



Experimental Study on the Durability of Red Clay Modified by Plant Fiber

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Abstract

In order to study the influence of time on the mechanical properties of red clay improved by plant fiber, the red clay in Guilin was taken as the research object. Three kinds of plant fibers, lignin, coir and ramie, were mixed into red clay respectively. The shear strength index and unconfined compressive strength of red clay improved by plant fibers at different curing ages were analyzed through indoor direct shear test and unconfined compressive strength test. The test results show that the shear strength index and unconfined compressive strength of red clay improved by plant fiber decrease with the increase of curing age. The effect of ramie on improving the mechanical properties of red clay is worse than that of coir on improving the mechanical properties of red clay, but its durability is better than that of coir on improving red clay. Lignin has the worst effect in improving the mechanical properties of red clay and has poor durability. When considering the durability of plant fiber improved red clay in engineering, ramie can be used as the optimal plant fiber to improve red clay. The above research results are of great significance in providing reference for engineering construction and red clay improvement in red clay areas.

Subject Areas

Civil Engineering

Keywords

Red Clay, Plant Fiber, Mechanical Properties, Time Effect, Durability

1. Introduction

Red clay is a special soil widely distributed in my country. It is increasingly used in engineering construction as building foundations and building media [1].

Plant fibers have a significant effect on improving the mechanical properties of red clay. Currently, domestic scholars are conducting more and more in-depth research on the mechanical properties of red clay improved by plant fibers. At present, scholars at home and abroad have conducted preliminary research on improving soil with plant fibers. Liu [2] took the silty clay of a foundation pit in Heilongjiang as the test object, and obtained the shear strength and unconfined compressive strength change law of wood fiber soil with different dosages through direct shear test and unconfined compressive strength test. Ceylan [3] believed that lignin is a good improvement material and that it is feasible to apply lignin to soil. Tingle [4] conducted an experimental study on the effect of lignin on the mechanical properties of clay and found that lignin can effectively improve the strength of soil. Vinod [5] found that lignin can effectively improve the erosion and impact resistance of dispersed clay. Dong [6] used consolidation tests, triaxial compression tests and SEM tests to study the influence of lignin fiber content on the strength and deformation characteristics of red clay and found that lignin fiber can improve the strength of red clay to a certain extent and enhance the engineering application value of red clay. Chen [7] added lignin fiber to red clay and conducted limit moisture content test, pH test and unconfined compressive strength test. They found that as the amount of lignin increased, the liquid limit and pH value continued to rise, thereby improving the corrosion resistance of red clay. Yang [8] studied the crack characteristics of red clay improved by palm fiber through indoor shrinkage cracking test, and found that 0.3% palm fiber addition and appropriate moisture content can effectively inhibit the development of red clay cracks. Wang [9] conducted comparative analysis on the chemical composition, tensile strength and elongation at break of coconut shell fiber, ramie, bamboo and cotton fibers. Su [10] used orthogonal experimental design to study the tensile and compressive properties of loess with palm fiber and found that adding palm fiber to loess can effectively improve the tensile and compressive strength of loess. Li [11] conducted a study on the shear strength of coconut shell fiber reinforced red clay using a direct shear test and found that coconut shell fiber can improve the shear strength of red clay, and the effect of coconut shell fiber content on the shear strength of red clay is greater than that of coconut shell fiber length. Qin [12] used an indoor triaxial test method to study the stress-strain relationship and strength characteristics of coconut shell fiber soil and found that adding coconut shell fiber to red clay can improve the soil's ability to resist deformation.

From the above research results, it can be seen that domestic and foreign scholars have conducted relatively more research on the application of plant fibers in red clay engineering, but there are relatively few experimental studies on the durability of plant fiber-improved red clay, and there is a lack of research on the effect of the durability of plant fibers in red clay on the mechanical properties of red clay. This paper takes Guilin red clay as the research object, and mixes three kinds of plant fibers, lignin, coir and ramie, into the red clay respectively.

