Analysis of the acid and alkali resistance of superhydrophobic paper mulch

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Abstract Agricultural paper mulch is an indispensable part of modern agriculture. It had the functions of heat preservation, moisture preservation, insect resistance, disease prevention, and weed growth inhibition. In order to extend the service life of the paper mulch, we use the solution immersion method to modify the surface of the paper mulch. A super-hydrophobic paper mulch is mainly prepared by using hydrophobic silica. The static contact angle of the super-hydrophobic paper mulch with water is 160.6°. The super-hydrophobic paper mulch samples were immersed in acid solution (pH = 4.6 H2SO4) and alkaline solution (pH = 8.5 NaOH). The main instruments are contact angle tester, tensile testing machine and high-speed camera. The hydrophobic properties, mechanical properties and rebound properties of the two kinds of paper mulches were compared. The results showed that the tensile strength and droplet bounce height of the superhydrophobic paper mulch decreased after being soaked in acid or alkaline solution for 48 h. The mass loss rate of paper mulch was more significant in acid solution, but its contact angle was still greater than 145°, and it had good bounce performance. After observing the microscopic morphology of its surface, it was found that silica had a micro-rough structure on the surface of the paper mulch. The method was simple and environmentally friendly, and can alleviate the problem of poor acid and alkali corrosion resistance of the paper mulch, and had extraordinary significance for environmental protection.

Keywords Superhydrophobic · Paper mulch · Mechanical property · Acid–base resistance property · High-speed bounce behavior

Introduction

The main components of agricultural mulch are polyethylene (PE) and polyvinyl chloride (PVC). Microplastics enter the soil environment through long-term agricultural mulch residues, sludge and organic fertilizer application, surface water irrigation, and atmospheric deposition. In general, the thickness of agricultural mulches in my country was much thinner than that of developed countries such as Europe and Japan, which makes it difficult to recycle, with a recycling rate of less than 60%. It was also easy to age and fragmentation. It remains in the soil to form microplastic pollution. At the same time, it was easy to release plasticizer pollutants such as phthalate esters. Paper mulch was made of plant fiber, which was essentially different from traditional plastic mulch in...
composition. Since plant fiber can be degraded by microorganisms, it does not need to be recycled after use and had almost no side effects on the environment (Zhang et al. 2020a, b; Yang et al. 2020; Larkin 2020). However, there are still some problems in the actual application of paper mulch. Because the fiber contains a large number of hydroxyl groups, it was a hydrophilic material and will absorb water and expand in a humid environment, destroying its mechanical properties and durability (Kasirajan and Ngouajio 2012; Chen et al. 2019). Because of the exposure in the harsh outdoor environment for a long time, the paper mulch needs to have good durability. In both of the slightly acidic and alkaline soil and under the erosion of rain, it can still provide heat preservation and moisturizing living environment for plants (Landuzzi and Ghosh 2003; Kalisz et al. 2018).

Many plants and insects in life have super-hydrophobic properties. For example, the upper surface of the lotus leaf had a pointed vault-shaped papillary structure, which can make water droplets roll freely on the surface without wetting the lotus leaf. This was also called “The lotus leaf effect” (Ensikat et al. 2011); a drop of water was nailed to the surface of the rose petal, even if the surface was inclined 90 degrees. Therefore, the surface was considered to be a water binder and a superhydrophobic surface (Lin et al. 2008). The feet of the water strider have bristles that are 20° to the surface of the foot and are in the same direction. The bristles also have nano-scale lines. This structure allows the water strider to crawl freely on the water surface without falling into the water (Dickinson 2003; Gao and Jiang 2004). The surfaces of these plants and animals have a special superhydrophobic structure, and the contact angle with water can reach more than 150°. If the surface of the paper mulch was given a super-hydrophobic property, it can effectively resist the penetration of water into its internal structure, and its durability can be improved to a certain extent. There are many ways to prepare superhydrophobic, including chemical graft modification (Bongiovanni et al. 2013), surface coating (Hejazi et al. 2017; Li et al. 2014), electrospinning (Lee et al. 2017; Song et al. 2014), sol–gel method (Xiang et al. 2011; Heinonen et al. 2014), corrosion Method (Zhao et al. 2007; Balu et al. 2008), template method (Wang et al. 2020), solution immersion method (Kong et al. 2015) and so on.

