-for cement densities was studied by the combined methods of theoretical analysis,permeability test and numerical simulation.They found that both the reinforcement ways of georgic and geotextile will reduce the permeability coefficient of tailing sand [16].

Tailings impoundment is a man-made debris flow hazard with high potential energy. Once the tailings dam broke down, it would cause serious damage. The strength of tailings dam and the height of saturation line have significant influence on the stability of tailings dam. The present research on fiber-reinforcement technology mainly focuses on the strength and mechanical properties of fiber-reinforced soil or sand. There are a few papers study the strength and permeability of basalt fiber-reinforced tailings. In this paper, basalt fiber was added into raw tailings where the length and content of basalt fiber were under control, and direct shear and permeability tests on basalt fiber-reinforced tailings samples were followed. Then the effects of fiber length and content on the shear strength, cohesion, and internal friction angle and permeability coefficient of basalt fiber-reinforced tailings were analyzed. The experiment purpose is to provide some suggestions on how to enhance the safety factor and improve the stability of tailings dam.

2. Experimental procedure

2.1. Experiment material

The experiment tailings samples were taken from a tailings impoundment of Yunnan Province, China, and the experimental fiber for use is basalt fiber. Basalt fiber is inorganic fiber made from natural basalt ore's high temperature melting, drawing and cooling. Which demonstrate high tensile strength and elastic modulus, great corrosion resistance and chemical stability and other fine properties. Basalt fibers usually bind together into bundles. They should be separated manually before added to raw tailings samples and then mixed the mixture so the basalt fiber could distribute evenly in the raw tailings. The physical and mechanical properties of the basalt fiber used in the experiment are shown in Table 1.

Table 1. Basalt fiber's physical and mechanical properties

Density /g.cm-3	Tensile Strength/MPa	Fracture Strength/MPa	Elastic Modulus/GPa	Acid and Alkali Resistance/%	Breaking Elongation/%
2.7	2650	3200	89	75	3.1

2.2. *Experiment method*

In order to study the effects of different fiber length and mass content on the shear strength, cohesion, internal friction angle and permeability coefficient of the basalt fiber-reinforced tailings, the length l of basalt fiber under control of 3mm, 9mm and 12mm respectively, and the mass content w of basalt fiber was 0.6%,0.9%,1.2%. Direct shear test and variable water head permeability test would be carried out under these conditions. In the preparation of the experiment sample, the fibers should be manually separated into monofilaments and added to raw tailings to be mixed uniformly. Appropriate amount of water was also needed in the process. The experiment samples were prepared and tested in accordance with the "Standard for Soil Test Method".

3. Shear strength of basalt fiber-reinforced tailings

The strength of the tailings particles themselves is far greater than the cohesion strength between the particles. The tailings would be damaged under the action of shear stress if the shear stress greater than or equal to the shear strength. Therefore, the main task of tailings research is the study of tailings' shear strength. The tailings shear strength can be expressed by Mohr-Coulomb law

$$\tau = c + \sigma \tan\varphi \tag{1}$$

Where: τ is shear strength; σ is vertical stress; c is cohesion; φ is internal friction angle.

Cohesion and internal friction angle are essential indexes of tailings' shear strength. In direct shear test, take the shear strength for the vertical axis, the vertical stress for the horizontal axis, and plot the straight line graph based on corresponding data respectively. This line is the shear strength line of basalt fiber-reinforced tailings. The inclination of the line refers to internal friction angle, and the intercept refers to cohesion.