By controlling the curing age, indoor direct shear test and unconfined compressive strength test are carried out to explore the influence of time effect on the mechanical properties of plant fiber improved red clay and the type of plant fiber with the best durability of improved red clay, providing new ideas for the application of plant fiber improved red clay in practical engineering.

2. Experiment Overview

2.1. Experiment Material

The soil used in this experiment was collected from a place in Guilin, with a depth of 5 - 6 m. The obtained red clay was naturally air-dried, ground, and then passed through a 2 mm sieve and sealed for storage, as shown in **Figure 1(a)**. According to the Geotechnical Testing Code (GB/T50123-2019) [13], compaction test, moisture content test and liquid limit test were carried out on the original soil in an indoor laboratory to determine its basic physical properties, as shown in **Table 1**. The plant fibers required for the experiment are lignin, coir and ramie, as shown in **Figure 1**. Among them, lignin is white wood fiber, and the length of coir and ramie are both 5 cm.

Table 1. Basic physical parameters of red clay.

Natural Moisture Content (%)	Specific Gravity	Maximum Dry Density (g/cm ³)	Optimum Moisture Content (%)	Liquid Limit (%)	Plastic Limit (%)
27.20	2.72	1.78	18.44	68.1	28.5

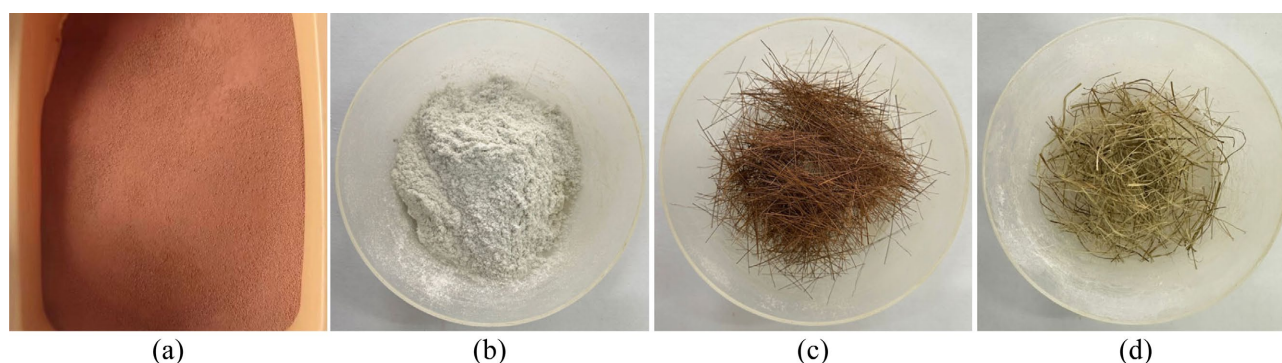


Figure 1. Test materials. (a) Red clay; (b) Lignin; (c) Coir; (d) Ramie.

2.2. Experimental Plan

In order to study the effect of the durability of plant fibers in red clay on its mechanical properties, this experiment conducted direct shear tests and unconfined compressive strength tests by adding different plant fibers into red clay. In this experiment, three kinds of plant fibers, lignin, coir and ramie, were added to soil samples at the dosage of 0.8%, 0.5% and 0.5% respectively. After adding water to reach the optimum moisture content of red clay, the soil was fully stirred for 15 minutes and then placed in sealed bags to be moistened for a day and night for use. The compression method was used to prepare a 61.8 * 20.0 mm ring knife

sample, and the layered compaction method was used to prepare a soil column with a diameter of $d = 50.0$ mm and a height of $h = 100.0$ mm. The compaction degree was controlled at 90%. The prepared specimens were placed in a curing box for constant temperature curing at a humidity of 95% and a temperature of 22°C . The curing age was 30 days, 60 days, 90 days, 120 days, 150 days, 180 days, 210 days, 240 days, 270 days, and 300 days. That is, a direct shear test and an unconfined compression test were performed once in a cycle of 30d. Three parallel tests were performed in each test, and a total of 10 cycles were completed. The test instrument is shown in **Figure 2**.