In general, the fabrication of superhydrophobic surfaces starts from two aspects, one was to modify the surface of materials using low surface energy substances, and the second was to construct micro and nano rough structures on the surface of materials, reducing the contact area between water and the surface of materials. Making a low surface energy coating on the surface of material paper using powder particles was a relatively simple way to change the superhydrophobic property of material paper. As reported by Adamopoulos (Adamopoulos et al. 2021) that a coating material with superhydrophobic and water repellent properties, which could be coated onto paper, was prepared by adding fatty acid synthetic enzyme in a silica sol solution, resulting in extremely high wetting properties. As reported by Chatzigrigoriou (Chatzigrigoriou et al. 2013) a method to prepare superhydrophobic solution by dispersing SiO₂ nanoparticles in siloxane solution, studying the effect of particle concentration on the hydrophobic properties of this solution when applied on marble and wood, and found that its contact angle can reach around 160° when the silica/siloxane mass ratio is larger than 0.2. Karapanagiotis (Karapanagiotis et al. 2015) reported a method for simple preparation of superhydrophobic paper surface by surface coating, which applied different concentrations of silica nanoposts to four types of different paper surfaces and found that only appropriate concentrations of nanoparticles could prepare superhydrophobic paper surface with excellent performance. At present, the preparation of superhydrophobic nanoparticles had been reported as four-pin type ZnO (Zhou et al. 2020), SiO₂ (Teng et al. 2020), CeO₂ (Zhang et al. 2020a, b) and so on. The fibers in the paper mulch will be corroded in an acidic or alkaline environment (Yang et al. 2019; Li et al. 2019), and the surface was covered with a layer of low surface energy material, which can make the paper mulch achieve the super-hydrophobic effect. However, it also produces certain protection to enhance the corrosion resistance of the paper mulch in acidic or alkaline environments.

In order to make the hydrophobic surface of the paper mulch and the resistance to acids and alkalis, we adopted a simple and easy-to-implement solution immersion method while reducing the cost. A hydrophobic SiO₂ was attached to the surface of the paper mulch to prepare a acid and alkali-resistant
paper mulch that also had a good hydrophobicity and protect the fibers in the paper mulch.

**Experimental procedure**

**Materials**

The fully degradable paper base mulch (hereinafter referred to as paper mulch) was purchased from Shandong Ruibosi Tobacco Co., Ltd. (China), with an average weight of 73.95 g/m² and an average thickness of $73.36 \times 10^{-3}$ mm. HB-139 hydrophobic SiO$_2$ was provided through Hubei Yichang Huifu Silicon Materials Co., Ltd. (China). This material had good hydrophobicity and the particle size was about 6 \( \mu \)m. KH550 coupling agent was provided from Qufu Chenguang Chemical Co., Ltd. (China), which was used to increase the combination of polymer materials and inorganic materials, and it was often used as a binding agent to modify the surface of the paper mulch. The role of KH550 in this article was to enhance the bond between paper and silica. Anhydrous ethanol was supplied from Tianjin Fuyu Fine Chemical Co., Ltd. (China). The H$_2$SO$_4$ solution was purchased from Hubei Xinrunde Chemical Co., Ltd. (China). The NaOH solution was purchased from Jinan Chuangshi Chemical Co., Ltd. (China). Homemade distilled water in the laboratory.

**Main experimental equipment and instruments**

The NANO SEM450 scanning electron microscope was purchased from NOVA Co., Ltd. (USA).

**Table 1** Sample number

| Sample           | pH4.6 SiO$_2$/ paper mulch | pH4.6 paper mulch | pH8.5 SiO$_2$/ paper mulch | pH8.5 paper mulch |
|------------------|---------------------------|------------------|----------------------------|-------------------|
| Num              | 4.6 SPM                   | 4.6 PM           | 8.5 SPM                    | 8.5 PM            |

![Superhydrophobic paper mulch sample preparation process](image)
SMT-5000 electronic universal testing machine was purchased from Yangzhou Saisi Testing Equipment Co., Ltd. (China). The FA3104N electronic analytical balance was purchased from Shanghai Jinghai Instrument Co., Ltd. (China). The FE28 pH meter was purchased from METTLER TOLEDO Instruments Co., Ltd. (China). HKCA-15 contact angle tester was purchased from Beijing Harco Experimental Instrument Factory (China). DHG-9070A blast drying oven was purchased from Shanghai Heng Science Instrument Co., Ltd. (China). Interferometric three-dimensional surface topography instrument (ZeGage type, ZYGO, USA). High-speed camera (NAC MEMRECAM HX-6E, Japan). Fourier infrared spectrometer (FTIR, IRTracer-100, Japan).

