Construction of organic-inorganic hybrid coating polymer with in situ SiO2/PDMS on the surface of wood

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Article

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Abstract

Wood has a large number of hydrophilic groups and pore structures, with strong moisture and water absorption abilities, and is prone to problems such as deformation, cracking, and discoloration. In order to improve this phenomenon, surface modification of wood has always been a hot topic in wood science research. To address the problem of poor water resistance of wood, the organic-inorganic hybrid superhydrophobic layer was constructed bionically on wood substrate by dipping coating method or spraying method based on the principle of lotus leaf effect, using inorganic fillers such as nano-silica/organosilicone oil and transparent polymer of water-based acrylic varnish as organic matrix. In this study, monodisperse nanometer-sized SiO$_2$ microspheres were prepared via the Stöber method and the wood surface was modified by self-assembly of a solution. Then, the prepared modified nanoparticles SiO$_2$/PDMS mixture solution was alternately and cyclically coated on the surface of the wood to obtain SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood samples. The results showed that the porous structure of the white wax wood surface was fully covered by SiO$_2$/PDMS in situ organic-inorganic hybrid coating polymer after coating, forming a dense protective layer. SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood samples not only did not change the original color and texture of the white wax wood material, but also had a contact angle greater than 150° for the surfaces of 7 common droplets (deionized water, tea, cola, juice, vinegar, ink, red wine), indicating that introducing a SiO$_2$/PDMS organic-inorganic hybrid coating to modify the wood surface can endow the wood with good superhydrophobic properties. This is mainly because the hydroxyl groups in the SiO$_2$/PDMS in situ organic-inorganic hybrid coating deposited on the wood surface are combined with the hydroxyl groups on the wood surface, reducing the number of hydroxyl groups on the surface. In addition, the presence of long-chain fluorinated polymers also increases the hydrophobicity of the wood surface.

1. INTRODUCTION

Wood is widely used in fields such as decoration, construction, and furniture manufacturing due to its unique material properties and environmental characteristics, and it is the only renewable resource among them[1–3]. The abundant pore structure and hydrophilic groups in the wood result in its strong water absorption and moisture retention, making it susceptible to problems such as deformation, cracking, decay, and discoloration when exposed to oxygen, sunlight, and water for a long time[4–6]. Among the existing research, the methods for surface modification of wood mainly include heat treatment, acetylation treatment, silane treatment, and monomer in-situ polymerization[6–8]. These methods can only reduce part of the wood's water absorption, but cannot fundamentally prevent moisture, especially liquid water, from invading it. In addition, traditional modification methods often affect the structure and mechanical strength of the wood itself, and the relevant reagents used in the treatment method can also be harmful to humans and the environment. Therefore, exploring a wood modification treatment method that meets performance, cost and environmental protection requirements has become an urgent issue to be addressed in the field of modification.
There are many superhydrophobic phenomena in nature[5, 8–11]. One typical example is described in the poem "After the overnight rain on the leaves in the morning sun, the water drops are crystal clear, and the wind lifts each lotus leaf one by one.[12]" Water droplets cannot stay on the surface of lotus leaves, but instead roll off, taking away dust and impurities adhering to the surface, thereby achieving a self-cleaning effect[13–15]. This phenomenon is called the "lotus effect" or "self-cleaning effect"[16, 17]. Research has shown that the hydrophobic properties of lotus leaves come from the nano-scale wax protrusions on their surface[18]. It is these tiny structures that give lotus leaves their superhydrophobic properties, and this discovery points to a method for producing superhydrophobic materials[19]. In addition, small aquatic insects such as water striders also have superhydrophobic surfaces on their legs[20]. When moving on the water surface, their legs neither break the surface nor get wet from the water, thanks to the thousands of micrometer-scale multiple layers of stiff hairs arranged regularly on their legs[21]. The nano-structured grooves on the surface of the stiff hairs cause air to be trapped in them, forming an air cushion, which isolates water from direct contact with the stiff hairs, and this demonstrates their superhydrophobic properties. The leaves of Salvinia plants, the legs of water striders, and the surfaces of lotus leaves all have a characteristic called "surface super-wettability", and this special surface is called a "superhydrophobic surface"[19, 22]. Water droplets roll on its surface but adhere with difficulty. Inspired by this, we can construct a superhydrophobic surface on wood, which is the substrate, to give it superhydrophobic properties and to some extent, prevent the invasion of liquid water, thereby solving the various problems of wood caused by water absorption[5–7, 23]. In addition, by properly controlling and designing the microstructure and chemical composition of the wood surface, it is possible to preserve the excellent properties such as porosity, biological materials, and environmental characteristics of superhydrophobic wood, and give it functions such as water repellency, oil repellency, self-cleaning, flame retardancy, anti-corrosion, and anti-aging under light[3, 5, 6, 24, 25]. This makes wood suitable for use in indoor and outdoor construction, decoration, kitchen and bathroom decoration, and other fields. Improving the properties of wood and reducing the damage to wood-related products caused by moisture infiltration is also of certain significance.