The test process is as follows: 1) Direct shear test: This test uses a quadruple direct shear apparatus, the shearing method is quick shear, the applied vertical load is 100 kPa, 200 kPa, 300 kPa, 400 kPa, and the shear speed is maintained at 0.8 mm/min. The obtained data is sorted out and the shear strength index of the improved soil under different curing cycles is calculated. 2) Unconfined compressive strength test: This test uses an unconfined compressive strength instrument. The prepared sample is placed on the base of the unconfined compressive strength instrument. The base rises at a speed of 3.0 mm/min to statically press the sample, while recording the displacement percentage meter and pressure ring data. When the axial strain of the sample reaches 8% or obvious damage deformation occurs, the test is stopped. At this time, the compressive strength corresponding to the axial strain is the unconfined compressive strength. The obtained data is sorted, and the unconfined compressive strength of the improved soil under different curing cycles is calculated.

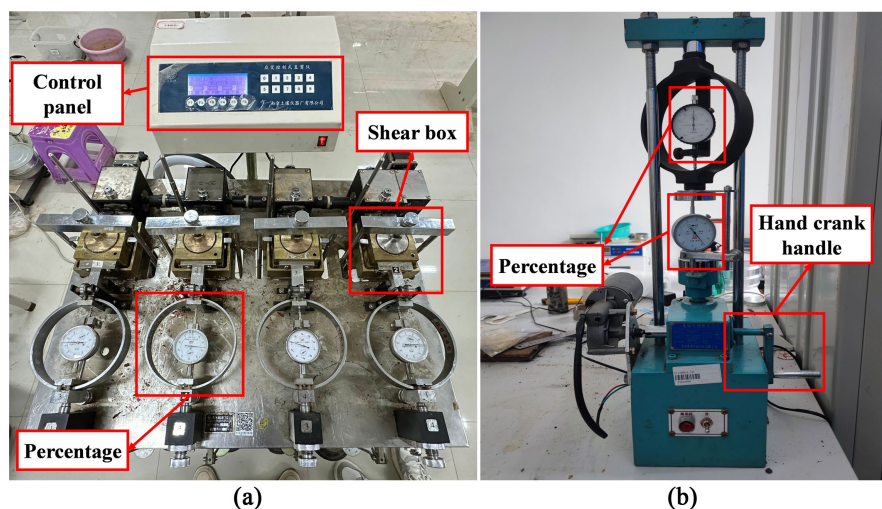


Figure 2. Test equipment. (a) Quadruple direct shear apparatus; (b) Unconfined compression instrument.

3. Test Results and Analysis

3.1. Influence of Time Effect on Shear Strength Index of Red Clay Improved by Plant Fiber

The change curve of the shear strength index of plant fiber improved red clay

under different curing ages is shown in **Figure 3**. As shown in **Figure 3**, under the influence of the time effect, the shear strength index of the plant fiber improved soil shows a downward trend with the increase of curing age. As shown in **Figure 3(a)**, when the curing age increased from 30 days to 300 days, the cohesion of the lignin-improved soil decreased from 15.89 kPa to 7.17 kPa, a decrease of 54.88%, the cohesion of the coir-improved soil decreased from 19.36 kPa to 8.47 kPa, a decrease of 56.25%, the cohesion of the ramie-improved soil decreased from 14.26 kPa to 7.81 kPa, a decrease of 45.23%. Among them, at different curing ages, the cohesion of coir improved soil was greater than that of the other two plant fiber improved soils. Before 150 days of curing, the cohesion of lignin improved soil was greater than that of ramie improved soil, and after 150 days of curing, the cohesion of lignin improved soil was less than that of ramie improved soil. As can be seen from **Figure 3(b)**, with the increase of curing age, the internal friction angle of lignin-improved soil decreased from 3.60° to 1.41° , a decrease of 60.83%, the internal friction angle of coir-improved soil decreased from 4.50° to 2.31° , a decrease of 48.67%, the internal friction angle of ramie-improved soil decreased from 3.93° to 1.54° , a decrease of 60.81%. Among them, at different curing ages, the internal friction angle of coir improved soil is the largest, followed by ramie improved soil, while the internal friction angle of lignin improved soil is the smallest.

