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Parameter Selection from Contact Angle Analysis for the Production of Nature Inspired Self Cleaning Taro Leaf Mimic Glass Surface for Automobile Windscreen

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Abstract: **this paper is about the contact angle analysis for the production of self-cleaning glass surface inspired from Taro/Lotus leaf. It includes the details of working of such surface, influencing parameters, selection of those parameters for manufacturing purpose. Mathematical models for the contact analysis are discussed and solved; manufacturing parameters are selected based on those solutions. The idea of this research is to learn about the way to mimic the characteristics of taro leaf and apply it to the windscreen of automobile. The paper provides the information to select various parameters required to manufacture such surface. A theoretical case study to demonstrate how the findings help to determine the parameters is also included in the paper. It also discusses about advantages of such glass surface applicable for the windscreen. The paper does not include process for manufacturing such glass surface but it helps to prepare for it. A mathematical model applicable for the windscreen application was selected based on literature and solved to have the desired information.**

Keywords: **contact angle, contact factor, surface energy, hydrophobicity, coating material, lithography.**

I. INTRODUCTION

Taro/Lotus (*Colocasia esculanta)* leaf is known to be purest plant in accordance to the Eastern culture. Its self-cleaning ability is the main attraction of this research. The water droplet on the surface of this leaf show unique behaviour of super hydrophobicity and thus shows poor wettability on its surface. This self-cleaning property is attributed to the interaction between the surfaces of the lotus/taro leaves and water, resulting in high water repellency of the surfaces. Due to the impressive demonstration of these self-cleaning and high water-repellency characteristics, this combined effect has been named as "lotus effect" by Prof. W. Barthlott, a botanist of the University of Bonn [5]. This roll-off characteristic that is observed in the taro leaf surface is due to the super hydrophobic characteristics shown by the water droplet at the interface. Such characteristic is described by the intermolecular/interfacial interaction among different phases i.e. solid, liquid and gas. When an interface exists between a liquid and a solid, the angle between the surface of the liquid and the outline of the contact surface is described as the contact angle. The contact angle is a measure of the wettability of a solid by a liquid so it can be also called as wetting angle. Similarly, when the angle between the water droplet and the solid surface is obtuse it is called hydrophobic and if acute it is called hydrophilic. In the case of taro leaf, the contact angle is observed to be 150 degree. Such high obtuseness of the angle results in super hydrophobic character. Angle hysteresis is another important term to consider, it describes about the fluctuation of contact angle (preceding and receding angle) until the droplet comes in equilibrium and shows static angle of contact. Taro leaf shows angle hysteresis of ±5 degree [5]. Contact factor is another term described as the ratio of the area of solid surface in contact with the area of droplet at the interface. This is important to evaluate the actual angle of contact which is discussed in section III. The surface energy is defined as the sum of all intermolecular forces that are on the surface of a material, the degree of attraction or repulsion force of a material surface exerts on another material. This force is named as surface tension force in the case of liquid. This force is an important parameter that determines the contact angle.

Figure 1 : Water droplets in Taro Leaf

II. TARO LEAF

A. Surface structural Characteristics:

Taro leaf super hydrophobic characteristics come due to the structural and chemical composition of the leaf surface [1]. SEM images of taro leaf shows that the leaf has dual scale surface roughness i.e. on micro scale and Nano scale. The surface has spherical projection in micro scale and when further zoomed, it has tentacles over the spheres i.e. on Nano scale. This dual scale roughness assists to obtain the hydrophobic character of the droplet. The air filled gaps in the surface pushes the droplet to form the obtuse curvature which is explained by the Caussie-Baxter's model which is discussed in section III.

