The Crack Characteristics of Expansive Soil Improved by Biochar and Sisal Fiber Composite

Long Ling[a], Aijun Chen[*], Weiliang Li[b], Shijie Lin[c], Rongxue Mu[d], Chuanyang Ding[e]

School of Architecture and Transportation Engineering, University of Electronic Technology, Guilin, China

[a]e-mail: 996340880@qq.com; [*]e-mail: caj3026@163.com;
[b]e-mail: 2651242178@qq.com; [c]e-mail: 1650960420@qq.com
[d]e-mail: 1278840369@qq.com; [e]e-mail: 2443170253@qq.com

Abstract. Expansive soil has a significant cracking tendency under arid environmental conditions, leading to numerous engineering hazards. To study the methods of inhibiting cracking of Nanning expansive soil, a desiccation cracking test was conducted on the soil samples improved by biochar and sisal fiber composite. Using image processing to record indicators of soil cracking changes, the influence of biochar and sisal fiber on the expansive soil cracking was investigated. The test results show that sisal fiber, biochar, and sisal fiber + biochar composite all have the potential to inhibit soil crack formation. The sisal fiber + biochar composite demonstrates the most significant improvement. The study results offer valuable reference for the prevention and control of foundation subsidence and slope hazards in expansive soil areas.

Keywords: Expansive soil; sisal fiber; biochar; desiccation cracking

1 Introduction

Expansive soil is a special type of soil composed of strongly hydrophilic clay minerals such as montmorillonite, illite, and kaolinite, which exhibit significant swelling and shrinkage properties. The cracks result in various engineering problems, such as foundation settlement, instability of embankment slopes, and cracking of constructions. Therefore, effectively improving the crack development of expansive soil to inhibit crack propagation has become a research hotspot in the engineering and academic communities both domestically and internationally.

Currently, extensive study has been conducted on the cracking characteristics of improved expansive soil. For instance, Han et al. [1] analyzed the cracking characteristics of fiber-reinforced expansive soil under dry-wet cycles. The results showed that the crack ratio and total crack length increased with the increase in cycle number, while the average crack width tended to decrease. Adding fibers can effectively inhibit crack development. Yu et al. [2] conducted a study on the crack development charac

D. Li et al. (eds.), *Proceedings of the 2023 9th International Conference on Architectural, Civil and Hydraulic Engineering (ICACHE 2023)*, Advances in Engineering Research 228,
https://doi.org/10.2991/978-94-6463-336-8_33

teristics and mechanism of sisal fiber-reinforced clayey soil. They found that with the increase in sisal fiber content, the length, width, and soil clod area segmented by cracks on the soil surface decreased. Physical [3,4] and chemical [5,6] improvement methods have been mainly employed to enhance the soil cracking properties. They all have a certain extent of inhibitory effect on the cracking properties of expansive soil.

In summary, using a single method to improve expansive soil has limitations. It is necessary to conduct a study on the composite improvement of expansive soil using multiple materials. In this study, biochar and sisal fiber were selected as improvement materials to conduct desiccation tests. The principal objective of this study was to analyze the effects of varying biochar and sisal fiber content on the crack length, crack area, and crack width.

2 Tested materials and methods

2.1 Test materials

The soil investigated in this study was an expansive soil with a brown-yellow color, which was recovered from Nanning, Guangxi, China. The basic physical properties of the soil are presented in Table 1. The biochar used in the test was made from wood and with a density of 0.55 g/cm^3. The sisal fibers were obtained from Guangxi, China, with an average tensile strength of 533.61 MPa, an average tensile modulus of 26.05 GPa, an average diameter of 0.11 mm, and an average elongation at break of 1.97%.

Table 1. Basic physical properties of expansive soil.

Dry density $\rho\,/\,(g.cm^{-3})$	**Optimal moisture content** $\omega\,/\,\%$	**Liquid limit** $\omega_L\,/\,\%$	**Plastic limit** $\omega_P\,/\,\%$	**Plastic limit index** I_P	**Free expansion rate** $F_S\,/\,\%$
1.908	14.1%	16.5	42.7	26.2	42.5

Table 2. Design mix proportion of soil samples.