Currently, many scholars have conducted research on the construction of superhydrophobic surfaces. The characteristics of superhydrophobic surfaces can be applied to many fundamental research and industrial production. The acquisition of superhydrophobic surfaces allows us to construct hydrophobic rough structures of a certain size on solid surfaces, and we can also use materials with low surface free energy to chemically or physically modify the solid surface to a certain extent. There are generally two ways to construct superhydrophobic materials[6, 7]: one is to modify the rough surface on the solid surface to varying degrees; the other is to construct a multi-level rough structure on the hydrophobic surface of the substrate. Common methods for hydrophobic treatment of materials include layer-by-layer self-assembly[26, 27], template method[2, 3, 5–7, 28], sol-gel[29, 30], chemical vapor deposition[23, 31], etc., but not all methods are applicable to wood surfaces.

The broad existence of surface superhydrophobic properties in the natural world has great application value in scientific research and daily life, especially in the field of wood science and technology research. In order to prevent the negative effects of water infiltration on wood, this article uses the Stöber method to
prepare nano-SiO$_2$ microspheres and modify them[7]. The modified superhydrophobic nano-particles SiO$_2$/PDMS mixed solution is alternately brushed on the surface of the wood, fully depositing the organic-inorganic hybrid superhydrophobic coating, so that the modified SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood samples can obtain good superhydrophobic properties.

2. EXPERIMENTAL SECTION

2.1 MATERIALS

The ash wood (fraxinus chinensis Rob) sample is cut into 200mm×10mm×5mm (Radial×Tangential×Longitudinal) from lumber and oven-dried at 105 ºC for 24 h. All specimens were collected in this study Wood Collection, Southwest Forestry University, Yunnan Kunming 650224, People's Republic of China. And all authors declare no conflict of original materials on plants. And were ultrasonically rinsed in acetone for several time, and then ultrasonically rinsed in demonized water for 15 min before use. The dry density of the original wood is 0.66 ± 0.05 g/cm$^3$. Polydimethylsiloxane (PDMS), Acetone, Absolute alcohol, Ethyl silicate (TEOS), 1H,1H,2H,2H-perfluorodecyltrioethoxysiloxane (FAS-17) (All purchased from the Chemical Technology Co. Ltd. Shanghai DB). And all used as received.

2.2 Preparation of PDMS prepolymer mixture solution

The PDMS prepolymer mix was prepared as shown in Fig. 1. Specifically, the following:

1) Take 20 mL of PDMS in a beaker, add 2 mL of curing agent (the volume ratio of the main agent to the curing agent is 10:1), and stir magnetically for 0.5 h.

2) Then, let the mixed solution obtained in step 1) stand quietly at room temperature until all the bubbles disappear. The obtained PDMS prepolymer mixed solution is ready for use.