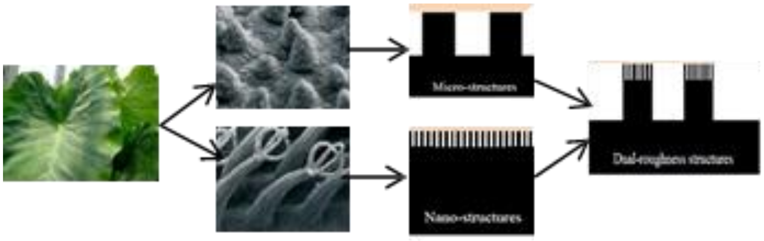


Figure 2: Structural Hierarchy of Taro leaf showing Micro and Nano-structure

B. Surface chemical Characteristics:

Another important character is the chemical composition of the surface which helps in determining the surface energy at the interface. Research shows that those pillars present in the surface of the leaves are composed of wax [1-4], which has low surface energy. This further helps the surface to show hydrophobic nature. This is explained by the ideal Young's model discussed in section III.

III. METHODOLOGY

Literature of various physical and chemical properties of the leaf leads to the understanding of the phenomenon. The mathematical model that describes the phenomenon is assimilated and those equations are solved using MATLAB program. From the solution, we can find different parameters required to manufacture such surface.

A. Parameters:

As discussed earlier, chemical composition of the leaf determines the surface energy of the surface, surface energy with respect to air and water are different for the surface. Contact angle effect is determined by the difference of surface energies. Let the surface energy with respect to water be γ_{sl} and with respect to air be γ_{sg}. Different material have different surface energies, this will help in selection of coating material for achieving the desired contact angle θ. We also need to define another parameter i.e. surface energy (surface tension) of water with respect to air γ_{lg}. Structural property of the leaf is defined by the contact factor f as a parameter. The parameter is an important variable to select for achieving desired contact angle. For the surface with dual scale roughness the contact factor is discretized as the product of micro scale contact factor and nano scale contact factor i.e. $f_{ms}f_{ns}$. This will help us to determine how much the surface must be roughened to get the contact angle.

B. Mathematical models:

Ideal contact angle is determined by the Young's equation which does not incorporate the contact factor. This equation is the foundation for determination of more accurate contact angle. The dependency of the equation is only the surface energy of the surface which is modeled as

$$\cos\theta = \frac{\gamma sg - \gamma sl}{\gamma lg} = \frac{Surface\ energy\ difference\ with\ gas(air)\ and\ water}{surface\ energy\ of\ water\ at\ 20°C} \quad (1)$$

The equation is solved to get the Young's angle of contact. Further, the model was improvised by Wenzel incorporating the roughness or contact factor in the equation. It was modeled as

$$\cos\theta = f\cos\theta_y \quad (2)$$

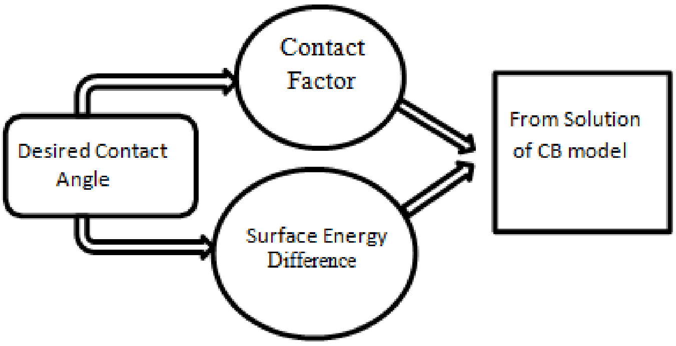
Still, air gap is present between the projections of the surface which has contribution to the contact angle formation, Wenzel model do not incorporate information about the heterogeneous surface. In order to improve the accuracy of the evaluation of contact angle, Caussie- Baxter modeled the equation for such heterogeneous surface as

$$\cos\theta_{cb} = f(\cos\theta_y + 1) - 1 \quad (3)$$

Among these three models, Young's model is solved for the evaluation of ideal contact angle; Wenzel and Caussie-Baxter model are solved depending on the requirement. Wenzel model seems to be dominant when the roughness is low, when the impinging velocity of the liquid is very high. Caussie- Baxter's model is dominant if the roughness factor is high. It is also accurate for the surface with dual scale roughness. Thus, we choose Caussie-Baxter's model and select the parameters from the solution of the model.

