FABRICATION OF SUPER-HYDROPHILIC/HYDROPHOBIC SURFACE AND DRAG REDUCTION EFFECTS

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1 Introduction

Many plants in the nature have hydrophobic leaves. Because of this property, these leaves don't get wet and can easily remove a dirty from the leaves. Many hydrophobic surfaces like lotus leaf have been studied for many years[1-2]. And many scientists have tried to mimic this property with many methods. Several methods like photolithography, thermal evaporation and plasma fluorination are used to make hydrophobic surface but these methods have some limitation. It is very hard to make large-sized hydrophobic surface and are difficult to maintain hydrophobic property and lose their property after several weeks. And they are expensive and take too much time to make hydrophobic surface. But using anodizing method, we can easily get hydrophobic surface.

To overcome these limitation, super-hydrophilic surface was fabricated by anodizing method and using SAM(Self Assembly Monolayer) method to the super-hydrophilic surface, we could get super-hydrophobic surface. And from water flow experiment, we could see the drag reduction effect of super-hydrophobic surface.

2 Fabrication

2.1 Hydrophilic aluminum surface

It is known that there are two factors which determine the contact angle of the surface. That is surface energy and structure of the surface. According the classical Young's equation[3] :

$$\cos\theta = \frac{\gamma_{sv} - \gamma_{ls}}{\gamma_{lv}}$$

Surface energy of the solid material determines the contact angle of the material. Contact angle is calculated by the surface energy between solid/liquid(γ_{ls})and solid/vapor(γ_{lv}). That means material property itself determines hydrophilicity or hydrophobicity of the surface.

But one more factor effect the property of the surface. Surface structure (roughness) can maximize its property. From the equation of Bico et al.[4]

$$\cos\theta_A = \alpha\cos\theta_f - (1-\alpha)$$

where α is the fraction of the contact area.

If the roughness of the surface increases, that means contact area increase. And hydrophilic surface changes to super-hydrophilic surface and hydrophobic surface changes to super-hydrophobic surface. Therefore if we change the surface structure, we can easily get the super-hydrophilic and super-hydrophobic surfaces.

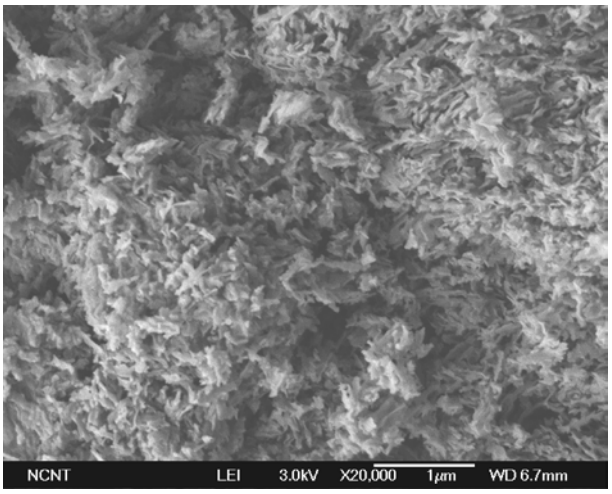

Fig.1. SEM image of anodized super-hydrophilic surface

To get the super-hydrophilic surface, we prepared industrial aluminum sheet (300mm X 140mm X 5mm, 99.5%). Anodization was then carried out with oxalic acid at 26°, 40V for 12 hours. Usually we anodize aluminum at 15° and we can get AAO(Anodic Aluminum Oxide) template which has porous surface[3]. But when we raise the temperature up to 26°, holes on the aluminum surface start to merge each other we can get new structure surface. Nano scale structure was made from anodization process. And after they merged each other, we can observe micro scale structure because empty spaces where holes emerged and group of nano scale structures is micro scale crests and troughs. This micro/nano dual scale structures on the surface change the anodized aluminum surface to super-hydrophobic surface.

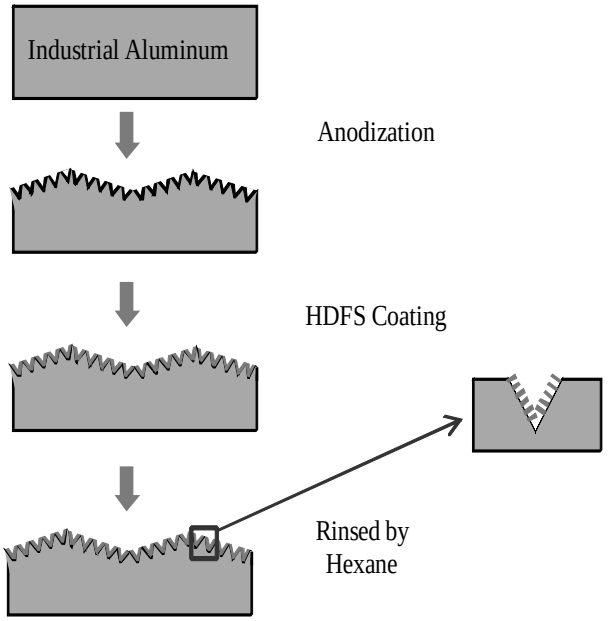

Fig.2. Overall Process for Fabrication of Super-hydrophilic/hydrophobic surface

2.2 Hydrophobic aluminum surface

To achieve super-hydrophobic surface, SAM (Self Assembly Monolayer) technique was used with HDFS (heptadeca-fluoro-1,1,2,2-tetrahydrodecyl trichlorosilane) solution[5-6]. We prepared n-hexane solution which is containing 0.1% HDFS solution. We immersed super-hydrophilic aluminum surface into the solution for 10 minutes. A specimen was then rinsed by hexane for 20 minutes. After this process, only HDFS monolayer remains by hexane treatment. Then, a specimen was dried at room temperature for 24hr.