Sample number	**Sisal fiber content (‰)**	**Biochar content (%)**	**Sample number**	**Sisal fiber content (‰)**	**Biochar content (%)**
(1)	0	0	(13)	1.5	10
(2)	0	4	(14)	3	4
(3)	0	6	(15)	3	6
(4)	0	8	(16)	3	8
(5)	0	10	(17)	3	10
(6)	1.5	0	(18)	4.5	4
(7)	3	0	(19)	4.5	6
(8)	4.5	0	(20)	4.5	8
(9)	6	0	(21)	6	4
(10)	1.5	4	(22)	6	6
(11)	1.5	6	(23)	6	8
(12)	1.5	8	(24)	6	10

2.2 Test design

Four types of soil samples were tested in this study: untreated expansive soil, sisal fiber-improved soil, biochar-improved soil, and biochar + sisal fiber composite-improved soil (composite-improved soil). The biochar content was expressed as the mass ratio of biochar to dry expansive soil, and the sisal fiber content was the mass ratio of sisal fiber to dry expansive soil. The design mix proportions of different soil samples are presented in Table 2.

2.3 Test method

The desiccation test in this study involved evaluating the cracking behavior of four types of soil samples, each with dimensions of 250 mm (length) × 250 mm (breadth) × 15 mm (thickness). The soil was air-dried, crushed, and passed through a 2 mm sieve before being stored in a sealed container. The sieved soil was mixed thoroughly with other materials according to the predetermined design mix proportion, and distilled water was added and mixed evenly. The mixture was then placed in a sealed container and stood for 24 hours. The prepared soil was weighed and placed in a mold and pressed using a hydraulic press.

In the indoor desiccation cracking test, a thin layer of lime powder was evenly sprinkled on the soil sample surface. The sample was then placed on an electronic balance. The LED light, camera, and electronic balance were turned on in sequence to start the test. The electronic balance can automatically record the mass changes of the sample. The camera recorded crack development on the soil surface throughout the entire desiccation process. The test was completed when the mass changes of the soil sample were less than 0.5 g within half an hour.

3 Test results and discussions

3.1 Effect of biochar on cracks

Figure 1(a) shows the variation in crack width of biochar-improved soil with increasing biochar content. The results show that adding biochar to the soil can effectively reduce the crack width. The crack width first decreases and then increases with increasing biochar content. The minimum crack width of 0.73 mm is achieved when the biochar content is 8%, which is a 66.97% reduction compared with the maximum crack width of 2.21 mm in the untreated expansive soil.

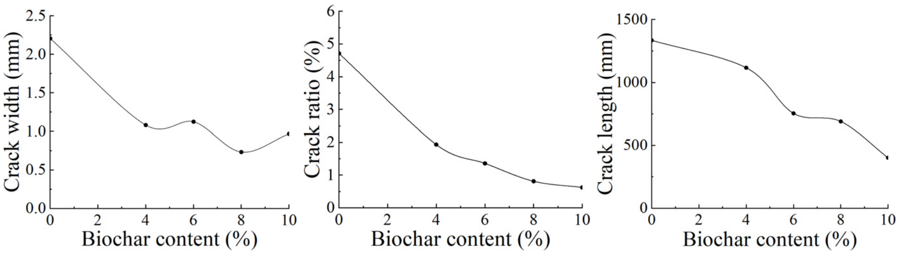
Figure 1(b) shows the variation of crack area ratio in biochar-improved soil with increasing biochar content. The results indicate that adding biochar can significantly reduce the crack area, which decreases continuously with increasing biochar content. The crack ratio is reduced to 0.622% when the biochar content reaches 10%. It is an 86.8% reduction compared with the crack ratio of 4.712% in the untreated expansive soil.

The curve in Figure 1(c) shows the variation in crack length of biochar-improved soil with increasing biochar content. When the biochar content adds 10%, the crack length is 401.01 mm, representing a 69.95% reduction compared to the untreated expansive soil with a crack length of 1334.51 mm.