2.3 Preparation and modification treatment of nano-SiO$_2$ microspheres

The modification treatment of nano-SiO$_2$ microspheres was prepared as shown in Fig. 2. Specifically, the following:

Preparation of monodisperse nanosized SiO$_2$ microspheres using the Stöber method is shown in the figure. Firstly, 3.8 ml of tetraethyl orthosilicate (TEOS) was added to 5.7 ml of ammonia solution and mixed with 144 ml of anhydrous ethanol. Secondly, the resulting mixture was stirred for 24 hours at room temperature and purified by repeated centrifugation in anhydrous ethanol, resulting in pure silica microspheres. Hydrophobic modification using 1H,1H,2H,2H-perfluorodecyltrioethoxysilane (FAS-17) was performed using a self-assembly method on the silica spheres. Thirdly, 0.3 g of nanosized silica particles, 10.2 ml of butyl acetate, and 0.12 ml of ammonia solution were mixed and stirred for 0.5 hours at room temperature. Then, the resulting mixture was suspended in a 50 ml volume ratio of 0.6% FAS-17 solution...
and subject to ultrasonication for 0.5 hours, followed by magnetic stirring at 65°C for 2 hours. The modified superhydrophobic silica nanoparticles were collected and purified using repeated centrifugation at 10000 rpm for 10 minutes. Finally, the separated SiO2 nanoparticles in step three were redispersed in a solution of butyl acetate and kept for further use.

2.4 Preparation of waterborne acrylic varnish

Specifically, dilute the waterborne acrylic varnish with deionized water with a volume fraction of 10%, then stir magnetically for 0.5 h and leave it for use.

2.5 Preparation process of modified superhydrophobic nanoparticles SiO$_2$/PDMS hybrid solution

The modified superhydrophobic silica nanoparticles SiO$_2$/PDMS hybrid solution was prepared as shown in Fig. 3. Specifically, the following:

1) Mix the prepared precursor solution of polydimethylsiloxane with butyl acetate in a volume ratio of 1:30, and stir under magnetic agitation at 60°C for 0.5 h.

2) Then, disperse modified superhydrophobic silica nanoparticles SiO$_2$ in the above PDMS pre-polymer solution, and ultrasonically disperse for 1h to obtain the modified superhydrophobic silica nanoparticles SiO$_2$/PDMS hybrid solution.

3) Mix the precursor solution of polydimethylsiloxane with butyl acetate in a volume ratio of 1:15 using the same method, to obtain another modified superhydrophobic silica nanoparticles SiO$_2$/PDMS hybrid solution.

4) Mix and stir the two hybrid solutions prepared in 2) and 3) in a 1:1 volume ratio to obtain SiO$_2$/PDMS nanoparticle composite solution.

2.6 Wood surface modification treatment

The modification treatment of wood surface was prepared as shown in Fig. 4. Specifically, the following:

1) Brush the waterborne acrylic clearcoat with a volume fraction of 10% onto the wood surface, repeating the process 5 times with a 2-hour interval between each application. After the 5th coating, let it cure at room temperature for 24 hours before use.

2) Apply the prepared SiO$_2$/PDMS nanocomposite solution onto the wood sample coated with the 10% waterborne acrylic clearcoat by dropping two drops evenly each time, repeating the process for a total of 3 cycles.
3) Then, apply a layer of PDMS mixed solution onto the wood surface prepared in step 1) to enhance the bonding between the multiple drop coatings.

4) Repeat the drop coating process alternately for 10 times to ensure sufficient deposition of SiO$_2$/PDMS organic-inorganic hybrid super-hydrophobic coating on the wood surface.

5) Dry and cure the sample prepared in 4) at 105°C for 24 hours until the coating is fully cured, obtaining the in-situ organic-inorganic hybrid modified wood sample with SiO$_2$/PDMS super-hydrophobic coating.

