The preparation of a straw engineering sand-fixing plank and its sand-fixing and replanting performance exploration

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Abstract. To improve the shortcoming of sand fixation in traditional engineering, the study prepares a kind of porous composite for sand fixation and replanting by taking waste straw as the skeleton, polyvinyl alcohol and aquasorb as the composite agent, then pressing moulding by a press machine. Firstly, the effect of PVA on the mechanical properties is studied by sheering strength. In addition, the fracture mechanism of the composite is analysed by infrared spectrum of the PVA and photos under the optical microscope. Then, it is studied the influence of the amount of aquasorb on the water absorption and retention ability of the composite through the water absorption ratio and water content. Besides, the good water retention and replanting performance of aquasorb is visualized through the macro humidity contrast. The results show that, with the increase of PVA content, its sheering strength first decreases and then increases to the peak value, which is as high as 4.79MPa. It can be seen through the analysis of fracture morphology, that the composite crosslinking of PVA and aquasorb forms a three-dimensional network structure. And the structure enhances the toughness of the composite. With the increase of the content of the aquasorb, the water absorption ratio and the water content first increase and then decrease. When the content is 33.33%, the effect reaches to the optimal level, the water absorption ratio reaches to 3.76 and the repeated water absorption ratio reaches to 2.71. What’s more, the water content is always higher than other proportions. Therefore, the composite can effectively cooperate with plants and extend the years of sand control. The study provides a new idea and basis for the combination of sand fixation and waste straw.

1. Introduction

With the continuous development of agriculture, there is a large amount of waste straw produced every year in the world. However, its reuse technology is not comprehensive. In fact, its utilization rate is
about only 33.33% and the utilization rate after technical treatment accounts for only about 2.6%. Resulting in a large number of biomass resources are wasted. What’s more, the burning of straw has caused serious air pollution, fire and traffic accidents, damaged soil structure, harmed human health and other consequences [1]. Therefore, how to reuse straw has become the hot focus of people's attention.

At present, the comprehensive utilization of straw mainly consists of five aspects: become into energy, feed, fertilizer, raw material or base material [2]. Zhengtao Shen et al. [3] use intermittent adsorption test, microstructure analysis and continuous metal leaching and other methods to study the effects for adsorption characteristics of straw biochar and lead removal mechanism from production temperature, the results show that the 500 °C and 700 °C relative to 300 °C, the biochars’ pH value and surface area is higher and is more suitable for pb soil restoration. Dan Wang et al. [4] study the regulation mechanism and effectiveness of straw mulching on soil se morphology by co-incubating straw and selenate in four different soils for one year. The results show that straw mulching can reduce the loss of soluble se and restore the se content in soil. However, these technologies have not been applied on a large scale due to their immaturity, high cost or small demand in the field of technical application, which cannot fully solve the waste of a large number of waste straw. It’s exciting that we find the vast desert provides a platform for efficiently reuse of straw.

According to relevant studies, global desertification land area is up to 3.618 billion km², which has seriously affected the production and life of about 110 countries and 1 billion people in the world [5].

Presently, methods of sand control mainly include mechanical sand fixation, plant sand fixation and chemical sand fixation [6]. Mechanical sand fixation [7] is mainly to delay the expansion of the sand area by means of sand barrier or guide sand, which has a short-term effect of sand fixation. Plant sand fixation [8] is to fix sand by planting viable plants and increasing vegetation coverage rate. Unfortunately, its survival rate is very low in harsh environment. It has to collaborate with other means of sand control. Chemical sand-fixation become widespread attention of research direction [9] due to its simple, convenient and quick effect features. But as a result of chemical sand-fixation may cause secondary pollution, easy to be quicksand buried, it didn't get the large-scale promotion. Therefore, it is particularly important to prepare an environmentally friendly material that can better combine with plant sand fixation and make full use of straw.