3.2 Effect of sisal fiber content on cracks

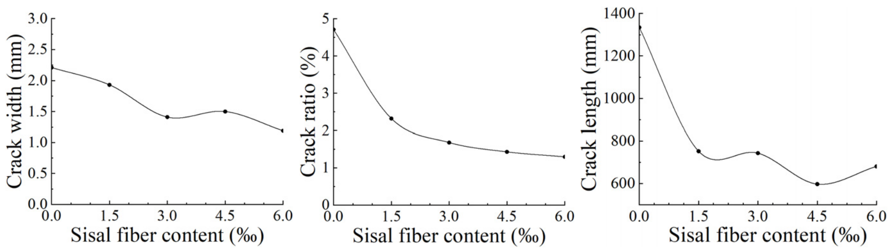
Figure 2(a) shows the variation of crack length of sisal fiber-improved soil with the increasing sisal fiber content. Adding sisal fiber can reduce the crack length. As the sisal content increases, the crack length decreases first and then increases. The minimum crack length of 597.41 mm is achieved at a sisal fiber content of 0.45%. This represents a reduction of 55.23% compared to the crack length of 1334.54 mm in the untreated expansive soil.

Figure 2(b) shows the variation of crack ratio of sisal fiber-improved soil with the increasing sisal fiber content. The addition of sisal fiber can decrease the crack area. The crack ratio continuously decreases with the increase of sisal fiber content. The optimal reduction in the crack ratio is achieved at a sisal fiber content of 1.5%. The crack ratio is 2.319% when the sisal fiber content of 0.6%. This represents a decrease of approximately 2.393% compared to the crack ratio of 4.712% in the untreated expansive soil.



(a) Crack width (b) Crack ratio (c) Crack length

Fig. 1. Crack characteristics of biochar-modified expansive soil



(a) Crack width (b) Crack ratio (c) Crack length

Fig. 2. Crack characteristics of expansive soil modified by sisal fiber

Figure 2(c) shows the variation of crack width of sisal fiber-improved soil with the increasing sisal fiber content. The addition of sisal fiber can effectively reduce the crack width, which gradually decreases with increasing sisal fiber content. The minimum crack width of 1.19 mm is achieved at a sisal fiber content of 0.6%. This represents a reduction of 46.15% compared to the maximum crack width of 2.21 mm in the untreated expansive soil.

3.3 Crack development characteristics

Figures 3, 4, and 5 show the crack development in four different types of soil, including untreated expansive soil, biochar-improved soil, sisal fiber-improved soil, and composite-improved soil, respectively. Biochar and sisal fiber can inhibit the crack development of expansive soil. According to Figure 3, cracks in the untreated expansive soil develop in a circular trend along the soil sample periphery, and the main crack is closed with a large width and depth. However, adding 4% biochar significantly reduces the main crack width. The crack length and width continue to decrease with increasing biochar content. According to Figure 4, adding 1.5‰ sisal fiber significantly reduces the main crack length, and soil surface cracks decrease gradually with increasing sisal fiber content. Figure 5 demonstrates that the combined addition of biochar and sisal fiber can more effectively inhibit crack development than adding either material alone under the same sisal fiber content.

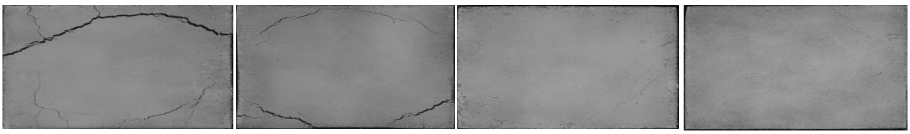
3.4 Discussions

The circular crack pattern of untreated expansive soil is attributed to the soil shrinkage towards the sample center during water evaporation, and the adhesion force generated between the peripheral soil and the container wall due to internal and external pull tendency. This eventually results in cracks when the stress exceeds the peripheral soil's ability to withstand it.

Biochar has highly developed pore characteristics. Large specific surface areas allow the pores to absorb water when the sample is moistened, delaying water loss during soil drying. In addition, the biochar particles have certain compressive strength, forming a skeleton between particles, which can support expansive soil to reduce crack width.

