Study on tensile properties of rice straw rope considering degradation

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Abstract. Many scholars have used crop straw to reinforce soft soil foundation and studied its reinforcement effect and mechanism. However, the crop straw will degrade in the soil for a long time, which reduces the tensile strength of the straw and weakens the shear resistance of the reinforced soil. In order to study the degradation law of rice straw rope and its influence on tensile properties, the straw rope was immersed in water for different time, and then taken out, the quality before and after immersion was measured and tensile test was carried out. The results showed that: the degradation of rice straw rope in water experienced two stages of rapid degradation and slow degradation, and the quality of loss in the rapid degradation stage was more; the tensile force of straw stalk rope increased slowly with the increase of tensile displacement. When immersed for 20 days, the failure mode was brittle failure, and after 40 days of immersion, the failure mode changed into ductile failure; the straw stalk rope was the main tensile force of the straw fiber, and the tensile strength peak decreased with the increase of the immersion time. The deterioration law accorded with the third-order polynomial function.

1. Introduction

Amount of straw resources in China by 2017, compared with the early 1990s, increased by about 400 million tons of [1], represented by rice, corn, wheat crop straw in excess of seasonal and regional resources, Tons of straw became agricultural waste straw resources, not only waste resource, but also brought environmental hazards [2-6]. Therefore, many scholars have devoted themselves to exploring ecological treatment methods of crop straw [7-10].

In the field of geotechnical engineering, some scholars [11-13] have conducted a series of studies on wheat straw fiber reinforced saline soil. Guizhong Xu et al. [14] proposed that in vacuum drainage technology, wheat straw was used to make vertical drainage water body, and the experiment proved that the straw drainage water body had good water permeability. They found that long wheat straw was suitable for replacing sand cushion as horizontal drainage water body, and short wheat straw was suitable for replacing plastic drainage board as vertical drainage water body.

It should be pointed out that, when the straw long-term contact with the aqueous solution, can produce degradation, Cheng, etc. [15] research shows that the temperature reaches 100°C in the alkali treatment, 60% - 70% of the lignin can be dissolved in the straw, the straw lignin is to provide one of
the main components of the tensile strength. Corleone down [16] found that the straw in the acid and alkali environments such as solution, the longer its tensile strength is lower. The tensile property of straw is one of the factors that influence the compressive and shear properties of reinforced soil.

Based on this, the author puts forward the use of rice straw rope made vertical row of water body, by conducting quality loss test and tensile test, studied the rice straw rope soaked after a certain time in the water law of mass loss and tensile properties of rice straw rope degradation on structure are analyzed the appearance, the influence of the limit tensile resistance, ultimate elongation, made for the use of rice straw rope line laid the foundation of the water body.

2. Test program

2.1. Test materials

2.1.1. Rice straw rope

Due to the limitation of test conditions, the rice straw rope with a diameter of 1cm was used in this experiment. It is made into mass loss samples, as shown in figure 1, and into tensile samples, as shown in figure 2.

![Fig1 Sample of straw straw rope mass loss](image1)

![Fig2 Rice straw rope tensile test specimen](image2)

2.2. Test methods

2.2.1. Rice straw rope quality loss test

Select the tightly woven, uniform diameter and undamaged part from the straw rope bundle, and select 15 straw rope mass loss samples, each of which is 300mm long. The selected straw rope segments were numbered and the quality of each rope segment was measured using an electronic balance with an accuracy of 0.01g. The samples were then divided into 5 groups according to the sequence of numbering, immersed in 5 containers containing water respectively, and sealed with
plastic wrap to prevent evaporation of water.

The samples of the 5 groups were soaked for 5d, 10d, 20d, 40d and 60d, respectively, and then taken out. The samples were put into the oven and dried to constant weight at a temperature of 50°C. After the samples were cooled to normal temperature, the quality of the samples after drying was measured. Drying temperature 50°C, because the purpose of drying the sample is on the premise of keep the rice straw fiber organic matter, adsorption in the straw pore water evaporation, high temperature will affect the rice straw fiber organic matter, low temperature drying the straw in the pore water completely, hard and 50 degrees Celsius is a more ideal drying temperature.

2.2.2. Rice straw rope tensile test

Fifteen straw rope tensile samples were taken, each 300mm long. Mark the two ends of the 100mm range in the middle of the sample, tie the two ends of the straw rope segment tightly with a plastic tie belt, and then divide the sample into 5 groups according to the sequence of Numbers, soak them in 5 containers containing water respectively, and use plastic wrap to seal the container to prevent water evaporation. The samples of the 5 groups were taken out after soaking for 5d, 10d, 20d, 40d and 60d respectively, and the clamps were strengthened by dripping quick-dry glue at both ends of the samples, in order to make the failure point of the samples within the range of standard distance in the process of stretching.

