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Experimental Study on the Influence on Water Drop Impacting by the Surface Wettability of Plant Leaves

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Abstract

The experimental study on water drop's impacting characteristics on typical wettability of surface of plant leaves (lotus leaf, piemarker, etc) has been taken in this paper, mainly including: the impacting process of water drops on the surface of lotus leaf and piemarker was shot by high-speed camera; the impacting distance of water drops on the surface of lotus leaf with different heights was measured by self-made slope. The results show that: (1) water drop has good wettability on the surface of piemarker, while it can bounce for several times on the surface of lotus leaf; the morphologic change of water drop during impacting process was observed and the energy dissipation process was analyzed; (2) water drop's impacting distance on different slopes with different dip angles presents linear relation with the dripping distance. This study has laid certain foundation for realizing water drop's controlled motion on the surface with super hydrophobicity.

Keywords: *wettability; lotus leaf; piemarker; water drop impacting*

1. Introduction

In recent years, the public awareness on the wettability of the plant surface has been gradually increased, but at present, the majority of studies are on the drop impact on the liquid and solid surface and it is rare in drop's impacting on the surface of plant leaves [1-6]. In this paper, taking typical hydrophilic plant such as piemarker and hydrophobic plant such as lotus leaf as examples, $45^{\#}$ steel is made into steel block with dip angle of 0°, 15°, 30° and 45°. Piemarker and lotus leaf are stuck on steel block and the impacting process of water drops on surface and the impacting distance of water drop on slope are recorded by high-speed camera; the form and energy variation of water drop during impacting process are analyzed and preliminary study has been taken to analyze the relationship between impacting distance and impacting height of water drop on the surface of lotus leaf.

2. Test Materials and Equipment

The piemarker used in the test was picked from Jilin Engineering Normal University at the beginning of August, 2013 and lotus leaf was picked from Changchun South Lake Park. DSA100 type Contact Angle Meter from Germany KRUSS Company is used to measure the contact angle of the front surface of the leaves and S-300 type scanning electron microscope from Japan HITACHI Company is used to analyze and observe the microstructure and morphology of the surface; phontom v5.2type high-speed camera from US Vision Research Company is used to shoot the impacting process of water drop on the

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surface of piemarker and lotus leaf and self-made steel slope is used to measure the impacting distance of water drop on the surface of lotus leaf.

3. Test Process and Result Analysis

3.1. Contact Angle Measure Test

Select the part without obvious vein from piemarker and lotus leaf and cut into 2cm*1cm samples. It is measured by Contact Angle Meter that the water drop volume is $7\mu l$, front contact angle of peimarker is 43.2° and front contact angle of lotus leaf is 155°.

3.2. Microstructure Test on Piemarker and Lotus Leaf

After taking metal spraying processing to piemarker and lotus leaf test samples, observe it under scanning electron microscope (S-300 type from Japan HITACHI Company). It can be seen from the micrograph of piemarker in Figure 1 that the piemarker leaf surface presents honeycomb and there are long and thin burrs on the rough surface with length of 200~ 400 μm and the distribution density is about 50 burrs/ mm^2; The diameter of concave on the honeycomb surface is between 20~ 30 μm and the depth of concave is 5~ 10 μm [7]. It can be seen from Figure 2 that the surface of lotus leaf is constituted of a lot of mastoid process with average diameter of 5~ 9 μm . Every mastoid process is composed of branches of nano-structure. In addition, nano-structure can also be seen from the surface of lower layer of lotus leaf, which can effectively prevent the lower layer of lotus leaf from wetting. The nono-structure, especially these on micrometer mastoid process will play an important role in super-hydrophobicity [8].