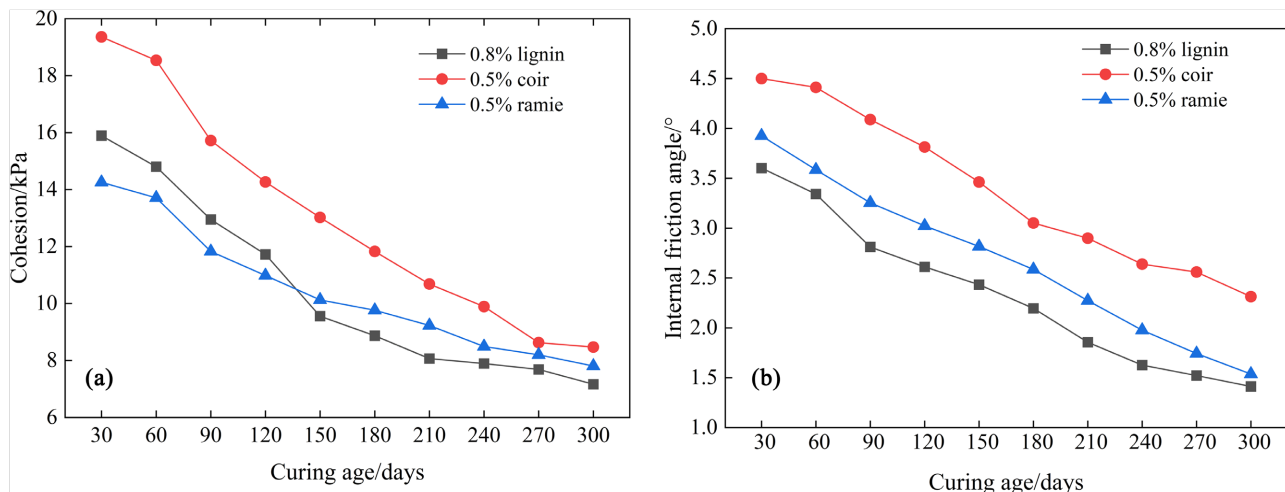


Figure 3. The change curve of the shear strength index of plant fiber improved red clay under different curing ages. (a) Cohesion; (b) Internal friction angle.

After 300 days of curing, the internal friction angle and cohesion of the three types of plant fiber-improved soils all showed a significant downward trend under the effect of time. The factor that caused the mechanical properties of plant fiber-improved red clay to drop significantly during the curing process was mainly the result of the action of plant fiber-related decomposition bacteria. With the increase of curing age, under the effect of time, the interaction between soil particles and plant fibers under the action of decomposition bacteria weak-

ened the “bridge” connection between plant fibers and soil particles, resulting in a significant decrease in the shear strength index and unconfined compressive strength of plant fiber-improved red clay.

3.2. Influence of Time Effect on Unconfined Compressive Strength of Red Clay Improved by Plant Fiber

The failure morphology of red clay improved by different plant fibers is shown in **Figure 4**. As can be seen from **Figure 4**, the samples of lignin-improved soil and ramie-improved soil both suffered splitting failure, with multiple cracks, and no soil blocks fell off during the failure. The sample of ramie-improved soil suffered drum-shaped failure, with cracks appearing at the drum-shaped location, and the crack length and width were small, and small soil blocks fell off during the failure.