C. Analysis:

The parameters required for the manufacturing of such surface are discussed. We need to find out those parameters required to manufacture surface with the desired contact angle. There might be combination of contact factor and energy gradient values to obtain the desired contact angle. Contact factor helps in determining the lithography target, whereas the surface energy difference in two mediums helps in selection of coating material. The surface energy of water droplet in ambient temperature was found to be 72.8mN/m. The analysis was done using the strategy as shown below:



The model was solved using MATLAB program. Contact angle was varied from 0 to 180 degree and the contact factor from 0 to 1 to obtain the contour as shown in the graph below:

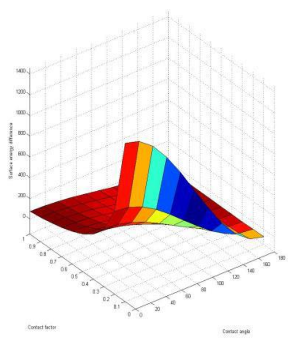


Figure 3: Solution of CB model for water as a liquid droplet

IV. CASE STUDY

Paraffin wax has a contact angle of 107 degree with the glass surface. Considering it as a coating material, a theoretical demonstration how the other manufacturing parameters are selected has been presented in the paper. Surface tension of water is 72.8mN/m. In order to determine the surface energy difference of wax with air and water, a reverse calculation was done using Young's ideal equation and found to be -21.28mJ/m^2.

A. Parameter selection:

In order to manufacture the super hydrophobic surface using Paraffin wax as a coating material, surface roughness must be developed. To find the roughness factor, above graph was used where the contact angle is 150 degree and the surface energy gradient is -21.28mJ/m2. The contact factor we need to develop was 0.2, which is very hard to achieve. Simply using paraffin wax as a coating material would be more tedious and impracticable. So the interest was dragged to material with higher surface energy gradient like FDTS chemicals

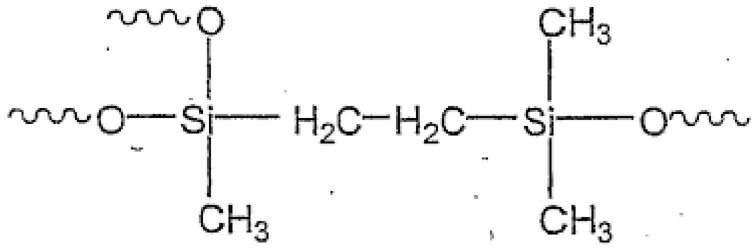


Figure 4: Molecular Structure of FDTS chemical

It is mostly recommended to use the FDTS chemicals like Per-fluorodecyltrichlorosilane / fluorooctylethyltrichlorosilane etc. for coating which has very low surface energy; this will help to increase the contact factor making manufacturing process comfortable and fast. After the coating material is fixed, the parameters are selected based on chosen contact factor.

V. CONCLUSION

There are various techniques developed for manufacturing of such surface like Colloidal Lithography and Plasma Etching, Laser ablation and Reactive Ion Etching etc. The paper provides valuable information that is required to produce hydrophobic surface by evaluating initial parameters like contact factor and surface energy difference, which can provide other valuable data's like depth of ablation, diameter of ablation or alignment and number of colloidal spheres, etc. selected after the selection of coating material with certain surface energy difference during the manufacturing process. Current challenges of production are the stability of such surface and cost-reduction for manufacturing. Stability of such surface for production over a large surface like windscreen of automobiles is achieved properly via. Laser ablation technique [5].

A. Advantages:

If the automobile windscreen is developed with super hydrophobic characteristics, its self-cleaning ability will reduce the usage of wipers and also provides clear vision providing comfort for the drivers in rainy condition. This could prevent possible accidents. As we know that, various automobile companies these days are moving towards the revolution of electric vehicle. One of the electric power consuming equipment of vehicle is wipers and if such surface is applied on the windscreen it might assist to replace the wipers making electric vehicles more efficient and reduce power consumption.

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