Durability Tests of Silt Reinforced by Tr Materials Under Humid Environment

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Abstract. TR material is the abbreviation of glutinous rice and tung oil, which is a traditional organic reinforcement material since ancient China. Taking Qiantang River silt reinforced with TR material as the research object, 9 samples with different mass mix proportions were placed in the standard curing environment (20 °C, humidity 60%) for 7 days, 14 days, 30 days, 90 days and 180 days respectively. Shear test, permeability test and dry-wet cycle test were carried out on the treated samples. The optimum mass ratio of tung oil, glutinous rice juice and soil was determined as 5:10:85. After 180 days, the increased rate of cohesion c and internal friction angle φ is 26.3% and 15.7%, respectively. At the same time, the long-term permeability coefficient of the best mass ratio is the smallest, and the permeability coefficient K_T of 180 days is 1.775 × 10^-6 cm / s. In the dry-wet cycle test, the best performance is T_5R_10S_80, the strength reduction rate is the least, and the permeability coefficient increased rate is the least. From the perspective of absolute value, the optimum ratio T_5R_10S_85 is still the best after the dry-wet cycle test.

Keywords. TR material, durability, dry-wet cycle, best mass ratio, humid environment.

1. Introduction
At present, the reinforcement and protection of earthen sites is in the research stage [1-2]. More and more researches have been carried out on the reinforcement of soil sites with organic polymer materials. Kim et al. [3], Bhardwaj et al. [4] carried out corresponding experimental research on polyacrylamide modified soft clay. In the southern humid areas, the traditional reinforcement materials of organic materials have gradually become a research hotspot due to their low cost, environmental protection and good reinforcement effect. Glutinous rice flour or paddle was studied as additive to loess and tabia [5-6]. Chen [7] studied the effect of tung oil and lime on strengthening the tomb soil of Yoshinori cemetery in Japan. The results showed that the soil samples added with 4% tung oil and lime can greatly improve the performance of rammed earth against dry and wet deterioration. Tang et al. [8] studied the effect of glutinous rice and tung oil in strengthening clay and Qiantang River silt. From the micro mechanism, it was found that the glutinous rice tung oil can well wrap the soil particles, which shows the characteristics of increasing strength and decreasing permeability coefficient. In this paper, Qiantang River silt, which is similar to Hemudu site soil, is selected to study its durability and resistance to dry and wet deterioration after adding TR materials.
2. Materials & Samples Preparation

2.1. Preparation of TR Material
TR material is the abbreviation of glutinous rice and tung oil. The glutinous rice used in this study is water milled glutinous rice flour produced by Changzhou Jintan Maoshan flour milling Co., Ltd. The preparation of glutinous rice juice refers to the practice of Hu [9]. 150 g glutinous rice powder is added into 1000 ml deionized water and boiled for 1.5 h, and its concentration can reach 1.0 g/cm³. In the process of preparation, the density of glutinous rice pulp is controlled by a high-precision liquid densimeter, the volume of glutinous rice pulp is controlled by measuring cylinder, and then its quality is controlled, and then cooled to room temperature for standby.

There are two kinds of tung oil available on the market. One is raw tung oil used in the manufacturing industry, drying time is about 1~2 months, and the other is mature tung oil used as a home coating, and the drying time is only 2~5 hours. Considering the demand for durability tests, the raw tung oil which can be purchased on the market was selected as one of the repairing materials. When making soil samples, the mass of tung oil to be added is calculated according to the mix proportion, converted into volume, and absorbed by a needle cylinder.

2.2. Qiantang River Silt
The soil was taken from the estuary of Qiantang River and at the depth of 50 cm below the ground surface. The physical and mechanical property of the soil is shown in table 1, including Grain-size composition, Atterberg limits, organic content, specific gravity and mineralogical composition. Before the manufacturing of the specimens, the silt soil was sieved by 2 mm standard sieve and dried under 60 °C for 48 hours.