2.7 Characterization

The micro-morphology of the ash wood and the SiO$_2$/PDMS organic-inorganic hybrid modified wood sample surfaces were observed using a scanning electron microscope (SEM, Quanta 200, FEI Company, USA). The chemical composition of the sample elements was analyzed using the X-ray energy spectrometer EDS/EDX Genesis (EDS). The crystal structure of the sample was analyzed using X-ray diffraction spectroscopy (XRD, Rigaku, D8 Advance, UK). D8 Advance used nickel-filtered Cu Kα radiation ($\lambda = 1.5418$ Å) with a scanning speed of 2°·min$^{-1}$, tube current of 40 mA, and tube voltage of 40 kV, and the characterization range was 5°~60°. Fourier transform infrared spectrometer Nicolet iN10 MX (FT-IR, Nicolet, USA) was used to characterize the main chemical groups and element variations on the sample surfaces involved in this project: wavelength range was 400–4000 cm$^{-1}$, and resolution was 4 cm$^{-1}$. The surface wettability of the samples was measured using the OCA40 optical video contact angle detector (WCA, Dataphysics, Germany). The droplet volume was 5 µL (including deionized water, vinegar, saline, tea, fruit juice, ink, cola, red wine), and the contact angles of five different parts were measured at room temperature, and the average was taken.

3. RESULTS and DISCUSSION

3.1. Structural and morphological characterization

The surface structures and microscopic morphology of unmodified materials and modified materials treated with different modification agents are shown in Fig. 5. As shown in Fig. 5a, the surface of the unmodified white wax wood sample is rough and has obvious porous structure, and therefore does not have superhydrophobic properties. After being coated with waterborne acrylic lacquer, the porous structure on the surface of the white wax wood sample is partially covered by the waterborne acrylic ester, but the surface is still not smooth and is exposed to varying degrees (Fig. 5b). The microscopic morphology of the SiO$_2$/PDMS in-situ organic-inorganic hybrid modified wood sample obtained by the SiO$_2$/PDMS in-situ organic-inorganic hybrid coating polymer treatment is shown in Fig. 5c and Fig. 5d. Under low magnification conditions, the SiO$_2$/PDMS coating deposited on the wood surface covers all the original porous structure, further improving the dense protective layer on the surface of the white wax wood[7]. Under high magnification conditions, it can be observed that the SiO$_2$ microspheres and the
PDMS pre-polymer mixture effectively combine to increase the roughness of the wood sample surface and provide good hydrophobic properties for the wood.

### 3.2. X-ray energy spectrometry (EDS)

The EDS spectra of the untreated beech wood and SiO$_2$/PDMS in-situ hybrid-modified wood samples are shown in Fig. 6. According to Fig. 6a, the untreated beech wood sample contains three chemical elements, carbon (C), oxygen (O), and gold (Au). The C and O elements originate from the wood and air, and Au is from the thin conductive film sputtered by the electron microscope. EDS analysis of the water-based acrylic clear-coated beech wood shows that it contains C, O, and Au elements (Fig. 6b), which also come from the wood and air, and the thin conductive film, but not Si. EDS analysis of the SiO$_2$/PDMS in-situ hybrid-modified wood sample in Fig. 6c shows that it contains silicon (Si) in addition to the C, O, and Au elements, which is from the SiO$_2$/PDMS in-situ hybrid coating polymer on the surface of the beech wood.

**Figure 6** EDS spectra of unmodified ash wood, waterborne acrylic varnish modified ash wood and SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens

### 3.3. X-ray diffraction spectroscopy (XRD) of SiO$_2$/PDMS in situ organic-inorganic hybridization-modified wood specimens

Figures 7 show the XRD spectra of pure SiO$_2$ particles, untreated ash wood, waterborne acrylic varnish modified ash wood, and SiO$_2$/PDMS in-situ hybrid modified wood, respectively. From Fig. 7, it can be seen that there is a strong diffraction peak of the crystal face of pure SiO$_2$ particles at approximately $2\theta = 28^\circ$, $2\theta = 46^\circ$, and $2\theta = 51^\circ$. Figure 7 shows that there are diffraction peaks of cellulose at approximately $2\theta = 16^\circ$ and $2\theta = 22^\circ$ in untreated ash wood. Interestingly, these two diffraction peaks are also observed in Fig. 7 for water-based acrylic modified ash wood, indicating no significant changes after coating. However, for SiO$_2$/PDMS in-situ hybrid modified wood in Fig. 7, a new strong diffraction peak is observed at approximately $2\theta = 28^\circ$, in addition to the original diffraction peaks of cellulose. This is consistent with the strong diffraction peak observed for pure SiO$_2$ particles at $2\theta = 28^\circ$. Therefore, it can be concluded that the SiO$_2$/PDMS in-situ hybrid coating is present.