Experimental preparation process

Figure 1 shows the sample preparation process. Firstly, we add 1.5 g of SiO$_2$ powder to 100 ml of absolute ethanol, and sonicate it for 10 min to make the SiO$_2$ powder dispersed uniformly. Then 0.15 g of coupling agent (KH550) was added, and sonicate for 10 min. Finally, the paper mulch was immersed in the prepared SiO$_2$ solution, and it was taken out after standing for 1 min and placed in a high-temperature drying oven at the temperature of 35 °C for 10 min to obtain SiO$_2$/superhydrophobic paper mulch samples.

The acid and alkali resistance test mainly use the H$_2$SO$_4$ solution (pH = 4.6) and NaOH solution (pH = 8.5) to simulate acidic and alkaline environments. The paper mulch was immersed in H$_2$SO$_4$ solution or NaOH solution with 24 h as a gradient, and 0 h, 24 h and 48 h tests were set respectively. After the soaking was completed, the paper mulch was placed in a drying oven at a temperature of 35 °C and dried for 10 min. Finally, the paper mulch was taken out for other performance tests. The sample numbers of the paper mulch (the sample names of the paper mulch are abbreviated as the number names) are shown in Table 1.

Performance testing and characterization

Contact angle (CA): Cutting the paper mulch that had been processed in different ways into a 10 mm × 20 mm rectangle, we fix it on a glass slide with double-sided tape and measure the contact angle with a contact angle tester. Using the laboratory-made deionized water with a droplet size of 4 μL, six different points on the sample surface were selected for repeated experiments to reduce measurement errors.

Horizontal bounce test: to ensure the same size of droplets each time, the test uses the same needle, and the drop height was set to 10 cm. A high-speed camera was used to photograph the process of droplets falling onto the surface of the paper mulch and bouncing repeatedly which can be used to analyze the bounce behavior of the droplets on the paper mulch.

SEM and EDS: The particle size and shape of the SiO$_2$ powder and the three-dimensional morphology of the paper mulch surface were observed by scanning electron microscopy, and the surface structure of the superhydrophobic paper mulch was changed after

![Fig. 2 Tensile tear sample model](image)

![Fig. 3 a is the SiO$_2$ particles uniformly dispersed on the conductive adhesive. b is a SiO$_2$ particle in a. c The state of different droplets of acid, alkali, salt, etc. on the surface of SiO$_2$ powder](image)
silica was attached to the surface. The element distribution and content on the surface of the sample were analyzed by X-ray energy spectrum. By scanning the surface of the paper mulch soaked in acid or alkaline solution for 24 h and 48 h, we can analyze the hydrophobic properties and acid and alkali resistance properties of the paper mulch.

Mass-loss ratio: First, weigh the mass of the sample with an electronic balance, and then soak it in acidic and alkaline solutions for 24 h and 48 h, then dry the sample in a high-temperature drying oven, and then weigh the mass of the sample with an electronic balance. The mass loss rate was the ratio of the difference in mass before and after soaking to the mass before soaking. The data was collected five times to find the average value, which was used to analyze the influence of the acid–base environment on the performance of the sample.

Mechanical properties: The sample size and dimensions are shown in Fig. 2. We use the electronic universal testing machine to test the tensile properties of the original paper mulch, the silica-treated paper mulch, and the samples soaked in the acid or alkaline
solution for 24 h and 48 h. The tensile rate was 100 mm/min ± 10 mm/min.

Results and discussion

SiO₂ powder characterization

Figure 3a shows the SiO₂ particles uniformly dispersed in the anhydrous ethanol solution. Figure 3b was an enlarged view of one SiO₂ particle with slightly larger size. The measured particle size was 6.758 μm, which was a loose and porous spherical structure. However, the spherical structure was beneficial to reduce the surface energy of the paper mulch surface, thereby it was hydrophobic. Figure 3c shows the hydrophobic effect of silica powder. NaOH, H₂SO₄, NaCl, Distilled water (D H₂O), and Deionized water (DI) all have a large contact angle on the surface of silica, which proves that the dioxide Silicon powder had good hydrophobic property.