Table 1. Grain-size composition, Atterberg limits, organic content, specific gravity and mineralogical composition of the tested sediments evaluated by X-ray diffraction.

| Atterberg limits | Liquid limit | Plasticity index | Grain composition: % |
|------------------|--------------|------------------|----------------------|
|                  |              |                  | >0.05 mm | 0.01~0.05 mm | 0.05~0.005 mm | <0.005 mm |
| Organic content: %<sub>o</sub> | Specific gravity | Maximum dry density: g/mm³ | Mineralogical composition: % |
| 1.8              | 2700         | 1.59             | Quartz | Albite | Muscovite | Clinochlore |

2.3. Preparation of TRS Samples with Different Proportions
The best water content of the screened Qian Tang Silt was 20.48%. The distilled water was poured into the sprayer and sprayed onto the surface of the dried soil sample to mix evenly. Then the tung oil and the glutinous rice juice were added evenly in proportion. Nine groups of samples with different mass ratios of tung oil, glutinous rice juice and Qiantang River silt were prepared. As shown in table 2, T is tung oil, R is glutinous rice juice, S is Qiantang River silt, and the subscript number is the mass percentage of each component in the mixed sample. If there is no special description below, the “mass ratio” refers to “tung oil quality: glutinous rice juice quality: Qiantang River silt quality”; TRS refers to the mixed soil samples of tung oil, glutinous rice juice and Qiantang River silt in different proportions.

Table 2. 9 Types of mass ratios of the treated soil specimens.

| Name | Mass ratio | T<sub>0</sub>R<sub>0</sub>S<sub>100</sub> | T<sub>0</sub>R<sub>5</sub>S<sub>95</sub> | T<sub>5</sub>R<sub>0</sub>S<sub>95</sub> | T<sub>5</sub>R<sub>5</sub>S<sub>90</sub> | T<sub>5</sub>R<sub>10</sub>S<sub>85</sub> |
|------|------------|---------------------------------|-----------------|-----------------|-----------------|-----------------|
| Name | Mass ratio | T<sub>10</sub>R<sub>5</sub>S<sub>85</sub> | T<sub>10</sub>R<sub>10</sub>S<sub>80</sub> | T<sub>10</sub>R<sub>15</sub>S<sub>80</sub> | T<sub>10</sub>R<sub>20</sub>S<sub>80</sub> | T<sub>10</sub>R<sub>25</sub>S<sub>80</sub> |
| Name | Mass ratio | T<sub>15</sub>R<sub>5</sub>S<sub>80</sub> | T<sub>15</sub>R<sub>10</sub>S<sub>75</sub> | T<sub>15</sub>R<sub>15</sub>S<sub>70</sub> | T<sub>15</sub>R<sub>20</sub>S<sub>65</sub> | T<sub>15</sub>R<sub>25</sub>S<sub>60</sub> |
3. Experiments & Results

3.1. Shear Strength Durability Test
In this paper, the shear strength indexes, cohesion $c$, and internal friction angle $\phi$, are obtained by indoor consolidation quick shear test. Nine TRS samples prepared according to Section 2.3 were placed in a standard curing environment (20 °C, humidity 60%) for 7 days, 14 days, 30 days, 90 days and 180 days, respectively. The specific steps of the test are as follows: four TRS samples of each mass ratio and reaching a certain curing time are taken and consolidated for 24 h under the vertical pressure of 100 kPa, 200 kPa, 300 kPa and 400 kPa respectively. The consolidated soil sample is placed in the direct shear apparatus, and the computer is set to advance at a rate of 1.2 mm/min. the displacement $R$ at the dynamometer and the displacement $L$ of the propulsion device are recorded every 10 s until the peak value of the reading occurs or the shear displacement stops when the shear displacement is 6 mm. Finally, the data are processed to obtain the shear strength indexes: $c$ and $\phi$.

The shear strength indexes ($c$ and $\phi$) of 9 TRS specimens with different mass ratios measured by consolidation quick shear test under standard conditions (20 °C, humidity 60%) for 7 days, 14 days, 30 days, 90 days and 180 days are shown in Table 3 and Figure 1.