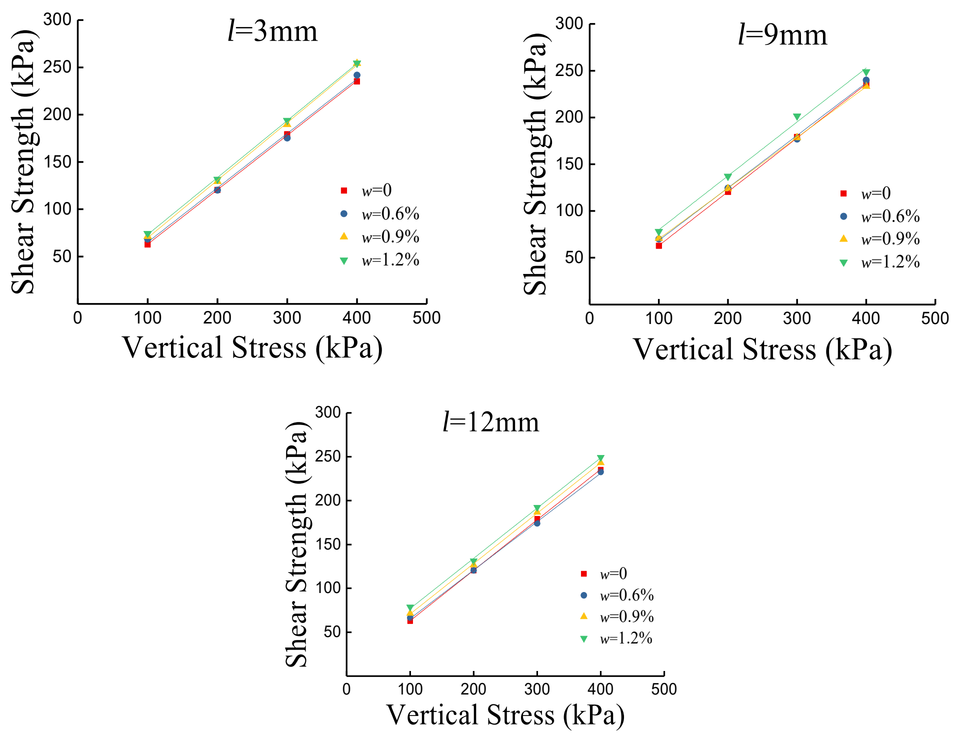

Figure 1. Relationship curve between shear strength and vertical stress of basalt fiber-reinforced tailings under different fiber parameters

As shown Figure 1, the shear strength is increased by 2.8%, 8.07% and 8.2% respectively when the fiber length is 3mm and the fiber content is 0.6%, 0.9% and 1.2%. When the content of fiber is increased from 0.9% to 1.2%, the increment of shear strength is not obvious. When the content of fiber is 1.2%, the increase of shear strength is the largest, with an increment of 8.2%.

The shear strength of basalt fiber-reinforced tailings individually increased by 11.49%, 12.47% and 24.28% when the fiber length was 9mm and fiber content was 0.6%, 0.9% and 1.2%. When the fiber content increased from 0.6% to 0.9%, the increment of shear strength was not significant. While the increase of shear strength is the most significant, with an increment of 24.28%, when the content of fiber is 1.2%.

The shear strength increased by 5.72%, 13.72%, 25.2% when the fiber length was 12mm and the fiber content was 0.6%, 0.9% and 1.2% respectively. Under this fiber length, the basalt fiber-reinforced tailings shear strength's increment differed significantly between different fiber content. It secured the best effect with shear strength increment of 25.2% when the fiber length was 12mm and content is 1.2%.

The above analysis manifests that the basalt fiber added into raw tailings can effectively improve the shear strength of raw tailings, but the margin of improvement in shear strength varied from different fiber parameters. Under the same fiber length, the shear strength of the fiber-reinforced tailings rise up with the increase of fiber content. In this experiment, the fiber-reinforcement effect is the most significant when the fiber content is 1.2%.

