Scientific Research Publishing

Open Journal of Composite Materials, 2025, 15(4), 210-216
https://www.scirp.org/journal/ojcm
ISSN Online: 2164-5655
ISSN Print: 2164-5612

Morus alba Leaves-Modelled Superhydrophobic Surface

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How to cite this paper: He, Z.Y., Xia, M. and Zhang, Y.H. (2025) *Morus alba* Leaves-Modelled Superhydrophobic Surface. *Open Journal of Composite Materials*, **15**, 210-216.
https://doi.org/10.4236/ojcm.2025.154012

Received: September 2, 2025
Accepted: October 20, 2025
Published: October 23, 2025

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Abstract

We use the lotus effect, since the lotus leaves surface have the property of superhydrophobic. And the lotus surface is anti-structured microscale roughness. Then we use the *Morus alba* leaves as a model to copy the lotus leaves' nano-microscale surface, then we can get identically the same superhydrophobic property for the *Morus alba* leaves. When water drops contact with the *Morus alba* leaves the angle is slightly more than 150 degrees, indicating its hydrophobic properties. Moreover, water drops could not stick to its surface even at a very small angle, improving its low adhesion. Nowadays, the superhydrophobic property has been used widely. Such as in the field of medicine, it can be used to self-clean some medical device or in our clothes or textile, we don't need to wash our clothes frequently since the droplets can fall into the ground automatically. Additionally, scientists are trying to copy micro-nano hierarchical structures in the form of 3D painting at a low price, at the same time improving its durability.

Keywords

Morus alba Leaves, Superhydrophobic Property, Nano-Microscale, Anti-Structured Microscale

1. Introduction

In the natural world, many plants have some amazing functions or special structures that people try to mimic and experiment in the real life. The water-repellent property exists on many biological plants' surface. And water-repellent materials provide some level of protection against moisture. Water-repellent coatings can wear off over time or with repeated use, so they may require reapplication to maintain their effectiveness. Like today's surface science, which focus on the atomic surface's arrange modes or the chemical composition of the surface. Our paper will introduce the surface science on the *Morus alba* leaves, to discover these leaves special property of superhydrophobic. Trying to copy the *Morus alba* leaf in micro-nano structures, also in the form of 3D painting. And we have learnt that in surface science that the unbalanced force in the surface molecules, so we can easily use this science theory into the superhydrophobic property in the leaves' surface. In the present paper, we will use the mulberry leaves as a sample to do some experiments. Mulberry leaves (MLs) have been used traditionally to raise silkworms and as herbs and herbal drinks. *In vitro* and *in vivo* studies as well as some clinical trials provide some evidence of health benefits, mostly for ML extracts. ML extracts showed antioxidant, hypoglycemic, anti-cholesterol (affecting lipid metabolism), anti-obesity, anti-inflammatory, anticancer activities, and so on. White mulberry originated in China, red or American mulberry originated in the United States, and black mulberry originated in western Asia. China has cultivated mulberry trees for more than 7000 years and is the country with the most mulberry species in the world. There are 15 species of *Morus* in China, which are divided into cultivated species and wild species. Among them, cultivated species include baisang and guangdongsang, etc [1] [2]. It is a typical plant with the property super-hydrophobic (water-repellent) and low-adhesiveness, "Lotus effect" can apply to folium mori, which means that the droplet can't steadily remain on the folium *Morus alba* leaves' surface since a very small slant angle can cause the droplet slip away. The relationships among contact angles, surface tensions, and surface roughness are reviewed. The various numerical formulae related to contact angles were used to predict the surface tension and wetting behavior of polymer surfaces. The apparent contact angle of a droplet deposited on a textured surface is presented, and the characteristics required for a superhydrophobic surface are described. This study also presents the effect of the sliding angles of liquid droplets on smooth and rough surfaces. The contact angle hysteresis was found to be very important in understanding the drop motion on a surface. Contact angle hysteresis increased on a Wenzel-type surface, while a Cassie-Baxter type surface reduced the hysteresis for the same surface roughness and surface tensions. In people's daily life, the property of super-hydrophobic put into use in many fields of aspects, such as the oil, water separators, microfluidic devices and the anti-fogging technologies. Compare to the artificial hydrophobic material, this plant surface's unique character. In the present paper, we will explicitly show the experiments design and procedure to examine folium mori and account for the lotus effect [3]-[5].

2. Experimental Section

2.1. Laboratory Equipment and Materials

Experimental Equipment: mulberry leaves, Silicone For Manual Mold-Making, Small Plastic Cup, Clean Stirring Rod, Vacuum Drying Oven, Double-sided adhesive tape, petri Dish, Microscope or Small Syringe, Purified water.