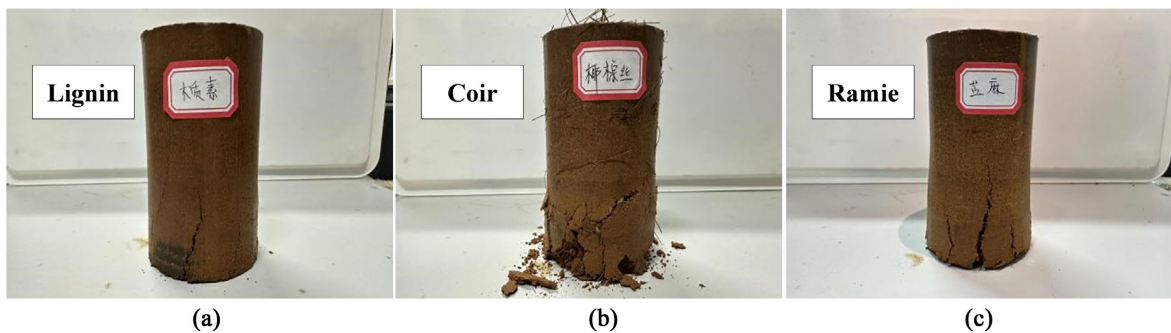


Figure 4. The failure morphology of red clay improved by different plant fibers. (a) Lignin; (b) Coir; (c) Ramie.

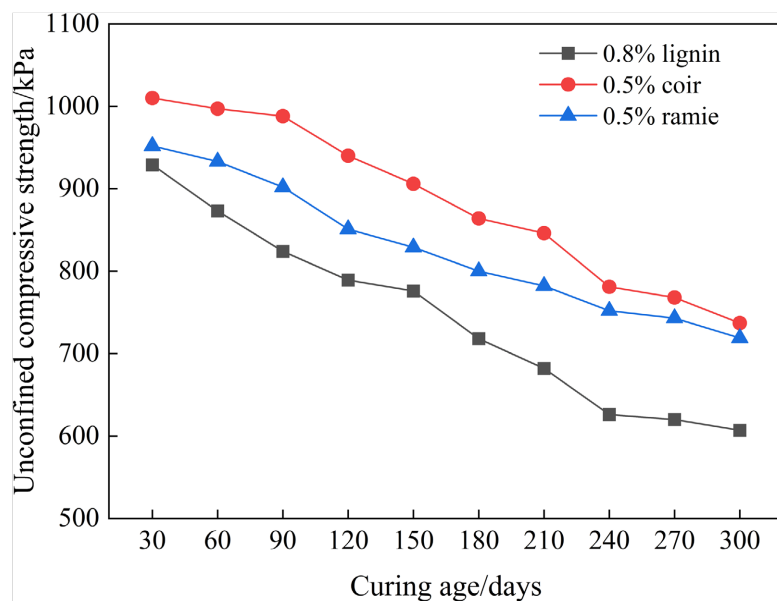


Figure 5. The change curve of the unconfined compressive strength of red clay improved by plant fiber.

The change curve of the unconfined compressive strength of red clay improved by plant fiber at different curing ages is shown in **Figure 5**. As shown in

Figure 5, under the influence of the time effect, the unconfined compressive strength of the soil improved by plant fiber shows a downward trend with the increase of curing age. When the curing age increased from 30 days to 300 days, the unconfined compressive strength of the lignin-improved soil decreased from 929 kPa to 607 kPa, a decrease of 34.66%, the unconfined compressive strength of the coir-improved soil decreased from 1010 kPa to 737 kPa, a decrease of 27.03%, the unconfined compressive strength of the ramie-improved soil decreased from 952 kPa to 719 kPa, a decrease of 24.24%. Under different curing ages, the unconfined compressive strength of soil improved by coir is the largest, followed by that of soil improved by ramie, while that of soil improved by lignin is the smallest. Under the effect of time, the central reinforcement mechanism of plant fiber in soil gradually decreases. The longer the curing age, the stronger the time effect, and the more obvious the local defects in the soil. Therefore, with the increase of curing age, the mechanical properties of soil improved by plant fiber was weakened.

3.3. Analysis of Time Effect on Durability of Red Clay Improved by Plant Fiber

Lignin, coir and ramie are three types of plant fibers that can effectively improve the mechanical properties of red clay. However, under the effect of time, the three types of plant fibers have the problem of “durability” in improving the mechanical properties of red clay. In this paper, the mechanical properties of soil improved by plant fiber after 30 days of curing were taken as the control group, and compared with the mechanical properties of soil improved by plant fiber after 300 days of curing. The reduction amplitude was used as the quantitative index to analyze the influence of time effect on the durability of red clay improved by plant fiber.