3.1. Cohesion of basalt fiber-reinforced tailings

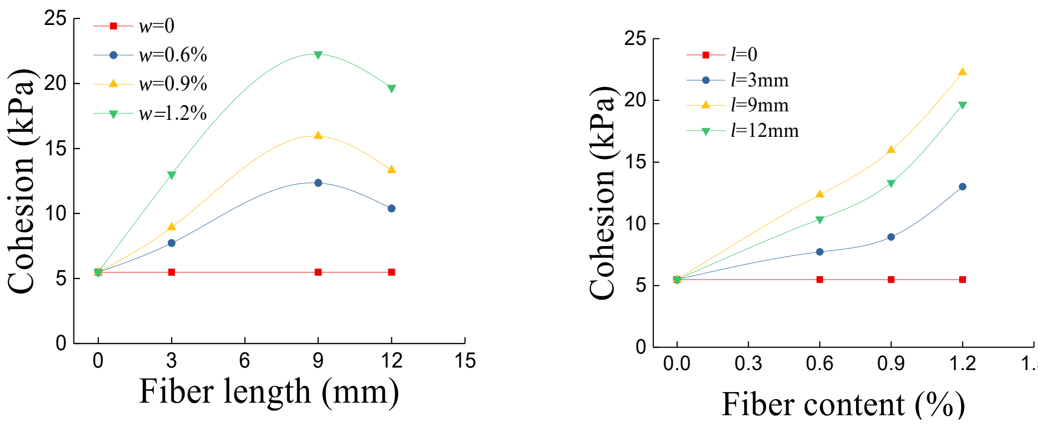

Figure 2. The curve of cohesion of basalt fiber-reinforced tailings with variable fiber parameters

As shown in Figure 2, the cohesion increases after the added of basalt fiber into raw tailings. With the increase of fiber length, the curve of cohesion is similar to the parabola, firstly goes up and then down with fiber content increases. It denotes that the cohesion does not increase all the time with fiber getting longer, but an "optimal value" appears. When the fiber length exceeds the "optimal value", the cohesion decreases instead. In this experiment, when the fiber is 9mm, the cohesion obtains the maximum at each fiber content. The fiber-reinforced tailings cohesion increased by 125.23 %, 190.85%, 305.74% respectively at the fiber content of 0.6%, 0.9%, 1.2% under the length of 9mm.

With the increase of fiber content, the cohesion under each fiber length is positively correlated to fiber content, and shows an increasing trend with fiber content getting larger. That is, under the same fiber length, the higher the content is, the larger the cohesion is, and the maximum is obtained when the content of fiber is 1.2%. When the fiber content is 1.2%, the cohesion of fiber-reinforced tailings with fiber length of 3mm, 9mm and 12mm increase by 137.21%, 305.74% and 258.71% respectively.

3.2. *Internal friction angle of basalt fiber-reinforced tailings*

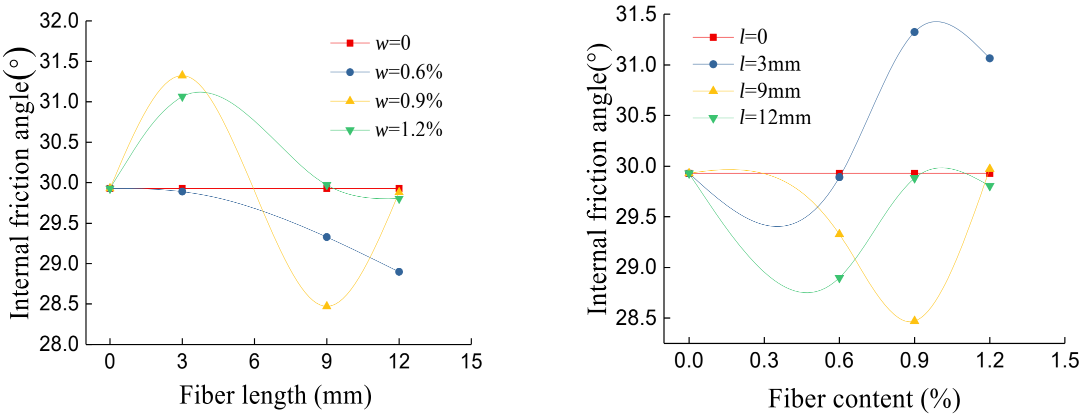

Figure 3. The curve of internal friction angle of basalt fiber-reinforced tailings with fiber parameters

Figure 3 manifests that the four internal friction angle curves does not alter regularly with different fiber length. When the fiber content is 0.6%, the internal friction angle monotonically decreases with the increase of fiber length and gets the minimum at the fiber length of 12mm. When the fiber content is 0.9%, the curve demonstrates that: with the fiber getting longer, the internal friction angle firstly rise up to the maximum, then decreases to the minimum and then increases again, the fluctuation trend is similar to the sine function. Under the fiber length, internal friction angle reaches the maximum and minimum at the fiber length of 3mm and 9mm respectively, the increment and decrement are 4.66% and 4.87% individually. When the fiber content is 1.2%, the internal friction angle firstly increases and then decreases with the augment of the fiber length, and the curve declares a single peak. The internal friction angle is the largest when the fiber length is 3mm. When the fiber is longer than 3mm, the internal friction angle of fiber-reinforced tailings tends to decrease.