Table 3. Shear strength index cohesion $c$ (kPa) and internal friction angle $\phi$ (°) of TRS samples with different mass ratios from 7 days to 180 days.

| Shear strength index | 7 Days | 14 Days | 30 Days | 90 Days | 180 Days |
|----------------------|--------|---------|---------|---------|---------|
| T₀R₀S₁₀₀             | $c$ (kPa) | 14.24   | 14.43   | 14.24   | 13.05   | 13.06   |
|                      | $\phi$ (°) | 29.98   | 30.24   | 30.17   | 30.21   | 30.06   |
| T₀R₅S₅₅             | $c$ (kPa) | 14.65   | 15.03   | 15.11   | 15.09   | 15.07   |
|                      | $\phi$ (°) | 30.12   | 30.56   | 30.28   | 31.47   | 30.78   |
| T₅R₀S₅₅             | $c$ (kPa) | 14.82   | 14.84   | 14.73   | 14.26   | 14.15   |
|                      | $\phi$ (°) | 29.78   | 30.88   | 31.22   | 31.24   | 31.34   |
| T₅R₅S₅₀             | $c$ (kPa) | 14.61   | 17.60   | 17.53   | 17.42   | 17.35   |
|                      | $\phi$ (°) | 30.07   | 32.14   | 31.42   | 32.08   | 32.19   |
| T₅R₁₀S₅₅            | $c$ (kPa) | 22.55   | 30.26   | 26.14   | 27.3    | 28.49   |
|                      | $\phi$ (°) | 31.09   | 35.72   | 34.53   | 34.72   | 35.98   |
| T₁₀R₅S₅₅            | $c$ (kPa) | 13.86   | 16.14   | 16.74   | 16.71   | 16.21   |
|                      | $\phi$ (°) | 29.76   | 33.45   | 33.47   | 33.43   | 33.48   |
| T₁₀R₁₀S₈₀           | $c$ (kPa) | 15.84   | 20.47   | 21.08   | 19.53   | 19.44   |
|                      | $\phi$ (°) | 30.86   | 35.06   | 34.09   | 33.89   | 33.78   |
| T₅R₁₀S₈₀            | $c$ (kPa) | 18.82   | 22.42   | 21.88   | 21.45   | 21.51   |
|                      | $\phi$ (°) | 30.65   | 34.15   | 33.88   | 33.67   | 33.51   |
| T₁₀R₅S₈₀            | $c$ (kPa) | 14.03   | 15.86   | 15.94   | 16.01   | 15.29   |
|                      | $\phi$ (°) | 30.31   | 34.68   | 33.93   | 33.86   | 33.74   |

It can be seen that $c$ and $\phi$ of TRS samples with all ratios increase first and then decrease with time and tend to be stable. Among them, $c$ mostly reaches the maximum value in 14 days or 30 days. Compared with the data of curing for 7 days, T₅R₁₀S₈₀ has the largest growth rate in 14 days, reaching 34.2%. After 180 days, the growth rate is slightly reduced, remaining 26.3%. However, after 180 days, $c$ of the control group T₀R₀S₁₀₀ decreased by 8.3%, while that of T₅R₅S₅₅ decreased by 4.5%. In addition, the 180-day data of other TRS samples showed a positive increase compared with 7-day data. In terms of internal friction angle, all TRS samples reached the maximum value on the 14th day, and except for the control group T₀R₀S₁₀₀ and T₁₀R₅S₅₅, they all decreased sharply at 30 days, and the data from 30 days to 180 days did not change much. Compared with the 7-day maintenance data, the largest growth rate of T₅R₁₀S₅₅ is 14.9% in 14 days and 15.7% in 180 days. The growth rate of T₁₀R₅S₈₀ was 14.4% in 14 days and 11.3% in 180 days.
Figure 1. Shear strength index cohesion $c$ (kPa) and internal friction angle $\phi$ (°) of TRS samples with different mass ratios from 7 days to 180 days.