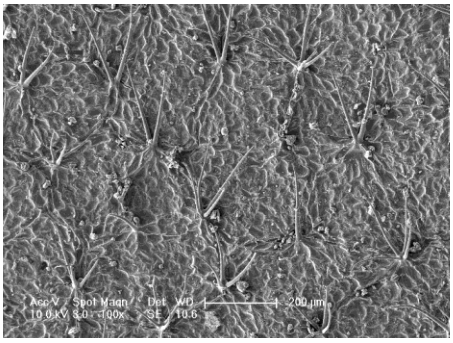


Figure 1. Microstructure of Piemarker

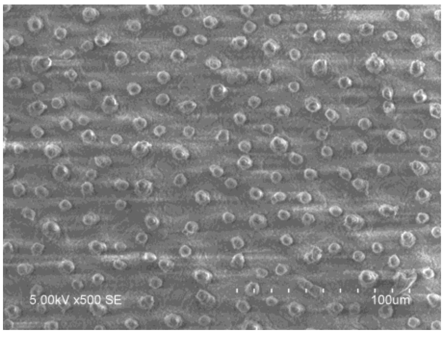


Figure 2. Microstructure of Lotus Leaf

3.3. Impacting Test of Water Drop on Piemarker and Surface of Lotus Leaf

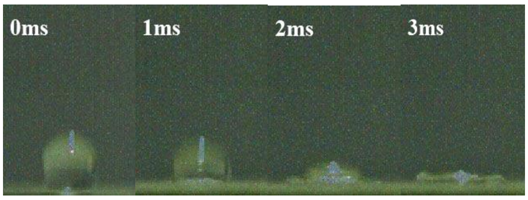
High-speed camera is taken to shoot the dripping process of water drop on the surface of piemarker and lotus leaf and the shooting speed is 1000f/s, image pixel is 1152x896 and monochrome HPSL is adopted as background light source. The water drop for testing is purified water and volume is $7\mu l$ and indoor temperature is 25°.

3.3.1. Impacting Test and Analysis of Water Drop on the Surface of Piemarker

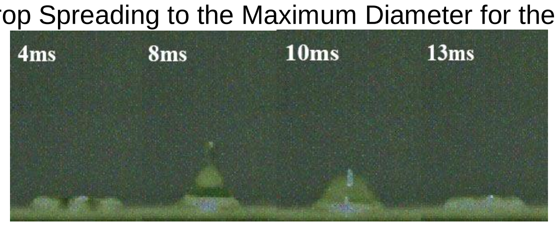
Figure 3 is the sequence picture of impacting process of water drop on the surface of piemarker. It can be seen from the picture that water drop did not bounce after dripping on the surface of piemarker, but took place several times of creeping deformation at the falling position. The previous three times of creeping deformation and energy variation conditions are explained as follows:

In Figure 3(a): After water drop dripped, it is approximately sphere and the total energy of water drop at the initial moment (0ms) is the sum of kinetic energy and initial surface energy. However, since the large quantities of fine and thin burrs distributed on the surface of piemarker will puncture the water drops contacting with piemarker, the water molecule will rapidly permeate the concave of rough surface and increase the contact area and adhesive force between water drops with leaf surface, thus the water drop will not bounce. During the water drop spreading and deformation process, part of the kinetic energy of water drop will turn into water drop surface energy and part will be used to overcome the kinetic friction force and adhesive force during spreading process and on the surface of leaves. The water drop height will decrease rapidly within 3ms to spread into a disk to reach the maximum diameter.

In Figure 3(b): impelled by inertia force, water drop will overcome the kinetic friction force and adhesive force of leaf surface and retract to form a fine-top-thick-lower chess-shaped water drop. After rising to certain height, water drop will descend. But due to the constant loss of energy of itself, it is not larger than the disc formed on the surface of piemarker previous time and this process is called the creeping process from the first closing-up and assembly to falling until the lowest position and the time is about 13ms. In subsequent time, water drop took about 7, 8 times similar creeping, but since the second time, water drop’s rising height during closing-up and assembly process was obviously decreased and with the increase of creeping times, the creeping scope is smaller and smaller and the required time is shorter and shorter and will not be in static state until all the energy is dissipated.



(a) Water Drop Spreading to the Maximum Diameter for the First Impact



(b) Water Drop Closing up and Falling to the Lowest Position for the First Time

Figure 3. Deforming Sequence Diagrams After a Drop Impact on the surface of the Piemarker Samples (Partly)

3.3.2. Impacting Test and Process Analysis of Water Drop on the Surface of Lotus Leaf

The conditions of water drop impacting on the surface of lotus leaf and piemarker are totally different. Under the test conditions, water drop bounced for several times after dripping on the surface of lotus leaf and the time of duration from dripping on the leaf surface to bounce finish is about 210ms and later crept at falling position until reaching the balanced state.

We divide the process of every advance and return movement into several stages: 1) falling onto the surface of lotus leaf from the highest position; 2) spreading to the lowest position from touching the leaf surface; 3) retracting from the lowest position to complete bounce; 4) complete bounce from leaf surface to rising to the highest position in the sky; 5) creeping and deformation stage in the sky. Below is the brief introduction of the deformation condition of water drop during bouncing process and the causes.