Morphological characterization of paper mulch under different processing methods

By observing Fig. 4a and b, the fiber structure on the surface of the paper mulch was intertwined to form a network structure with a certain mechanical strength. The shape and outline of the fiber can be clearly observed. After further observation, it was found that the surface of the paper mulch was not smooth, and there are many gaps between the fibers. By zooming in, it was found that the width and length of the fiber are different. An interferometric three-dimensional profiler was used to measure the surface roughness of paper mulch. Figure 4c was a three-dimensional cloud map of the surface roughness of the paper mulch. By calculating the average surface roughness, the arithmetic average height of Sa was 5.784 μm. The highest and lowest height difference (Sz) reached to 64.893 μm. Observing Fig. 4d, it was found that the silica powder was evenly covered on the surface of the paper mulch. By Fig. 4e, a part of the SiO₂ powder was filled into the voids of the fibers on the surface of the paper mulch, and a part was covered on the fiber surface of the paper mulch. As shown in Fig. 4f, the measured Sa of SiO₂/paper mulch was 6.637 μm. The
SiO₂/paper mulch was compared with the untreated paper mulch. As the SiO₂ powder was covered on the surface of the paper mulch, the roughness increases. We conducted an EDS analysis on the paper mulch. As shown in Fig. 5, the surface elements of the untreated paper mulch are mainly C and O. These are also the main components of the fibers. After SiO₂ treatment, the percentage of the C, and O on the surface of the paper mulch was reduced, and a small amount of Si element was added to the paper mulch which proves SiO₂ had covered on the surface of the paper mulch.

Observing Fig. 6a and b, it was found that part of the fiber structure was broken after the paper mulch was immersed in an acidic solution for 24 h, and a small part of the fiber was corroded by acid. But the shape and contour of the fiber can still be identified. Therefore, the mechanical properties of the fiber are reduced. Compared with the unsoaked original paper mulch, the roughness of the paper mulch soaked in the acid solution for 24 h had increased. The Sa of the original paper mulch soaked in H₂SO₄ with a pH of 4.6 for 24 h was 6.641 µm. It can be seen from Fig. 6c that the measured Sa increased to 7.975 µm after the paper mulch was immersed in the acidic solution for 48 h. Observing Fig. 6d, it was found that most of the fibers on the surface of the SiO₂/paper mulch have been corroded by the acid solution. Meanwhile some of the fibers are broken and fall off and the outline of the fibers had gradually blurred.

It can be seen from Fig. 6e that after the SiO₂ treated paper mulch was soaked in an acidic solution for 24 h, the SiO₂ particles on the surface have a little shedding and a little dent was produced. Shown in Fig. 6f, the acidic solution had contacted the fibers and corroded the fibers, which increasing the roughness of the SiO₂/paper mulch. It can be seen from Fig. 6g and h that after 48 h of H₂SO₄ soaking, due to the acid

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**Fig. 7** The surface of SiO₂/paper mulch (4.6 SPM) soaked in H₂SO₄ with pH 4.6 for 24 h a EDS element distribution diagram, b Si element distribution diagram; soaked in H₂SO₄ pH 4.6 for 48 h SiO₂/paper mulch (4.6 SPM) surface c EDS element distribution map, d Si element distribution map.
corrosion of the fiber, some of the raised SiO\textsubscript{2} had fallen off.

As shown in the results of Fig. 7a and b, it was found that the Si element on the surface of the SiO\textsubscript{2}/paper mulch soaked for 24 h was reduced. It was consistent with the result that the surface of the SiO\textsubscript{2}/paper mulch covered by SiO\textsubscript{2} particles had a little peeling off in the SEM image. Observing Fig. 7c and d, it was found that the Si element content of the SiO\textsubscript{2}/paper mulch surface immersed for 48 h was less than that after 24 h. Part of the SiO\textsubscript{2} had fallen off, but SiO\textsubscript{2} still adheres to the SiO\textsubscript{2}/paper mulch.

Figure 8a showsthat after the original paper mulch (PM) was soaked in an alkaline solution for 24 h, the surface fibers are deformed. This phenomenon reduces the mechanical strength of the paper mulch. Since the paper mulch did not break or fall off, the quality loss was not obvious. Comparing Fig. 8b and c, it was found that the surface roughness of the paper mulch increases after being immersed in the alkaline solution for 48 h. Observing Fig. 8d, it was found that part of the fiber structure had changed from a strip-like fiber structure to a sheet-like fiber structure. The result shows that the fiber structure had undergone significant corrosion. Observing Fig. 8e, it was found that the fiber structure of the SiO\textsubscript{2}/paper mulch had not changed significantly after being immersed in an alkaline environment for 24 h. The reason for this result may be that SiO\textsubscript{2} was an acidic oxide. At room temperature, SiO\textsubscript{2} reacts slowly with NaOH to produce Na\textsubscript{2}SiO\textsubscript{3} and H\textsubscript{2}O. The SiO\textsubscript{2} particles covered on the paper mulch can protect the fiber structure of the paper mulch. Comparing Fig. 8f and g, it was found that the surface roughness of the paper mulch increased after being soaked for 48 h. Also, it was found that the Si element on the surface of the SiO\textsubscript{2}/paper mulch was reduced by Fig. 8h. It shows that the SiO\textsubscript{2} particles on the surface of the SiO\textsubscript{2}/paper mulch have fallen off.