Even though they have same dual scale structures, HDFS coated surface has super-hydrophobic property.

The Contact angle between the coated super-hydrophobic surface and the water droplet was 160°. It was measured by contact angle meter (DSA-100, Kruss Co.)

Fig.3. Contact angle of the HDFS coated surface (160°)

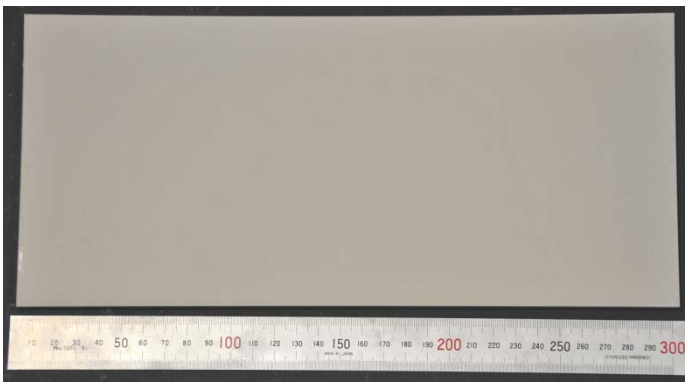

Fig.4. Anodized aluminum plate (Super-hydrophilic, contact angle: 0°)

3 Experiment

Three kind of specimens was prepared; smooth industrial aluminum sheet, super-hydrophilic sheet and super-hydrophobic sheet. Test plates were 600 X 140 X 20mm which is joint of two 300 X 140 X 20mm. Two plates are joined by 12 screws. And test plates are attached to the load cell to measure drag force during the experiment. During experiment, water flows to the horizontal direction. If the shape of plate's front part is not smooth, there is turbulence flow and it can have bad effect on the experiment result. To eliminate this disturbance, the triangular shape tip was attached at the plate's front part. Tip was 50mm length and 20mm thickness.

The experiments were conducted in Circulating Water Channel (CWC). The dimension of the test tank was 3.0 X 1.0 X 0.8m. The maximum water velocity that the twin-impeller can generate was 1.5 m/s. The drag force acting on the model was measured by 3-compoment load cell among which, X component was used.

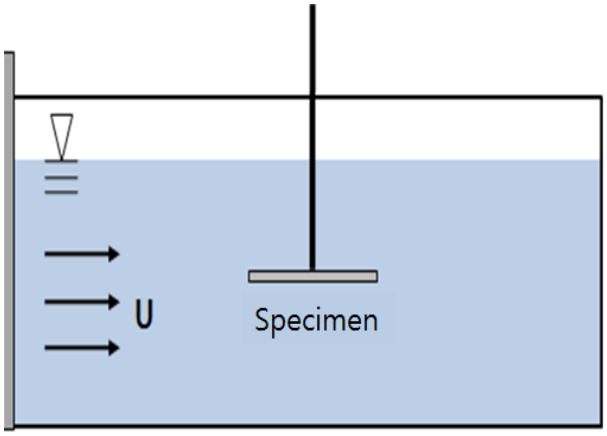

Fig.3. Schematic image of the
drag reduction experiment of the specimens

4 Result and Discuss

New fabrication method was used to get super-hydrophilic and super-hydrophobic surface. Normal AAO template has arranged porous structures and is hydrophilic property. To get super-hydrophobic surface, additional widening process was required. But we could reduce complex fabrication process and time by changing anodization condition. When we increase anodization temperature to 26°, holes on the surface start to merge each other. Anodized holes are nano scale structure and merged surface is micro structure. This nano/micro dual scale structure maximizes a wetting characteristic of the surface. Then, the anodized hydrophilic surface changed to super-hydrophilic surface. Super-hydrophobic surface can be also easily fabricated by this dual structure. Super-hydrophilic surface was coated with HDFS solution by SAM method. Because coated monolayer has hydrophobic property, dual scale structure which is fabricated by new anodization condition changes the surface to super-hydrophobic surface.

Drag reduction experiment was also conducted. To see drag reduction effects of hydrophobic surface, smooth and hydrophilic surface were compared. The specimen was placed horizontal direction and water flowed different speed from 50,000 to 350,000 of Reynolds number. At the front part of the specimen, triangular tip was attached to eliminate turbulence disturbance during experiment.

During experiment, an air layer between the specimen and water was observed. This air layer trapped made slip condition at the boundary and water velocity increases. As a result, drag load which is applied to the specimen decreased compared to other specimens.

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