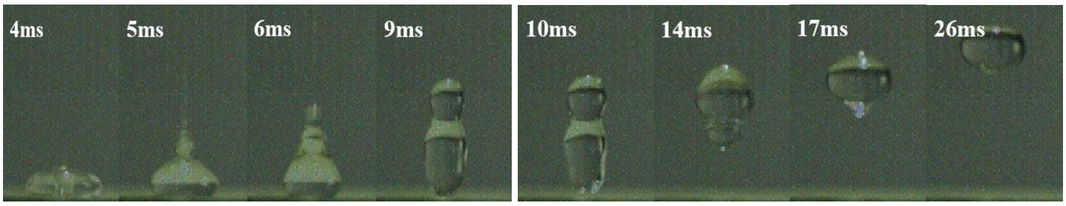
In Figure 4(a): After falling onto the leaf surface, liquid drop will spread to the maximum diameter within 3ms, which is the same with the spreading time of falling onto surface of piemarker and the morphologic change is similar. However, the nano-composite hierarchical structure on the surface of lotus leaf will enable the scraggly rough surface to store up lots of air after drop falling onto it, which equivalently means that liquid drop is adhering on a layer of thin gas film. During the liquid drop spreading process, the kinetic energy of liquid drop will be gradually turned into drop surface energy and dissipated energy during spreading process; when reaching the maximum spreading diameter, drop will be in unbalanced state.

In Figure 4(b): Impelled by the surface tension, liquid drop will overcome the kinetic friction force and adhesive force of wall surface and retract. During the process, liquid drop surface energy will be turned into kinetic energy and dissipated energy of liquid drop. When the part of converted energy is larger than the sum of dissipated energy during retraction process and initial surface energy, the surplus energy will make liquid drop bounce from the leaf surface. It took 6ms for the water drop to bounce to break away from the leaf surface for the first time. During this extremely short time, great shape change took place. Due to the combined action of bounce, viscous force, surface tension and surface energy of water drop itself, the internal liquid of water drop flowed, representing the increase of longitudinal dimension on the whole and the change of disc into cylinder with necking phenomenon at about 1/3 of the height.

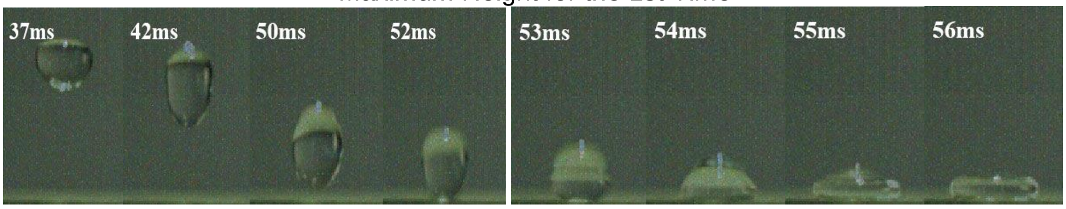
In Figure 4(c): it took 17ms for water drop to depart from the leaf surface and rise to the maximum height. During this process, the morphologic change is diversified due to the elastic effect of water drop. Since the constant loss of energy during motor process, the rising height is far lower than the height of initial falling.

In Figure 4(d): The morphologic change of water drop's second free falling body to impact onto water surface is different from the first free falling body and the morphologic change is very obvious: stretching into oblate ellipsoid from spherical crown, shortening into spherical crown again from oblate ellipsoid and then stretching into oblate ellipsoid to impact onto the leaf surface. During the morphologic change process, the kinetic characteristic of regular horizontal and longitudinal stretching and retraction is presented.

During later bouncing process, due to the energy loss caused by impact of water drop and leaf surface, viscous dissipation and air friction caused by self stretching vibration during bouncing process have made the self energy gradually decrease and bouncing height gradually lower and the whole motor process presents regular dying oscillation motion like damped motion. The longitudinal and transverse flexible deformation during later bouncing process gradually decreased and nearly kept in spheroidicity in the air at the fifth and sixth bounce without large deformation. Till the seventh time, water drop retracted again to gather into spheroidicity, but cannot bounce to depart from leaf surface. Later on, creeping phenomenon took place at the original position on the surface of similar piemarker. At last, when viscous dissipation and all surplus energy are lost, water drop will be static on the leaf surface.