(a) Plain expansive soil (b) 4% biochar (c) 6% biochar (d) 8% biochar (e) 10% biochar

Fig. 3. Cracks of soil samples with different biochar content



(a) 1.5‰ sisal fiber (b) 3‰ sisal fiber (c) 4.5‰ sisal fiber (d) 6‰ sisal fiber

Fig. 4. Cracks in soil samples with different sisal fiber content

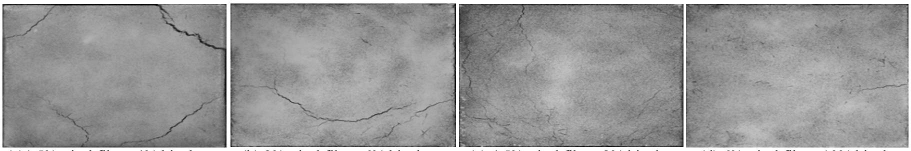


Fig. 5. Crack diagram of biochar + sisal fiber improved soi

Sisal fiber has the following properties: elasticity, rough surface texture, and high tension strength. When mixed with the soil, sisal fibers overlap each other to form a spatial network skeleton structure that inhibits the relative displacement between soil particles and slows down water evaporation.

4 Conclusions

(1) Sisal fiber, biochar, and sisal fiber + biochar can inhibit crack initiation and development in expansive soil. The best improvement effect is achieved by the composite improvement of sisal fiber + biochar. There are only small cracks in the sisal fiber-improved soil, but the crack width on the contact surface between the boundary and the container is relatively large. Biochar-improved soil has small cracks on the contact surface and some micro-cracks on the soil surface. The composite improvement can effectively inhibit the crack development on the soil surface and contact surface.

(2) In the desiccation test, there is a relative displacement between the soil particles under the suction force when the soil loses water and shrinks. However, the frictional force between the fibers and soil particles hinders the relative displacement. However, the physical adsorption force between soil particles and the side wall of the container is not sufficient to resist the inward soil shrinkage. Therefore, there are almost no cracks on the soil surface, and the cracks at the boundary and the contact surface with the container are relatively wide.

Acknowledgments

This work was supported by the National College Student Innovation Program (No. 202210595059) and Guangxi Natural Science Foundation (No. 2022GXNSFAA035485).

References

1. Han, C.P., Tian, J.Y., Zhang, J., Li, J.h.,(2019) Analysis of crack characteristics of fiber-reinforced expansive soil under wetting drying cycle [J]. Journal of Jilin University (Engineering and Technology Edition), 49(2):392-400. DOI: 10.13229/j.cnki.jdxbgxb20180019
2. Yu, Y.X., Min, W., Song, J.L., He, S.F., Jiang, B., Liu, J., Bu, F., (2021) Study on the crack development characteristics and mechanism of sisal fiber composite cohesive soil

[J]. MINERAL EXPLORATION,12(6): 1448-1454. https://kns.cnki.net/kcms/detail/ detail.aspx?FileName=YSJS202106018&DbName=CJFQ2021

3. MENG, L.C., PIAO, M., ZHANG, H.Q., HUANG Z.Q., (2023) SWELLING AND SHRINKAGE BEHAVIOUR OF EXPANSIVE SOIL AMELIORATED BY CALCIUM LIGNOSULPHONATE DURING WETTING-DRYING CYCLES[J/OL]. Journal of Engineering Geology. DOI: 10.13544/j.cnki.jeg.2022-0196
4. WANG, X., GU, K., ZHANG, Y.P., LU, Y., TANG, C.S., SHEN, Z.T., SHI, B., (2023) Effects of biochar on desiccation cracking characteristics of different soils and their mechanism[J]. Chinese Journal of Geotechnical Engineering. 2023,45(04):876-882. DOI: 10.11779/CJGE20220192
5. Zha, F.S., Liu, S.Y., Du, Y.J. , (2007) Experiment on improvement of expansive clays with lime-fly ash[J]. JURNAL 0F SOUTHEAST UNIVERSITY (Natura1 Science Edition). (02):339-344. DOI: 10.3969/j.issn.1001-0505.2007.02.031
6. Bian, J.M., Jiang, L., Wang, B.T. (2013) Experiment on the strength of lime-treated expansive soil [J]. Journal of Chang'an University (Natural Science Edition)33(2):38-43. DOI: 10.19721/j.cnki. 1671-8879.2013.02.007