### 3.2. Permeability Test

The permeability of TRS is measured by variable head permeability experiment due to the low permeability coefficient of Qiantang River silt. The specific parameters of the instrument are as follows: inner diameter of glass variable head pipe $d = 1.37$ cm, cross-sectional area $a = 1.47$ cm$^2$; from variable head pipe orifice to water outlet $H = 173$ cm; section area of penetration sample $A = 30$ cm$^2$, seepage diameter $L = 40$ mm. The permeability coefficient of the tested sample is calculated by the following equation:

$$K_T = 2.3 \frac{aL}{At} \log \frac{h_1}{h_2}$$

where $K_T$ is the permeability coefficient of the tested sample, unit: cm/s, $h_1$ and $h_2$ are the water head at the beginning and the end, unit: cm.

Nine TRS samples prepared according to Section 2.3 were placed in the standard curing environment (20 °C, humidity 60%) for 7 days, 14 days, 30 days, 90 days and 180 days respectively, and then the permeability coefficient was determined to explore the durability law of TRS permeability. It can be seen from table 4 and figure 2 that compared with 7~90 days, the permeability coefficient of all TRS samples under 180 days of standard curing increases significantly except $T_6R_0S_{100}$ and $T_{10}R_{10}S_{80}$. The increase of permeability indicates that the impermeability is becoming poor. Among 9 TRS samples, $T_5R_{10}S_{85}$ and $T_{10}R_{10}S_{80}$ have the smallest permeability coefficient after 180 days in the standard curing environment.

#### Table 4. Permeability coefficient $K_T$ ($\times 10^6$ cm/s) of TRS samples with different mass ratios.

| Treated Samples | Permeability coefficient $K_T$ ($\times 10^6$ cm/s) |
|-----------------|-----------------------------------------------|
|                 | 7 days | 14 days | 30 days | 90 days | 180 days |
| $T_6R_0S_{100}$ | 12.58  | 12.57   | 12.58   | 12.59   | 12.58    |
| $T_6R_5S_{95}$  | 7.73   | 7.718   | 7.727   | 7.736   | 7.758    |
| $T_5R_5S_{95}$  | 8.646  | 8.633   | 8.669   | 8.739   | 8.900    |
| $T_5R_5S_{90}$  | 4.984  | 4.959   | 5.004   | 5.105   | 5.165    |
| $T_5R_{10}S_{85}$ | 1.632 | 1.627   | 1.668   | 1.721   | 1.775    |
| $T_{10}R_5S_{95}$ | 9.914 | 9.866   | 9.914   | 9.962   | 10.20    |
| $T_{10}R_{10}S_{80}$ | 2.351 | 2.327   | 2.369   | 2.405   | 2.460    |
| $T_{10}R_5S_{80}$ | 1.846 | 1.824   | 1.864   | 1.900   | 1.989    |
| $T_{15}R_5S_{80}$ | 8.834 | 8.014   | 8.079   | 8.247   | 8.555    |
3.3. Dry-Wet Cycle Test

It can be seen from Section 3.1 that for $T_5R_5S_{90}$, $T_5R_{10}S_{85}$, $T_{10}R_{10}S_{80}$ and $T_5R_{15}S_{80}$ with good strength performance, the shear strength index of specimens under 14 days standard curing condition can basically represent 180 days standard curing condition. Therefore, for dry-wet cycle test of shear strength, $T_5R_5S_{100}$, $T_5R_5S_{90}$, $T_{10}R_{10}S_{85}$, $T_{10}R_{10}S_{80}$ and $T_5R_{15}S_{80}$ under 14 days standard curing conditions are selected. It can be seen from section 3.2 that compared with 7-90 days, the permeability coefficient of samples under 180 days of standard curing increases significantly. In order to be close to the real situation, $T_6R_5S_{100}$, $T_5R_5S_{90}$, $T_5R_{10}S_{85}$, $T_{10}R_{10}S_{80}$, $T_5R_{15}S_{80}$, and $T_5R_{15}S_{80}$ are used to get the permeability coefficient after 20 cycles of drying and wetting in this chapter. All the above preparatory work saves time to explore the dry-wet cycle characteristics of TRS with different proportions.