After reinforcing the clamping end of the sample, keep the wet state and put it into the fixture of the universal testing machine. Set the drawing rate as 5 mm/min. After setting zero, start the instrument and start drawing. Since the diameter of the sample is only 1cm, the universal test opportunity with a general range leads to a large error in the test results. Therefore, the tensile instrument selected in this test is a thin-film tensile testing machine with a small range. At the end of the test, keep the loading state and measure the distance length of the specimen after stretching.

2.3. Experimental data processing methods

2.3.1. Calculation method of mass loss rate

The calculation method of mass loss rate is as follows:

\[ R = \frac{m - m_0}{m} \times 100\% \quad (1) \]

Type:
- \( R \) -- quality loss rate;
- \( m \) -- original quality of sample;
- \( m_0 \) -- quality of sample after drying.

2.3.2. Elongation calculation method

The calculation method of elongation is as follows:

\[ \varepsilon = \frac{\Delta L}{L_0} \times 100\% \quad (2) \]

Type:
- \( \varepsilon \) -- elongation;
- \( \Delta L \) -- the specimen measures the elongation of the length at the peak tension;
- \( L_0 \) -- measuring length of sample.

3. Analysis of test results

3.1. Appearance changes of samples after degradation

The most direct change of straw rope after degradation in water is the appearance and structure of straw rope. The samples before soaking, after screening in the sampling stage, have good appearance,
close structure, and the rice straw is twisted with each other. After soaking the samples for a certain period of time, the rice straw was no longer tightly wound. It is not easy to see the structural deterioration of the sample under the condition of moisture because of the tension of water. After drying the samples, it can be observed intuitively that after soaking the samples, there are gaps between rice straw and the structure becomes loose. The degree of looseness at both ends of the samples is higher than that at the middle part of the samples. When the soaking time of the samples reached 60 days, the samples completely lost their structure and their appearance was no longer rice straw rope. The rice straw lost its connection and arranged in parallel with each other.

3.2. law of quality loss

![Fig3 Curve of average mass loss rate of rice straw with soaking time](image)

**Table1** The average mass loss rate of rice straw varies with soaking time

| Immersion time/days | Average mass loss rate /% |
|---------------------|---------------------------|
| 5                   | 14.82                     |
| 10                  | 26.78                     |
| 20                  | 44.25                     |
| 40                  | 45.38                     |
| 60                  | 54.72                     |

Figure 3 shows the change curve of average mass loss rate of rice straw with soaking time. It can be seen from the figure that the average mass loss rate of rice straw in water increases with the increase of soaking time. During the period from 0 days to 20 days of sample soaking, the average mass loss rate showed a linear increase with a large increase range. The average mass loss increased by 44.25% in total within 20 days. There was little increase in average mass loss between 20 and 40 days of immersion, and only a 1.13 percent increase in 20 days. During the period from 40 days to 60 days, the average mass loss increased gradually, but not as much as the first 15 days. The average mass loss of rice straw increased by 9.34 percent in the last 20 days.

This shows that the degradation of rice straw in water has gone through two stages: the first stage is the rapid degradation stage (soaking for 0 to 20 days). In this stage, the degradation rate of rice straw is extremely fast, with the average mass loss rate accounting for 80.87% of the total. The second stage is the slow degradation stage (soaking for 20 to 60 days). In this stage, the change curve of
quality loss of rice straw with time is relatively gentle compared with the first stage, and the degradation rate is relatively slow. By comparing the average mass loss rate of rice straw in the two stages, it can be found that the degradation of rice straw mainly occurred within 20 days after soaking. This is because the degradation difficulty and speed of different components in rice straw are different. Some scholars [17-19] studied the degradation process of rice straw and found that the elements such as proteins and minerals in rice straw were easy to be degraded, while lignin, hemicellulose and cellulose, which play the role of skeleton, had a long degradation time. After soaking rice straw rope for 20 days, the easily degraded elements were basically degraded. However, the degradation of lignin and other elements is less, so that the quality loss of rice straw rope is less during soaking for 20 to 40 days, and it does not start to degrade gradually until after soaking for 40 days.