When the fiber length is 3mm or 12mm, the curve shows peaks and troughs, the internal friction angle changed with the fiber content shares identical trend, firstly decreases to the minimum, then rise up to the maximum, and then decreases again. the internal friction angle of the fiber-reinforced tailings with length of 12 mm is always smaller than that of the 3 mm fiber reinforced tailings. When the fiber content is more than 0.6%, the internal friction angle of 3mm fiber reinforced tailings is always larger than that of raw tailings, and reaches the maximum at 0.9% fiber content. When the fiber length is 9mm, the internal friction angle firstly goes down and then goes up with the augment of fiber content, and the internal friction angle is the smallest when fiber content is 0.9%.

4. Permeability characteristics of basalt fiber-reinforced tailings

The water in tailings is not in a stable state, but in a state of motion. Under the action of gravity, the behavior of water flowing that is permeability. If the seepage flow in the tailings is laminar flow, the permeability velocity is proportional to the hydraulic gradient, the tailings permeability coefficient equals to the permeability velocity when hydraulic slope equals 1.

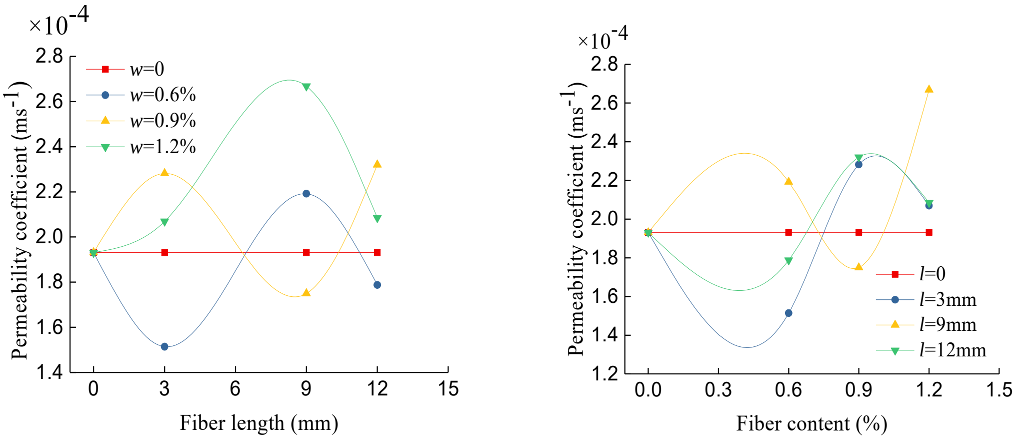

Figure 4. The curve of permeability coefficient of basalt fiber-reinforced tailings with basalt fiber parameters

Figure 4 reveals that, there is no uniform variation trend of the permeability coefficient under various fiber parameters. When the fiber content is 1.2%, the permeability coefficient of the fiber-reinforced tailings firstly rises up and then down with the increase of fiber length, the fluctuation trend is similar to the parabola. However, the permeability coefficient is always greater than that of the raw tailings regardless of the fiber length. And the permeability coefficient is the largest when the fiber length is 9mm, which is 38.16% higher than that of the raw tailings. When the fiber content is 0.9%, the curve of the permeability coefficient k is similar to sine function curve. When the fiber length is 12mm and 9mm, the maximum and minimum of the permeability coefficient are obtained respectively. Compared to raw tailings, the permeability coefficient increases by 20.14% and decreases by 9.41% respectively under the fiber length. When the content is 0.6%, the variation trend of permeability coefficient is opposite to that of 0.9%. The peak and lowest point of the permeability coefficient curve are obtained at 9mm and 3mm respectively, which increased by 13.49% and decreased by 21.6%.