By Fig. 9, we find that the Si element on the surface of the SiO\textsubscript{2}/paper mulch after immersing for 24 h in an alkaline environment was less than immersing in an acidic environment for same period. After soaking in the alkaline solution for 48 h, SiO\textsubscript{2} was significantly reduced. The results showed that SiO\textsubscript{2} and NaOH reacted when SiO\textsubscript{2}/paper mulch was soaked in the alkaline solution. At the same time, a large number of SiO\textsubscript{2} particles adhere to the surface of the SiO\textsubscript{2}/paper mulch, and the surface was hydrophobic.
Hydrophobic performance test

As shown in Fig. 10a, the PM surface contact angle of 135.9° was not a superhydrophobic surface (contact angle > 150°), while the SPM contact angle reached 160.6° after SiO₂ treatment, which might be due to the hydrophobic coverage of SiO₂ reducing the surface energy of SPM. In addition, the addition of SiO₂ particles increased the roughness of the specimen surface, which was known from Cassie’s theory, and this would decrease the contact area between water and the specimen, and then elevate the contact angle of the specimen. In the acid alkali resistance test of specimens, the contact angles of both PM and SPM showed a decreasing trend after soaking in acidic vs. alkaline solutions. 4.6 PM and 4.6 SPM decreased by 14.9° and 12.9°, respectively, after 48 h immersion in acidic solution. The contact angles of 8.5 PM and 8.5 SPM immersed in alkaline solution for 48 h decreased by 22.0° and 15.0°, respectively. The comparison found that the contact angle decreased more obviously after immersion in alkaline solution than after immersion in acidic solution, and the contact angle of SPM was larger than 145° after immersion in either acidic or alkaline solution for 48 h. Figure 10b demonstrates the hydrophobic effect on the surface of paper-based basement membrane under the droplets of NaOH, H₂SO₄, NaCl, D H₂O, DI, and it can be seen that the surface of SPM can maintain good infiltration under acid, base, and salt solutions.

From Fig. 10d, it can be seen that the PM would adsorb on the PM surface during the process of flipping over 180°, and rolling did not occur. After SiO₂ treatment, it can be seen that the surface contact angle of SPM was only 5.0°, its surface contact angle increased by 0.8° and 0.3° after 24 h immersion in acidic and basic solutions, respectively, and its rolling angle reached 6.0° and 5.7° after 48 h immersion in
acidic and basic solutions, respectively (Fig. 10c), all less than 10°, with good rolling properties.

Figure 11a was the diagram of the bounce behavior of the SiO$_2$/paper mulch surface after different treatments. The droplet falls from a height of 10 cm and can bounce multiple times on the surface of the sample. Combined with Fig. 11b, it was found that as the droplet bounces several times, the spread diameter gradually decreases. Because the droplet was in the Wenzel model when it encounters the paper mulch, it causes energy loss. A small part of the droplets remained on the surface of the paper mulch, causing a large loss of capacity when the droplets bounce. The silicon dioxide attached to the surface of the SiO$_2$/paper mulch was corroded and peeled off after immersion in the acid solution or alkali solution that makes the surface of the SiO$_2$/paper mulch form a more complex structure and then the contact area between the droplet and the surface of the SiO$_2$/paper mulch cut back. Observe Fig. 11c, the maximum bounce height of SiO$_2$/paper mulch was 3.2 mm. The maximum bounce height of the SiO$_2$/paper mulch after being soaked in acidic solution for 24 h was 6.2 mm. The maximum bounce height of the SiO$_2$/paper mulch after being immersed in alkaline solution for 24 h was 6.3 mm. The maximum bounce height of the SiO$_2$/paper mulch after being immersed in alkaline solution for 48 h was 4.1 mm. Experiments show that after soaking in acid or alkaline solution, the bounce performance of the SiO$_2$/paper mulch was improved.
The effect of pH on the quality of paper mulch