3.3. Stretching characteristics of straw rope

The tensile test results of straw rope are shown in table 2.

| The serial number | Immersion time/d | Ultimate tensile force /N | Ultimate elongation % |
|-------------------|------------------|---------------------------|-----------------------|
| 1                 | 5                | 490.33                    | 19.83                 |
| 2                 | 10               | 416.78                    | 14.54                 |
| 3                 | 20               | 353.04                    | 12.96                 |
| 4                 | 40               | 274.59                    | 12.06                 |
| 5                 | 60               | 259.88                    | 20.88                 |

![Graph showing the variation of tensile force with tensile displacement after soaking for 5-20d](image)

Fig4 The variation of tensile force with tensile displacement after soaking for 5-20d

Figure 4 shows the variation rule of tensile force with tensile displacement after soaking rice straw rope for 5d, 10d and 20d. It can be found that the variation curve of tensile force and tensile displacement under these three conditions is single peak value, and the tensile force of the sample gradually increases with the increase of tensile displacement. At this stage, the tensile force-tensile displacement curve was concave, and the corresponding displacement of the peak tensile force accounted for 97.51%, 96.40% and 88.72% of the total tensile displacement, respectively, which indicated that the tensile force of the sample rose slowly, and it took a certain time to reach the peak. However, after reaching the peak value, the tensile force of the sample immediately dropped significantly, and the residual tensile force was relatively low. At this time, the straw fiber under the main stress within the standard distance of the sample was pulled off, and the test was terminated. This indicates that the failure mode of the specimen is brittle, that is, the specimen fails at the moment
when it reaches the ultimate tensile force, and there is no obvious failure premonition before the failure.

FIG. 5 shows the variation rule of tensile force with tensile displacement after soaking rice straw rope for 40d and 60d. The variation curves of tensile force and tensile displacement under these two conditions have multiple peak values. At the beginning of the test, the tensile force still rose slowly, and the tensile force-tensile displacement curve was concave. After reaching the first peak value, the straw fiber in the sample was broken, and the tensile force decreased somewhat, but the decrease extent did not reach the stop condition of the testing machine. At this time, the broken straw fiber can no longer bear the tension, and the tension on the sample will be transferred to the straw fiber that has not broken. In this stage, the graph of tensile force-tensile displacement shows that the tensile force declines for a certain extent and then rises again, and the rising speed is close to the speed before reaching the first peak of the tensile force. When the tensile force reached the second peak, the straw fiber broke again in the sample, the tensile force decreased, and the tensile force was transferred to other unbroken straw fibers. That is to say, the essence of the tensile force rising after each drop in figure 5 is that the tensile force of the sample is transferred from the broken straw fiber to the unbroken straw fiber, which is a major feature of the rice straw rope.

This multi-peak curve also shows that during the tensile process, the sample starts to break from the fragile straw fibers, then gradually moves to the stronger straw fibers, and finally turns to the remaining straw fibers. However, the remaining straw fibers generally have weak tensile properties, so after the last peak value appears, the sample will soon be completely destroyed. After in-depth analysis of this conclusion, it is found that the stress of straw rope is actually provided by the main fiber and the secondary fiber, that is, the main fiber is the main fiber and the secondary fiber is the secondary fiber. At the same time, this failure mode also transforms the sample from brittle failure to ductile failure. The failure process of the sample is shown in figure 6.

FIG. 7 shows the change curve of the ultimate elongation of the sample with the soaking time. It can be seen from the figure that the soaking time can change the ultimate elongation of the sample.
Fig 6 Tensile failure process of rice straw rope sample

Fig 7 Graph of ultimate elongation of sample with soaking time

Fig 8 The peak value of the tensile force of the sample with the immersion time
Figure 8 shows the variation rule of the peak tensile force of the straw rope tensile sample with soaking time. It can be seen from the figure that the peak tensile force of the sample decreases with the increase of soaking time, and the deterioration rule roughly conforms to the third-degree polynomial function. Based on this, the peak tensile force of a certain soaking time can be predicted. When the soaking days reached 60 days, the peak tensile force decreased by 53% compared with the samples soaked for 5 days. This is because the sample degrades naturally during soaking, causing damage to lignin and cellulose in rice straw to a certain extent. Cellulose is an important component of straw cell wall, which is responsible for providing tensile strength for straw. Lignin strengthens straw cell wall and improves tensile strength. It should be pointed out that when the soaking time was between 20 and 40 days, the mass loss rate of rice straw was very low, only 1.13%, but the peak tensile force decreased by 78.45n, accounting for 34.04% of the total loss of the peak tensile force. This shows that during this period, although the quality loss rate hardly increased, the degradation of straw rope did not stop.

4. Conclusion

Through mass loss test and tensile test, the tensile characteristics of rice straw rope under degradation were studied. The appearance, mass loss rate, tensile force and elongation of rice straw rope before and after soaking in water were analyzed. The conclusions were as follows:

(1) the structure of rice straw rope becomes loose after soaking, and the degree of looseness increases with the increase of soaking time. The degradation of samples in water went through two stages, namely rapid degradation stage (soaking for 0 to 20 days) and slow degradation stage (soaking for 20 to 60 days). After 60 days of immersion, the average mass loss rate of the samples was 54.72%, and the degradation mainly occurred in the rapid degradation stage. The average mass loss rate was 44.25%, accounting for 80.87% of the total.