The dry-wet cycle test scheme is set as follows, as shown in figure 3:

(a) Firstly, the TRS samples prepared in accordance with Section 2.3 under the 14 days standard curing conditions were aspirated and saturated, and then left for 24 h;

(b) In the dehumidification process, the TRS sample was put into the oven, and the drying temperature was 40 ℃, and then it was taken out and placed in a cool place for cooling after baking for 2 h;

(c) The humidification process is to immerse the sample in water for 10 min.

(d) Repeat the steps a) ~ c) as a dry-wet cycle. In this section, the TRS samples with different proportions were subjected to 0, 5, 10, 15 and 20 dry and wet cycles respectively under the 14-day standard curing conditions, and then the soil samples were vacuumed and saturated, and then the shear strength index ($c$ and $\phi$) were measured according to the test procedures in Sections 3.1. Meanwhile, $T_5R_5S_{100}$, $T_5R_5S_{90}$, $T_5R_{10}S_{85}$, $T_{10}R_{10}S_{80}$ and $T_5R_{15}S_{80}$ are used to get the permeability coefficient $K_T$ after 20 cycles of drying and wetting after under 180-day standard curing conditions in this chapter, according to the test procedures in Sections 3.2.

From figure 4, it can be concluded that $c$ and $\phi$ decrease with the increase of dry-wet cycles for most TRS specimens. After the fifth dry-wet cycle, the downward trend of $\phi$ slowed down. Taking $T_2R_{10}S_{85}$ for example, $c$ decreased by 25.5% after 5 cycles, 37.2% after 10 cycles, and 49% after 15 and 20 cycles; $\phi$ decreased by 18.7% after 5 cycles, 16.1% after 10 cycles, and 18.5% after 15, and 15.8% after 20 cycles. Figure 5 shows that the permeability coefficient of TRS increases significantly with the increase of dry-wet cycles. One of the best is $T_6R_5S_{100}$, the permeability coefficient $K_T$ increased by 4.5% after 5 cycles, 7.8% after 10 cycles, and 11.4% after 15, and 12.0% after 20 cycles.
Figure 3. Steps (a-c) of TRS dry-wet cycle test process.

Figure 4. Variation of shear strength index of 5 different mass ratios of TRS with dry-wet cycles after 180 days standard curing condition.
Figure 5. Variation law of permeability coefficient of TRS with the cycle of drying and wetting after 180 days standard curing condition.

4. Conclusion
(1) The order of TRS shear strength under long-term curing condition is: $T_{5R10S85} > T_{5R15S80}, T_{10R10S80}, T_{5R5S90}, T_{10R5S90}, T_{5R0S100}$; the order of impermeability of TRS under long-term curing condition is: $T_{5R10S85}, T_{5R15S80} > T_{10R10S80}, T_{5R5S90}, T_{10R5S90}, T_{5R0S100}$. To sum up, the optimum mass ratio of tung oil, glutinous rice juice and soil was determined as 5:10:85. It also performed best in dry-wet cycle experiment, which means $T_{5R10S85}$ has best resistance to deterioration.

(2) When only tung oil or glutinous rice juice is added, the permeability of TRS is reduced to a certain extent, and the effect of adding glutinous rice juice alone is better than that of tung oil alone. However, when tung oil and glutinous rice juice are added to the improved soil at the same time, and the proportion of tung oil in the improved soil is not high, the synergistic effect of the two can further reduce the permeability of the improved soil. It should be noted that although tung oil and glutinous rice juice have a good effect on reducing soil permeability coefficient, when tung oil accounts for a large proportion in the improved soil samples, such as $T_{10R5S85}$ and $T_{15R5S80}$, the permeability coefficient of improved soil is lower than that of the unmodified soil, but it is larger than that of other groups of TRS samples.

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