In this study, sand fixation and replanting porous composites are prepared by using waste straw as the skeleton and PVA and aquasorb as the composites by pressure forming process. In addition to solving the current problem of waste straw treatment, it also combines with plant sand fixation effectively, improves the survival rate of plants, prolongs the years of sand control and makes sand control more complete, without secondary pollution. It provides a new type of sand fixation material for desertification control projects.

2. Materials and methods

2.1. Preparation of composites
Mixing PVA with deionized water (ratio of them is 1g: 6.7ml) for 40 min at 90 °C, then the PVA water solution has gotten (write as A). Then mix straw powder (mass is proportional to PVA) with A. Constant stirring for 10 min at 90 °C to get uniform mixture B. After that, add aquasorb (mass is proportional to B) to B, uniform mixture C has gotten after stirring for 10 min at 90 °C. Putting C into the press machine and shaped up under press. After shaping up, the composites is dried for 10 h under 80 °C.

2.2. Characterization
The infrared spectrum of PVA is tested by infrared spectrometer (FTIR-8400S, Shimadzu). It is tested that the composites’ thermal analysis data with thermal analyzer (HCT – 2, Beijing Henven Scientific Instrument Factory), air atmosphere, heating rate of 5 °C / min. The shearin g strength of the composites is tested with universal testing machine (WDW-3100, Kexin). Th e samples’ diameter is 10mm and the length is 90-100mm. After shearing, the truncation surfa
ce is taken microcosmic pictures with optical microscope (VGA3H1T, Huayu Digital Products Firm In Jiande).

2.3. Water absorption rate and repeated water absorption rate test
The specimens are cylindrical, with a diameter of 45mm and a height of 15mm. After drying, the sample is first weighed as its initial mass, then completely immersed in deionized water and taken out every 5 minutes to weigh and the water absorption ratio is calculated according to formula 1:

\[ Q = \frac{[M_1 - M_0]}{M_0} \times 100\% \]  

In this formula: Q - water absorption ratio (g/g); M₀ - initial mass (g); M₁ - real time mass (g).

In order to further explore the repeated water absorption capacity of the composites, the above steps are repeated after drying the samples, which pass the first water absorption test. The formula of repeated water absorption ratio is the same as formula 1.

2.4. Moisture content test
The samples prepared according to 2.1, first weighed each quality and recorded as the initial quality, then immersed in deionized water, taken out and weighed every 1 hour until the quality variation is negligible, then put the samples in the constant temperature and humidity box (HWS – 80B, Hongnuo Instrument Firm in Tianjin), 40 °C, 2% humidity. They are taken out and weighed every 2h, and tested continuously for 48h. Calculating its moisture content according to formula 2:

\[ R_i = \frac{(M_i - M_0)}{M_0} \times 100\% \]  

In this formula: Rᵢ - the moisture content (%); Mᵢ - real time mass; M₀ - initial mass.

2.5. Comparative experiment of simulated desert environment
According to the test results of 2.3 and 2.4, two samples with the optimal performance of the composites are prepared as 100mm long, 70mm high and 20mm thick. Only one of them contains aquasorb. Both samples are filled with water in advance. And three groups of sand with exactly the same quality and humidity are prepared at the same time. The humidity of three groups of sand is tested as the initial humidity. Then both of the samples are inserted into the sand of the corresponding group, and placed in the constant temperature and humidity box (hws-80b type, Hongnuo Instrument Firm in Tianjin) together with the blank control group, 40 °C, 2% humidity, to simulate desert environment. First take out and test their humidity every 1h for 24h, then test humidity every 24h for 20 consecutive days.

3. Results and analysis

3.1. Bond mechanism analysis and fracture mechanism analysis
Figure 1-(a) shows the infrared spectrum of PVA. The association peak of hydroxyl groups forming hydrogen bond appears between 3550cm⁻¹-3200cm⁻¹. As materials can be cross-linked by means of dehydro-condensation, a spatial network structure can be formed to enhance the bonding performance of composites as figure 1-(b): The white intersecting substances formed by PVA and aquasorb forms a network structure. At the initial stage, the external force keeps increasing, and when the critical force is reached, the edge of the material is damaged. However, with the progress of shear, the number of mesh structures inside the composites remains stable, so the pressure required is stable at a high level. Until most of the composite is destroyed, the shear force required becomes smaller and smaller as the mesh structure becomes less and less [10].
3.2. Thermal stability analysis