(a) Water Drop Bounced to Depart from Leaf Surface for the 1st time (b) Bounced to the Maximum Height for the 1st Time



(c) Water Drop Fell to Leaf Surface for the 2nd Time (d) Water Drop Spread on the Leaf Surface for the 2nd Time

Figure 4. Deforming Sequence Diagrams after a Drop Impact on the Surface of the Lotus Leaf Samples (Partly)

3.3.3. Impacting Test and Analysis of Water Drop on the Surface of Inclined Lotus Leaf

(1) Impacting process of water drops by high-speed camera. The impacting process of water drops on15^o, 30^o and 45^o slope with lotus leaves is about the same with that on plane. The difference is that water drop is in sliding motion state downward on the slope for 2-3ms after the first impacting on the slope and the track in the air after bouncing is parabola; in addition to the translational motion, there is rotary motion for mode of motion; in addition to horizontal and longitudinal stretching and retraction, the deformation of water drop still includes distortion.

(2) Impacting test of water drop on the slope with lotus leaf. Measure the impacting distance of water drop on 15^o, 30^o and 45^o slope respectively and the schematic diagram is as shown in Figure 5 and measurement results are as shown in Figure 6. The impacting distance and height of water drop presents approximately linear relation and the formula after fitting is as follows:

15°fitting formula $L=0.372H+3.5$; 30°fitting formula $L=0.978H+9.44$; 45°fitting formula $L= 1.1187H + 12.55$.

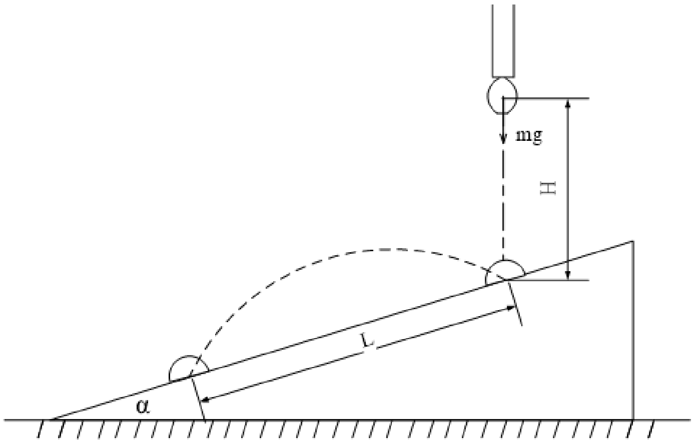


Figure 5. Schematic Diagram of Impacting of Water Drop on Slope

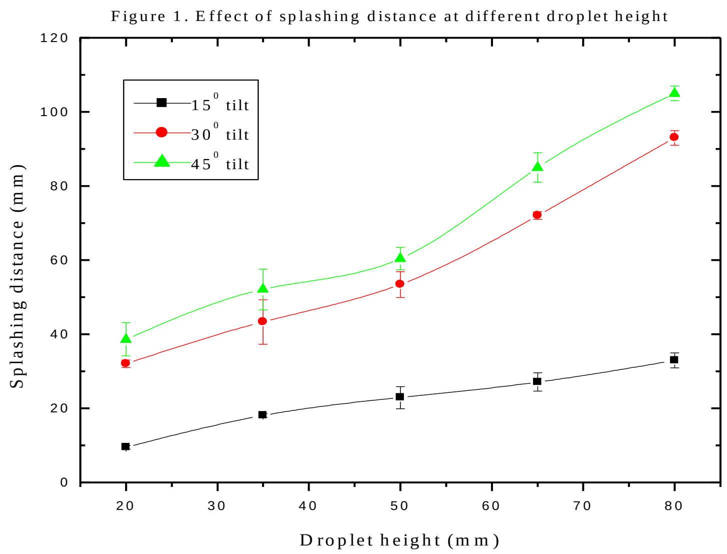


Figure 6. Relationship between Impacting Distance and Impacting Height

4. Conclusion

(1) Water drops will present totally different states when dripping on the surface of plant leaves with different wettability. Since the long and thin burrs on the surface of piemarker will puncture the water drop and represent wonderful hydrophilic properties, the energy of free falling body will not be enough to overcome the adhesive force and frictional force on the leaf surface to bounce, so it will be in balanced state after dissipating the surface energy after creeping; while the nano-composite structure on the surface of lotus leaf will form a layer of thin gas film, which will cause the reduction of surface friction and adhesive force and thus bounce for several times.

(2) The forms of motion of water drop's dripping on the plane and slope and bouncing are different. The motion curve after bouncing on plane is straight line and the form of motion is approximately translational motion; while the motion curve after bouncing on slope is parabola and the form of motion is planar motion.

(3) The impacting distance and falling height of water drop on slope present approximately linear relation.

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