2.2. Process of Experiments

Select mulberry leaves and wash the surface hairs and dust with pure water, then dry. Apply double-sided tape to the bottom of the petri dish and place the leaves flat inside. Mix the silicone into a beaker in a 1:1 ratio, 15 grams for a and b silicone. (As shown in Figure 1-2, the silicone for manual mold-making A + B) Use a glass rod to stir the silicone for 15 minutes. Place the beaker with the silicone into a vacuum drying oven (the vacuum drying oven's purpose is to significantly decrease the surface tension of energy of mulberry leaves sample, lead to maximally preserve the original rough morphology of the bionic sample) switch on the vacuum pump, and after the vacuuming process is complete. Take out the beaker. Repeat the process until there are no air bubbles in the silicone. Pour the silicone into the petri dish with leaves. Wait for the silicone to spread evenly over the petri dish.

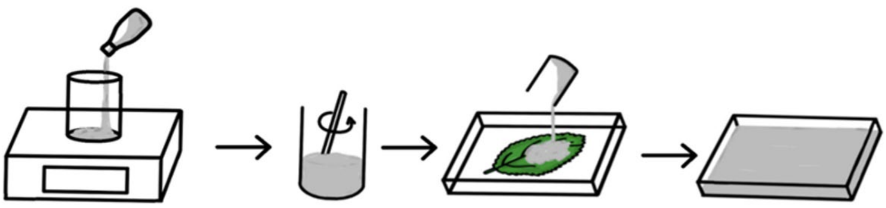

Figure 1. The silicone for manual mold-making.

Put the petri dish with silicone into the vacuum drying oven. Repeat the process until no bubbles remain between the leaves and silicone. Heat the petri dish until it hardens into shape. Gently peel the leaves off the silicone, obtaining a reverse-structured silicone template of the mulberry leaf surface. Trim the excess template. Weigh 0.35 g of ammonium salt and add it to a beaker. Add 100 ml of pure water. Weigh 0.74 g of zinc nitrate and add it to the beaker. Mix the solution thoroughly with a glass rod until the powders are fully dissolved. This mixing process is for the hydrothermal synthesis of ZnO nanostructures. It can create the required nanoscales roughness on the replicated microstructure. And pour into the reaction kettle. Put the reaction kettle (vessel) into the vacuum drying oven, heating at 95˚C for 10 hours. Take out the templates and dry for one hour. After drying for one hour, put all of them into the crystallizing dish to have the process of fluorination. By the reaction of the fluorine element and the atoms, a thin layer can form. Typically, the fluorination process can form a thickness of nanometers to micrometers. (The fluorination is the process to put the fluorine element into the *Morus alba* leaves physical surface. Fluorine-containing organic molecules are of high importance due to the unique properties that fluorination can impart upon a molecule. (1) Despite the paucity of fluorinated natural products, (2-5) fluorinated compounds are common in modern society—approximately 20% of commercial pharmaceuticals and 30% of agrochemicals contain fluorine [6].)

Figure 2. *Morus alba* leaves models.

3. Experimental Result

The superhydrophobicity of lotus leaves is not only a remarkable phenomenon in nature, but also holds significant biological and engineering implications. Biologically, the micro-nano rough structure on the surface of lotus leaves, in combination with hydrophobic waxy substances, causes water droplets to form spherical shapes and roll off easily. During the rolling process, dust and microorganisms are carried away, achieving a "self-cleaning" function. This characteristic helps maintain the efficiency of photosynthesis, gas exchange, and transpiration regulation of the leaves, reduces the attachment of pathogens and pollution blockage, thereby enhancing the survival ability and reproductive advantage of plants in humid or dusty environments. Additionally, superhydrophobicity can reduce the risk of surface wetting and frosting, improving the plant's resistance to environmental stress.

In the field of scientific research, the lotus leaf effect has become an important natural model for the research community to understand wetting dynamics, surface energetics, and the interaction between wet and solid phases. The multi-level structure it reveals and the Cassie-Baxter wetting state model provide a theoretical basis and bionic strategy for designing functional surfaces. In engineering applications, materials and coatings based on the superhydrophobic principle of lotus leaves have been widely explored for use in self-cleaning glass, anti-fouling and anti-corrosion coatings, anti-icing surfaces, oil-water separation, water-saving building materials, anti-pollution medical devices, and surface modification of microfluidics and sensors. The promotion of these technologies can significantly reduce cleaning frequency and the use of chemical cleaners, bringing environmental and economic benefits.