Figure 2 shows the thermo-gravimetric curve of the composites. There are two obvious gravimetric peaks in the pyrolysis process of the material: First weightlessness zone is at about 200 °C. The first peak of the decomposition rate is 295.92 °C. Here may be start depolymerization of straw decomposition temperature. 200-400 °C weightlessness rate reaches to 58%, may be a bound water, straw, aquasorb and PVA Hydroxyl dehydration. 400-500 °C weightlessness rate reaches to 42%, may be the decomposition of crosslinked network chain that from the hydrogen bond formed by aquasorb and PVA. It is worth noting that there is no small molecule volatilized before 200 °C, therefore the composites thermal stability is good and can maintain stable under the environment of the desert hot sun [11-12].

3.3. Mechanical analysis

Figure 3 shows the relationship between test force and displacement of the specimens with a ratio of 1:0.5 and the sheering strength of each proportion of the specimens when shear effect occurs (groups 1-5 correspond to the ratio of straw to PVA of 1:0.5, 1:0.75, 1:1, 1:1.25 and 1:1.5 respectively). The sheering strength of groups 1-5 are 2.90mpa, 2.40mpa, 4.79mpa, 1.48mpa and 3.13mpa. The sheering strength of the composites reaches to maximum when the ratio is 1:1. This is because the PVA crosslinking degree is insufficient when the PVA proportion is less than the straw. As a result, the structure is not stable and difficult to fixed straw. In addition, the intensity is small. When the proportion of PVA is more than the straw. Due to the partial PVA is excess and they cross-linked. So the real contact with straw and crosslinking is less, reducing the strength of the composites. The sheering strength of the material with a ratio of 1:1 can reach 4.79mpa, indicating that the mixture of PVA and straw has good sheering resistance. It can be seen from figure 3-(a) that composites need constant
external high shear force during the fracture process and have good toughness and are not prone to brittle fracture. Therefore, the composites are not easy to be damaged under the influence of large wind force, providing a stable environment for plant growth.

3.4. Water absorption rate and repeated water absorption rate analysis

Figure 4 shows the relationship for the primary water absorption rate and the repeated water absorption rate with time of each porous composite. When the proportion of aquasorb increased from 0.00% to 13.33%, the water absorption ratio and the repeated water absorption ratio do not change much, which is because the absolute amount of aquasorb is little, and the water absorption effect is not obvious. When the proportion of aquasorb increased from 13.33% to 33.33%, the water absorption ratio increase from 0.95 to 3.76, and the repeated water absorption ratio increase from 0.80 to 2.71. This is because the aquasorb contains hydroxyl, carboxyl and other hydrophilic groups, which can absorb water faster. When the proportion of aquasorb increased from 33.33% to 40.00%, the water absorption ratio and the repeated water absorption ratio decreased instead. This is because the aquasorb has been excessive at this time, and then infiltrated into the water after water absorption, resulting in a decrease in mass and water absorption ratio. According to the above discussion, it can be seen that the water absorption effect of the aquasorb with a ratio of 33.33% is the best.

Figure 4. (a) The curve of the first water absorption ratio of plates prepared with different proportions; (b) The curve of the second water absorption ratio of plates prepared with different proportions.
3.5. The moisture content points
Figure 5 shows the relationship curve of moisture content of the specimen prepared by each ratio with time. The moisture content of the composite prepared with the ratio of 33.33% of the aquasorb is always higher than that of the composites prepared with other ratios, so the water storage effect is the best.

![Figure 5. Relation diagram of moisture content of composites prepared with different proportions of aquasorb with time.](image)

3.6. Comparative analysis of simulated desert environment
Figure 6 shows the variation of humidity in each group over time. The humidity of the sand with the same humidity did not differ much after adding the specimen without aquasorb, and the change curve is basically parallel, while the humidity of the sand with aquasorb significantly increased after adding the specimen.