(2) the tensile force of straw rope increases slowly with the increase of tensile displacement, and it takes a period of time to reach the first peak value. In the first 20 days after soaking, the change curve of tensile force with tensile displacement was single peak, and the failure form was brittle failure. However, after 40 days of soaking, the change curve of tensile force with tensile displacement changed to multi-peak curve, and the failure form changed to ductile failure. That is, after soaking for a certain time, the destruction form of straw rope changed.

(3) the stress mode of the straw rope is that the main and secondary straw fibers bear the same stress, and the weak secondary straw fibers begin to gradually transfer to the main straw fibers. The peak of tensile force decreases with the increase of soaking time, and its deterioration is in accordance with the third-degree polynomial function. Based on this, the peak tensile force of a certain soaking time can be predicted.

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References

[1] Shi Zuliang. Current situation and countermeasures of straw recycling in China [J]. World environment, 2018, (5): 16-18.

[2] Si Kailing. Straw burning and rural environmental crisis: reflections on the theory of "metabolic fracture" [J]. Journal of China agricultural university (social science edition), 2018, 35(4): 61-68.

[3] Zhang Hongqing. Harm caused by straw burning and its comprehensive utilization technology [J]. China agricultural information, 2016(9): 117-118.

[4] Yuan Ding. Multiple hazards of straw burning to the environment [J]. Pollution control technology, 2016(2): 87.

[5] Huo Yaoqiang, Li min, Teng Zidong. Effects of straw burning on air quality in Harbin [J]. Journal of environmental pollution and prevention, 2018, 40(10): 1161-1166.

[6] Li Lili, Wang Kun, Jiang Junqiu, et al. Emission inventory and spatial and temporal distribution of
pollutants from straw burning in heilongjiang province [J]. Chinese environmental science, 2018, 38(9): 3280-3287.

[7] Wang Hongmei, Tu yan, Zhang Naifeng, et al. Resource amount of crop straw in China and its utilization of "five materials" [J]. Science and technology guide, 2017,35(21): 81-88.

[8] Liu Linlin. effects of straw mulching and nitrogen application on soil nutrients, microorganisms and rice yield [D]. Yangzhou: yangzhou university,2018.

[9] Sheng Li. Study on straw - EPS composite lightweight insulation wall material [D].Nanchang: nanchang university,2018.

[10] Xu Zhifeng, Chen zhongfan, zhu songsong, et al. Study on axial compression performance of straw slab light steel high-strength foam concrete shear wall [J]. Engineering mechanics, 2018,35(7):219-231.

[11] Yang Jiwei, Chai Shouxi, Wang Xiaoyan, et al. Reinforcement conditions of wheat straw reinforced saline soil with compressive strength [J]. Rock and soil mechanics, 2010, 31(10): 3260-3264.

[12] Li Min, Chai Shouxi, Wang Xiaoyan, et al. Evaluation of reinforcement effect of wheat straw reinforced saline soil by strength growth rate [J]. Rock and soil mechanics, 2011, 32(4): 1051-1056.

[13] Wei Li, Chai Shouxi, CAI Hongzhou, et al. Shear strength and deviant stress strain of wheat straw reinforced coastal saline soil [J]. Chinese journal of civil engineering, 2012, 45(1): 109-114.

[14] Guizhong Xu, Xiaojuan Yu, Fahong Wu, et al. Feasibility of Vacuum Consolidation in Managing Dredged Slurries with Wheat Straw as Drainage Channels[J]. KSCE Journal of Civil Engineering, 2016, 00 (0) : 1-7.

[15] Cheng Z S. Recent developments in China pulp and paper research on wheat straw [C]. Straw a valuable raw material conference proceedings, Cirencester, 20 to 22 April, 1993:1-23.

[16] Sun Hao, Xu Guizhong,Wu Fahong, et al. Corrosion of wheat straw fiber under different pH conditions [J]. Jiangsu agricultural sciences,2017,45(5):252-256.

[17] Gram H. Durability of natural fibres in concrete [R]. Stockholm: Swedish Cement and concrete Research Institute,1983.

[18] Wolfenden R, Snider m. j. The The depth of chemical time and The powder of enzyme as catalysts [J]. Ace Chem Res, 2001, 34 (12) : 938-945.

[19] CAI Yanlin, He Meidan. Research progress on rice straw degradation [J]. Guangdong agricultural sciences, 2014, (2): 120-124.