### 3.4. FTIR spectroscopy of SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens

The FTIR spectra of the pure SiO$_2$, unmodified ash wood, waterborne acrylic modified wood, and SiO$_2$/PDMS in-situ organic-inorganic hybrid modified wood samples are shown in Fig. 8. Based on Fig. 8, it can be seen that the strong and broad absorption band at 1095 cm$^{-1}$ corresponds to the Si-O-Si anti-symmetric stretching vibration peak, the peaks at 798 cm$^{-1}$ and 466 cm$^{-1}$ correspond to the Si-O bond symmetric stretching vibration peak, the broad peak at 3450 cm$^{-1}$ is the anti-symmetric stretching
vibration peak of structural water-OH, the peak near 1638 cm$^{-1}$ is the bending vibration peak of water's H-O-H, and the peak at 955 cm$^{-1}$ belongs to the bending vibration absorption peak of Si-OH. As seen in Fig. 5b, the peak at 3346 cm$^{-1}$ is the O-H stretching vibration peak, corresponding to cellulose, the peak at 2924 cm$^{-1}$ is the anti-symmetric stretching vibration peak of alkane CH$_2$, corresponding to cellulose, the peak at 1732 cm$^{-1}$ is the C = O stretching vibration peak of acetyl and hydroxyl groups, corresponding to hemicellulose. The peak at 1506 cm$^{-1}$ corresponds to the benzene ring skeleton vibration, which is the chemical component of lignin, the peak at 1456 cm$^{-1}$ corresponds to the bending vibration of C-H and the benzene ring skeleton vibration, which corresponds to the chemical substance of lignin and hemicellulose. The peak at 1421 cm$^{-1}$ corresponds to the benzene ring skeleton vibration and C-H in-plane bending vibration, which corresponds to the chemical substance of lignin. The peak at 1368 cm$^{-1}$ corresponds to C-H bending vibration, which corresponds to cellulose and hemicellulose. The peak at 1319 cm$^{-1}$ corresponds to C-H vibration, which corresponds to cellulose. The peak at 1027 cm$^{-1}$ is the C = O stretching vibration peak, corresponding to cellulose, hemicellulose, and lignin. The peak at 896 cm$^{-1}$ is the vibration peak of the carbon atom, corresponding to cellulose. As can be seen from Fig. 8, its vibration peak coincides with the FTIR spectrum of unmodified ash, indicating that ash has not been modified by waterborne acrylic clear coat. As shown in Fig. 8, the peak at 949 cm$^{-1}$ is due to the stretching vibration of Si-OH, and the peak at 1100 cm$^{-1}$ is the stretching vibration peak of Si-O-Si. The peak at 1330 cm$^{-1}$ is due to the stretching vibration of the S and 5-substituted G rings, and the peaks from 1375 cm$^{-1}$ to 1425 cm$^{-1}$ are the stretching vibration of the C-H group. The peak at 1625 cm$^{-1}$ is the absorption peak of ether bonds and C = O bonds. The peak at 2350 cm$^{-1}$ is the stretching vibration peak of C-H bonds. For the modified SiO$_2$ nanoparticles, the peaks at 2920 cm$^{-1}$ and 2853 cm$^{-1}$ are attributed to the anti-symmetric and symmetric stretching vibration of CH$_2$, respectively. The absorption peak from 3550 cm$^{-1}$ to 3230 cm$^{-1}$ is the stretching vibration of hydroxyl (-OH) groups, and the absorption peak at 3400 cm$^{-1}$ is enhanced due to the stretching vibration of the silicon hydroxyl groups, indicating that more -OH groups have reacted with monodispersed SiO$_2$ microspheres. The results indicate that nano-SiO$_2$ has been modified by FAS-17.