Figure 4 declares that the permeability coefficient shares the same variation trend on the condition that the basalt fiber is 3mm and 12mm. The curve goes down to the lowest point first, then goes up to the peak and then down again, and the maximum and minimum are obtained simultaneously. The permeability coefficient of fiber-reinforced tailings with fiber length of 12 mm is always greater than that of 3 mm. Under the two fiber lengths, the permeability coefficient gets the minimum at fiber content of 0.6%, decreasing by 21.6% and 7.43% respectively. When the fiber content is 0.9%, it reaches the peak and increases by 18.15% and 20.14% respectively. When the fiber length is 9mm, the variation trend is exactly opposite to the fiber length of 3mm and 12mm, and the maximum is obtained at the fiber content of 1.2%.

5. Discussion

The previous analysis concludes that basalt fiber could significantly improve the raw tailings shear strength and cohesion, and may increase the permeability coefficient too. However, cohesion does not increase all the time as the fiber length increases. Instead, an "optimal value" would appear, when the added fiber length surpasses the "optimum value", the cohesion would decrease on the contrary. Reference [4] also encountered the similar phenomenon in the experiment, according to the research results, the reasons for this phenomenon may be analyzed as follows: when the fiber is short, the fiber distributed uniformly in the tailings; the fibers are intertwined with each other to establish the fibrous network structure and interact with the tailings particles to increase fiber-reinforced tailings cohesion. However, when the fiber length exceeds the "optimal value", the fibers are unevenly distributed in the tailings. Some fibers are locally concentrated in the tailings thus instruct "fiber group". Some of the fibers are isolated with the tailings particles, which led to smaller interface force between the tailings particles and fibers. The permeability coefficient decreased under certain fiber parameters after adding the fibers. The reason may be that the added fibers blocked the original interstices between the tailings particles and impeded the water flow path. While the permeability coefficient increased under some fiber parameters. The reason may be that the basalt fiber itself poses permeability, and the added fiber provides seepage channels between the dense tailings particles. The water could flow along the fiber filament thereby the permeability coefficient increased.

When the fiber length is 9mm and content is 1.2%, the basalt fiber-reinforced tailings shear strength increases by 24.28%, the cohesion increases by 305.74% and the permeability coefficient increases by 38.16%. Under these conditions, not only the shear strength but the permeability coefficient effectively improved. It could lower the saturation line and enhance the stability of tailings dam, which is the best state. The experiment results provide some beneficial suggestions on how to improve the safety factor and enhance the stability of tailings dam.

6. Conclusion

(1)The added basalt fiber into raw tailings can effectively improve the shear strength of raw tailings, but the margin of improvement in shear strength varied from different fiber parameters. Under the same fiber length, the shear strength of the fiber-reinforced tailings rises up with the increase of fiber content. When the fiber content is 1.2%, the enhance effect is the most significant.

(2)Under the same fiber length, the higher the fiber content is, the larger the cohesion is; fiber-reinforced tailings cohesion does not continuously increase as the fiber length increases. Instead, an "optimal value" would appear, when the added fiber exceeds the "optimum value", the cohesion decreases on the contrary. In this experiment, when the fiber length is 9mm and the content is 1.2%, the cohesion meets the maximum, which increases by 305.74% to raw tailings.

(3)The internal friction angle does not alter regularly with different fiber length and content, but the fluctuation range of internal friction angle is small to raw tailings. Overall, when the fiber length is more than 3mm, the internal friction angle of the fiber-reinforced tailings tends to decrease. When the fiber length is 12mm or content is 0.6%, the internal friction angle is always less than that of raw tailings regardless the content and length of the fiber.

(4)When the fiber content is 1.2%, the permeability coefficient is always larger than that of the raw tailings regardless of the fiber length, when the fiber length is 9mm, the permeability coefficient meets the most maximum which is increased by 38.16% compared to the raw tailings. The permeability coefficient curve shares the same variation trend on the condition that the basalt fiber is 3mm and 12mm. The permeability coefficient of fiber-reinforced tailings with fiber length of 12 mm is always greater than that of 3 mm.

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