The experiment shows that like the lotus leaves, which have the function of self-cleaning, when the droplet falls to the lotus leaf during raining day, the droplet will bead up with a constant angle. In this experiment, we replace the lotus leaf with the mulberry leaf. After a series of experiment procedures, the fluorinated model of mulberry leaf successfully imitates the lotus effect and accurately give the contact angle. As shown in **Figure 3**, the 1 ml droplet is on the back of the mulberry leaf vein so this displays that the model successfully has the property of superhydrophobic. The experimental data indicates that the best, accurate static angle of the mulberry leaf model is about 165˚ more than 150˚. We also analyze the affecting factors when consider the static angle and the superhydrophobic property: 1) The synergy of multi-level structure, micro and nano can play an essential role in increasing the hydrophobic property. 2) The surface chemical energy: the superhydrophobic surface energy need to lower the 1ml droplet liquid's surface tension energy. In case the 1ml droplet penetrates into the model structure, which means the inverse property of superhydrophobic-hydrophilic. 3) The 1 ml droplet itself must have the proper PH value, it can't be strongly acidic or the alkaline.

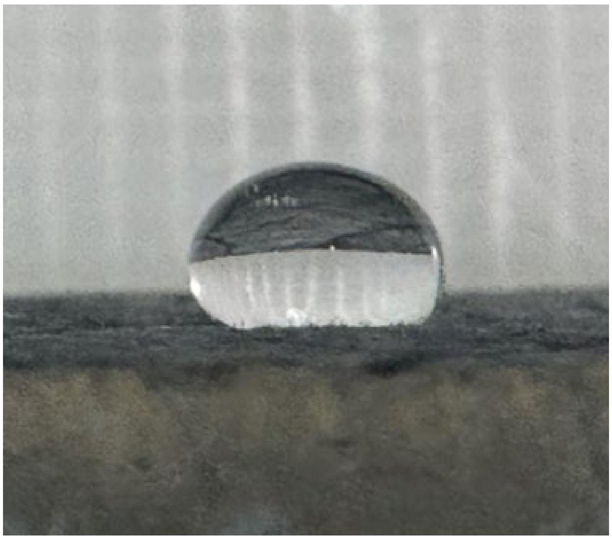

Figure 3. The Fluorinated model.

4. Conclusions

In this study, we used natural leaves as templates and replicated their surface features to obtain rough microstructures with the original leaf surface characteristics, which will like the 3D painting at the lower price. Subsequently, functional nanostructures were grown and modified on the surface by hydrothermal method. Finally, low surface energy chemical groups were introduced through fluorination treatment, successfully constructing a biomimetic surface with significant superhydrophobic properties. This preparation route takes into account the simulation of morphology and the controllability of chemical modification, and retains the multi-scale (from micrometers to nanometers) hierarchical structure of the leaves, which is crucial for achieving high static contact angles and extremely small rolling angles. Characterization results show that the treated samples present uniformly distributed nanoparticles or nanoneedle structures under scanning electron microscopy, with water droplets taking a spherical shape and easily rolling off. The measured contact angles are usually over 150˚, which is in line with the expectations of the Cassie-Baxter non-wetting model.

The significance of this research is manifested on multiple levels, to form like the 3D painting. Firstly, from the perspective of basic science, replicating natural surfaces and reproducing superhydrophobic behavior through controllable nanoscale growth and chemical modification helps to deepen the understanding of the impact of structure-chemistry synergy on wettability and self-cleaning functions, providing empirical evidence for the design of biomimetic materials. Secondly, from the perspective of engineering applications, the prepared superhydrophobic structures have potential value in anti-fouling, anti-icing, anti-corrosion, and reducing biofouling, and can be extended to the inner walls of medical devices, infusion tubes, outdoor textiles, building facades, and maritime energy-saving surfaces, among others, bringing about practical benefits such as reduced cleaning costs and extended service life.

Meanwhile, the research also pointed out several issues that need further breakthroughs: although fluorination treatment can significantly reduce surface energy, the long-term environmental and biological compatibility should be carefully evaluated. In the future, fluorine-free or degradable low-surface-energy alternative materials should be explored. The mechanical wear resistance and chemical corrosion resistance of micro-nano structures determine their reliability in practical applications, and life tests such as cyclic friction, scrubbing, ultraviolet aging and high-pressure sterilization should be carried out. In addition, the transformation from laboratory samples to industrial-scale production requires the optimization of the scalability and cost-effectiveness of template replication and hydrothermal processes.

Looking ahead, this research can be extended along two main lines: one is to optimize the material system and construction process to enhance structural stability and environmental friendliness, such as combining polymer encapsulation, ceramic coating or in-situ crosslinking methods to improve durability; the other is to conduct multi-scenario adaptation research, formulating specialized evaluation standards and functional tests for different applications such as medical, marine and construction fields, and quantifying performance indicators such as anti-pollution, drag reduction or anti-icing. In summary, this research not only provides a feasible path for the preparation of biomimetic superhydrophobic materials, but also lays a theoretical and experimental foundation for their application in practical engineering, with significant academic value and broad application prospects.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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