3.5. Stable surface wettability analysis of SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens

The macroscopic wettability of the surface of ash wood is shown in Fig. 9a-g. It can be seen from the figure that untreated ash wood has good wetting effect on seven solvents, demonstrating a certain hydrophilicity. Figure 9h-n shows that the surface of ash wood treated with SiO$_2$/PDMS in-situ organic-inorganic hybrid coating polymer has good hydrophobic effect on seven solvents. The ash wood has changed from hydrophilic to superhydrophobic. It can be seen that applying SiO$_2$/PDMS in-situ organic-inorganic hybrid coating polymer on the surface of wood can achieve the superhydrophobic property of the wood. Since the SiO$_2$ particles have reduced the roughness and surface free energy of the wood surface through FAS-17 modification, the interface changes from hydrophilic to superhydrophobic.
By testing the contact angle of the wood surface, the contact angles of unmodified and modified materials are shown in Fig. 10. From the Fig. 10, it can be seen that the contact angle of ash wood material to all solvents is < 20°, indicating that untreated ash wood has good hydrophilicity. However, SiO$_2$-PDMS organic-inorganic superhydrophobic wood has contact angles > 150° with 7 kinds of solvents, indicating that by introducing SiO$_2$-PDMS organic-inorganic hybrid coating to modify the wood surface, the wood can be endowed with excellent superhydrophobic performance.

3.6 Thermal stability of SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood

Figure 11 shows the variation of surface wettability of SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood under different temperature conditions. As can be seen from the figure, as the temperature rises from −5°C to 100°C, the contact angle of SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood samples has varied to some extent, but they are all greater than 155°, still maintaining their superhydrophobic characteristics, indicating that the SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood samples possess a certain degree of stability. Therefore, the sample exhibits superhydrophobicity in both cold and hot water, indicating a high water-repellent ability. The results show that SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood can be used under different temperature conditions.

3.7 Water absorption of SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood

After immersing the untreated wood samples, waterborne acrylic varnish modified ash wood, and SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens in water for 120 hours at room temperature, their moisture content curves are shown in Fig. 12. It can be seen from the figure that the moisture content of all three samples increased significantly within the first 30 hours, indicating that they absorbed more water during this period. After 30 hours, the moisture content of all samples stabilized, but the moisture content change rate of untreated wood was greater than that of waterborne acrylic varnish modified ash wood and SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens. After 120 hours of immersion, the moisture content of SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens was only about 75%, while the moisture content of untreated wood could reach 180%. This may be due to FAS-17 coating on the surface of wood samples, which prevents moisture from entering into the wood. The study found that the contact angle of SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens remained above 150° even after being immersed in water for 120 hours. The results show that SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens have extremely high-water resistance, and they can be used in high-humidity environmental conditions.

4. CONCLUSIONS
The experiment constructed SiO$_2$/PDMS in-situ hybrid coating polymer on the surface of ash wood through dip-coating method, and studied its stable superhydrophobicity. The specific conclusions are as follows:

1) SEM observation shows that the porous structure on the surface of ash wood is completely covered after being coated with SiO$_2$/PDMS in-situ hybrid coating polymer, forming a dense protective layer, increasing the surface roughness of the wood and giving it good hydrophobicity.

2) XRD and FTIR diffraction spectra analysis of the SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood compared with pure SiO$_2$ particles, unmodified ash wood, and water-based acrylic clear varnish-modified ash wood shows that the modified samples have new diffraction peak positions in addition to the peak positions same as Baiwax wood, indicating the existence of SiO$_2$/PDMS in-situ hybrid coating.