![Figure 6. Influence of aquasorb and sand fixation plate on sand humidity.](image)
3.7. Analysis of the combination of slabs and plants

Table 1 is a summary of the application of porous composites based on the influence curve of composite materials with aquasorb on sand humidity and the requirements of different plants on humidity:

| Plant species         | Humidity requirements                                                                 | Application in combination with fixed sand plate                                                                 |
|-----------------------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------|
| Roundhead wormwood    | Germination speed is positively correlated with humidity when humidity is from 1.7% to 14.7%, and negatively correlated with humidity when humidity is from 14.7% to 19.4%. Germination is inhibited when humidity is greater than 19.4% [13]. The germination characteristics of seeds reached the highest level at the humidity of 20% to 30% [14]. | The germination rate of artemisia sphaerophora seeds can be as high as 90% because the humidity of the composite is stable at 14% for a long time. Suitable for combination with roundhead wormwood. |
| Tetracentron sinensis | The optimal germination humidity is 20% [15].                                          | As the composite maintains above 20% humidity for about 4 days, it is not suitable for the growth of tetracentron sinensis. Therefore, the composite is not suitable for planting tetracentron sinensis. Because humidity of composite is in 4 days later under 20%, nevertheless humidity is maintained inside period of time in 14% above, because this composite can cooperate with Amygdalus mongolica planting. Because the composite can maintain the environmental humidity at 14% for a long time, it is suitable for the growth of Korshinsk peashrub. Therefore, the composite is suitable for Korshinsk peashrub. As a result of composite after a period of time to maintain the humidity in 14%, higher than 10%, but the gap is not large. Therefore, the composite can cooperate with the planting of the CaraganaintermediakuangetH.D.Fn. Because humidity of composite is in 4 days later under 20%, nevertheless humidity is maintained inside period of time in 14% above, because this composite can cooperate, plant beautiful bar. Because humidity of composite is in 4 days later under 20%, nevertheless humidity still maintains above 14% inside period of time, because this composite can cooperate with planting ammopiptanthus mongolicus. |
| Amygdalus mongolica   | The optimal germination humidity is 15% [16].                                         |                                                                                                               |
| Korshinsk peashrub    | The optimal germination humidity is 10% [16].                                          |                                                                                                               |
| CaraganaintermediakuangetH.D.Fn | The optimal germination humidity is 20% [16].                                     |                                                                                                               |
| sweetvetch            | The optimal germination humidity is 20% [16].                                         |                                                                                                               |
| Ammopiptanthus mongolicus | The optimal germination humidity is 20% [16].                                   |                                                                                                               |
As can be seen from table 1, the good water-retaining property of the replanted porous composite enables it to stabilize the water content at about 14% under desert conditions. It can conduct desert management with plants such as roundhead wormwood, amygdalus mongolica, korshinsk peashrub, caraganaintermmediakuangetH.D.Fn, sweetvetch and ammopiptanthus mongolicus to improve the survival rate of plants and the efficiency of sand fixation of plants.

4. Conclusion
The study prepares a porous composite for sand fixation and replanting. The conclusions are as follows:
When the ratio of straw to PVA is 1:1, the strength of the composite can reach 4.79mpa, which has good toughness and is not prone to brittle fracture. The laying direction can be perpendicular to the main wind direction or at a large angle. The white porous network structure formed by PVA and aquasorb can further enhance the strength and toughness of the composite.
When the ratio of aquasorb is 33.33%, water absorbing ratio can reach 3.76, repeated bibulous ratio can reach 2.71, the ratio of moisture content is always higher than other ratio. Therefore it that can effectively cooperate sand-fixation plants, prolong the years of the sand-fixation.
The composite begin to decompose at 200 °C, has a good stability under the environment of hot sun desert. It is non-toxic, environment protection and no secondary pollution.
The study not only solves the problem of difficult disposal of waste straw, but also improves the survival rate of plants. In addition, it provides a basis for the combination of waste straw treatment and desert control.

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