From Fig. 12a and b, it can be seen that PM and SPM show an increasing trend in mass loss rate in both acidic and alkaline solutions. After 48 h immersion in acidic environment, the mass loss ratio of both PMS and SPMS reached more than 8%. Mainly due to the large number of fibers contained in the paper mulch, the 1,4—β—glycoside bonds in the fibers are sensitive to acid comparison and will break under acidic
environment, so that a part of the paper floor material dissolves in acidic solution, resulting in the increase of the mass rate of the paper mulch (Bower et al. 2008). After 48 h immersion in alkaline solution, the mass loss rates of PM and SPM remained almost below 1.5%, and the mass loss rates of the paper mulch was not obvious. Moreover, it can be found that the mass loss rate of SPMS was less than that of PMS, whether in acidic or alkaline environments. It indicated that the addition of SiO$_2$ could effectively reduce the mass loss rate of the paper mulch membrane. This also indicated to some extent that the addition of SiO$_2$ could decrease the acid–base corrosion on the paper mulch.

The effect of pH on the mechanical properties of paper mulch

From Fig. 13a and b, we find that as the soaking time increases, the mechanical properties of the paper mulch decrease. From Fig. 13a, after the paper mulch was soaked in an acidic environment, the SiO$_2$/paper mulch (SPM) had mild higher tensile properties than the original paper mulch (PM), which may be since SiO$_2$ had a certain effect on the surface of the paper mulch, the reinforcing effect. From Fig. 13b, it can be seen that after immersion in an alkaline environment, the tensile properties of SiO$_2$/paper mulch (SPM) are much higher than that of original paper mulch (PM). This was mainly due to the slow reaction of SiO$_2$ with

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**Fig. 12** a mass loss rates of PMS and SPMS after soaking in acidic solutions. b Mass loss rates of PMS and SPMS after immersion in alkaline solutions

**Fig. 13** Paper mulch and SiO$_2$/paper mulch a Tensile strength after immersion in acidic environment. b Tensile strength after immersion in an alkaline environment
sodium hydroxide. The paper mulch had a certain protective effect.

Conclusion

1. SPMS were prepared by solution immersion, and their contact angle reached 160.6° and rolling angle reached 5.0° (PMS were turned and not rolled by 180°). In the acid–base resistance test, the paper mulch contact angle was still higher than 145° after soaking in acidic solution or alkaline solution for 48 h, and the highest rolling angle was only 6°, indicating that after soaking in acid–base solution, its surface still had excellent hydrophobic property.

2. Paper mulch had good acid and alkali resistance. After being soaked in the solution for 48 h, the mass loss of SiO2/paper mulch in acidic solution was reduced by 1.24% compared with the original paper mulch, and the mass loss in alkaline solution was reduced by 0.42%, indicating that the SiO2/paper mulch was in acid or the alkaline solution had a certain protective effect on the paper mulch. Interestingly, after 48 h of soaking, the quality loss of paper mulch in acidic solution was much greater than that of paper mulch in alkaline solution. This was because the 1,4-β-glycosidic bond in the fiber structure was more sensitive to acid, and the reaction between silica and alkali protects the fiber structure to a certain extent. This phenomenon was also confirmed in the mechanical performance test. When immersed for 24 h, the silica/paper mulch in acid solution decreased by 2.34 kN, and the SiO2/paper mulch in alkaline solution decreased by 0.7 kN, indicating the fiber structure strength of the paper mulch in the solution was better than that of the paper mulch in the acid solution.

3. The paper mulch had a good bounce performance. The results of the bounce test show that the droplets of the paper mulch treated with silica can bounce multiple times. Interestingly, due to the corrosion of the surface of the silica/paper mulch by acidic and alkaline solutions, a more complex spatial structure was formed on the surface. Compared with the unsoaked SiO2/paper mulch, the maximum spreading diameter and the maximum bounce height of the SiO2/paper mulch after immersing in an acid or alkaline solution for 24 h are increased. Although the maximum spreading diameter and the maximum bounce height are reduced after immersing for 48 h, they are still higher than the unsoaked silica/paper mulch.

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Declarations

Conflict of interest No potential conflict of interest was reported by the author(s).

Ethical approval Ethics Committee approval was obtained from the Institutional Ethics Committee of Anyang Institute of Technology to the commencement of the study.

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