3) The analysis of wood wettability shows that introducing SiO$_2$-PDMS organic-inorganic hybrid coating can provide the ash wood with good superhydrophobicity, which can be used in daily life.

4) The SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood has a certain stability, which can resist droplets used in daily life to some extent.

5) The SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens have water contact angles greater than 155° at different temperature conditions, and still maintain their superhydrophobic properties, indicating good stability and durability of the coating against water. It is suitable for use in cold or hot environments, expanding the scope and lifespan of wood usage.

6) Through size stability testing, it was found that the SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens maintain a low moisture content even after immersion for up to 120 hours, indicating strong resistance to water and can be used in high-humidity environments.

From the above results analysis, it can be concluded that by constructing SiO$_2$/PDMS in-situ hybrid coating polymer on the surface of wood, it can provide the wood with good hydrophobicity, prolong the service life of the wood, and alleviate the supply-demand contradiction of wood to some extent. Therefore, the SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens can be used in practical environments such as low temperature, high temperature, and high humidity, making wood applicable in more fields and broadening the prospects of the wood industry.

Declarations

Data availability

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.
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Author contributions

Huajie Shen wrote the main manuscript text and prepared Figs. 1, 2, 3, 4, 5, 6, 7, 8 9, 10, 11, and 12, Liangzhou Dong, and Xinyuan Zheng conducted SEM, EDS, XRD, and FTIR characterizations. Donghai Huang conducted the data analysis. All authors reviewed and corrected the manuscript.

Conflicts of interest

The authors declare no conflict of interest.

Additional information

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Statement

Experimental research and field studies on plants (either cultivated or wild), including the collection of plant material, comply with relevant institutional, national, and international guidelines and legislation.

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Figures
Figure 1
Preparation of PDMS prepolymer mixture solution

Figure 2
Preparation and modification treatment of nano-SiO\textsubscript{2} microspheres
Figure 3
Preparation process of modified superhydrophobic nanoparticles SiO$_2$/PDMS hybrid solution

Figure 4
Preparation process of SiO$_2$/PDMS in situ organic-inorganic hybridization modified wood specimens
Figure 5

SEM images of specimens. (a) Microscopic appearance of ash wood material. (b) Microscopic appearance of ash wood coated with water-based acrylic varnish. (c) Low magnification view of SiO$_2$/PDMS in situ organic-inorganic hybridization modified wood specimen surface. (d) High magnification view of SiO$_2$/PDMS in situ organic-inorganic hybridization modified wood specimen surface.
Figure 6

EDS spectra of unmodified ash wood, waterborne acrylic varnish modified ash wood and SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens
Figure 7

XRD spectra of unmodified ash wood with, waterborne acrylic varnish modified ash wood and SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens. (a) SiO$_2$; (b) unmodified ash wood; (c) waterborne acrylic varnish modified ash wood; (d) SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens
Figure 8

FTIR spectra of pure SiO$_2$, unmodified ash wood, waterborne acrylic varnish modified ash wood and SiO$_2$/PDMS in situ organic-inorganic hybridization. (a) SiO$_2$; (b) unmodified ash wood; (c) waterborne acrylic varnish modified ash wood; (d) SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens

Figure 9

Wettability of seven different common liquids on the surfaces of unmodified ash wood and SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens. (a-g) Liquid droplets on the surface of unmodified wood: (a) deionized water, (b) tea, (c) cola, (d) juice, (e) vinegar, (f) ink, (g) red wine; (h-n) SiO$_2$/PDMS in situ organic inorganic hybridization modified wood specimen surface droplets: (h) deionized water, (i) tea, (j) cola, (k) juice, (l) vinegar, (m) ink, (n) red wine.
Figure 10

Contact angle measurements corresponding to different liquids on the surfaces of unmodified ash wood and SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens

Figure 11

WCA of SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood under different temperature.
Figure 12

The Moisture content of the unmodified ash wood, waterborne acrylic varnish modified ash wood and SiO$_2$/PDMS in situ organic-inorganic hybrid modified wood specimens.