Table 2. Durability parameters of red clay improved by plant fiber.

Plant fiber type	Cohesion			Internal friction angle			Unconfined compressive strength		
	Curing age		R_c	Curing age		R_ϕ	Curing age		R_{UCS}
	30 days	300 days		30 days	300 days		30 days	300 days	
Lignin	15.89 kPa	7.17 kPa	54.88%	3.60°	1.41°	60.83%	929kPa	607 kPa	34.66%
Coir	19.36 kPa	8.47 kPa	56.25%	4.50°	2.31°	48.67%	1010kPa	737 kPa	27.03%
Ramie	14.26 kPa	7.81 kPa	45.23%	3.93°	1.54°	60.81%	952kPa	719 kPa	24.24%

Note: R_c is the reduction of cohesion, R_ϕ is the reduction of internal friction angle, R_{UCS} is the reduction of unconfined compressive strength.

The durability parameters of red clay improved by different plant fibers are shown in **Table 2**. As can be seen from **Table 2**, by comparing the mechanical properties of soil improved by plant fibers after 30 days of curing and soil improved by plant fibers after 300 days of curing, it is found that $R_{c-lignin} < R_{c-coir} < R_{c-ramie}$, $R_{\phi-coir} < R_{\phi-ramie} < R_{\phi-lignin}$, $R_{UCS-ramie} < R_{UCS-coir} <$

$R_{UCS-lignin}$. In order to better analyze the effect of different plant fibers on the durability of red clay, the durability coefficient (D) is introduced, as shown in Equation (1).

$$D = \frac{(R_c + R_\phi + R_{UCS}) \times 0.01}{3} \quad (1)$$

In Equation (1), D is the durability coefficient; R_c is the reduction in cohesion, %; R_ϕ is the reduction in internal friction angle, %; R_{UCS} is the reduction in unconfined compressive strength, %.

It can be seen from Equation (1) that the lower the durability coefficient is, the better its durability is. After substituting the durability parameter of plant fiber improved red clay into formula (1), the durability coefficients of different plant fiber improved red clay can be obtained, as shown in **Table 3**.

Table 3. The durability coefficients of different plant fiber improved red clay.

	Lignin	Coir	Ramie
D	0.50	0.44	0.43

It can be seen from **Table 3** that the durability coefficient of ramie-improved red clay is the smallest, and its durability is the best, followed by coconut palm fiber-improved soil, while the durability coefficient of lignin-improved red clay is the largest, and its durability is the worst. In summary, the effect of ramie on improving the mechanical properties of red clay is worse than that of coir, but its durability is better than that of coir, while the effect of lignin on improving the mechanical properties of red clay is the worst and its durability is poor. Therefore, when considering the durability of plant fiber improving red clay in engineering, ramie can be used as the optimal plant fiber to improve red clay.

4. Conclusion

Under the effect of time, the shear strength index and unconfined compressive strength of the three plant fiber improved red clay, lignin, coir and ramie, all showed a downward trend. At different curing ages, the unconfined compressive strength of the soil improved by coir was the largest, followed by the soil improved by ramie, and the unconfined compressive strength of the soil improved by lignin was the smallest. The cohesion of the soil improved by coir was greater than that of the other two plant fiber improved soils. Before 150 days of curing, the cohesion of the soil improved by lignin was greater than that of the soil improved by ramie, and after 150 days of curing, the cohesion of the soil improved by lignin was less than that of the soil improved by ramie. The effect of ramie on improving the mechanical properties of red clay was worse than that of coir, but its durability was better than that of coir, while the effect of lignin on improving the mechanical properties of red clay was the worst and its durability was poor. Therefore, when considering the durability of plant fiber improved red clay in

engineering, ramie can be used as the optimal plant fiber to improve red clay.

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Conflicts of Interest

The authors declare no conflicts of interest.

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