EDM 을 이용한 자연모사 이중구조 초소수성 금속표면의 분석

Analysis of the bioinspired multiscale metallic surface by EDM

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Key words : Micro nano structure, Lotus effect, EDM

1. Introduction

We present a simple one-step method of fabricating a superhydrophobic metallic surface with hierarchical, dual-roughness structures by employing the wire electrical discharge machining (WEDM) technique. Electrical discharge machining (EDM) is a machining method using electrical discharges to melt or vaporize workpiece material. WEDM uses a wire as an electrode to cut workpiece materials and can produce various complicated structures using a programmed wire path. In EDM process, an electrode and a workpiece are immersed in dielectric fluid such as kerosene and deionized water. When high voltage is provided with small gap between the electrode and workpice, a discharge is initiated. During the discharge duration, electrical energy is converted into heat and a small amount of meterial is molten and voporized at the electrode and workpice. A small cavity, called crater is generated both on the electrode and workpiece surfaces by single discharge. As a result of numerous discharges, the machining proceeds and the machined surface consists of many randomly distributed craters.

The surface roughness of these craters is determined by various discharge conditions such as discharge current and duration. In many industrial applications involving metal surface texturing, the WEDM technique is widely used as a viable method to generate surface roughness by controlling electric pulse parameters. There are several advantages with the method. First, a microscale sinusoidal roughness is formed by a programmed wire path with a wide range of wavelengths (λ = 200 to 500 μm).[18]. Second, a nanoscale roughness is spontaneously created on the machined surface in the form of craters. Taken together, the WDEM process is capable of producing a dual-roughness structure in one-step etching without additional chemical treatment.

2. Analysis of wetting states on the fabricated superhydrophobic metallic surfaces

The measurements of water CAs on the fabricated surfaces are shown in Figure 3B with comparisons to theoretical models. Here, we employed the recent theoretical model by integrating the Wenzel and Cassie states, in which the wetting states can be categorized into four types:

Wenzel-Wenzel or *W'-W"*:

$$\cos\theta_{app}^{W'-W"} = R'R"\cos\theta_e$$

Wenzel-Cassie or *W'-C"*:

$$\cos\theta_{app}^{W'-C"} = R'\left\{ f"\left(\cos\theta_e + 1\right) - 1\right\}$$

Cassie-Wenzel or *C'-W"*:

$$\cos\theta_{app}^{C'-W"} = R"\left\{ f'\left(\cos\theta_e + 1\right) - 1\right\}$$

Cassie-Cassie or *C'-C"*:

$$\cos\theta_{app}^{C'-C"} = f'f"\left(\cos\theta_e + 1\right) - 1$$

where *R*, *f*, θ_e represent the roughness, solid fraction, and equilibrium wetting angle, respectively, and the single and double apostrophes represent the first and second hierarchy scales, respectively. Based on the calculation of wetting angle on the secondary roughness of aluminum alloy, it is interesting to note that all cutting stages of WEDM produce a wetting angle that was highly matched with the C" state. The Wenzel state for the same roughness values turned out to deviate largely from the experiment.

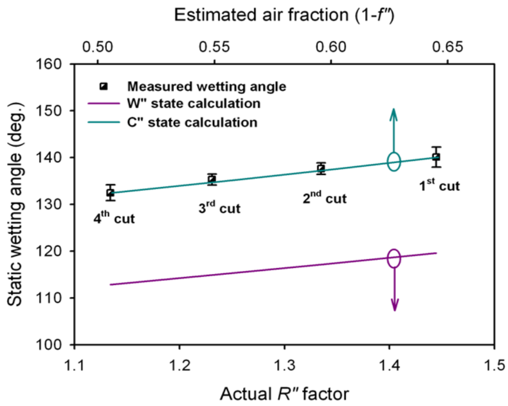

Fig. 1 Theoretical models and the comparison with measured wetting angle using the Wenzel (dotted line) and Cassie (solid line) states. Note that experimental measurements are highly matched with the Cassie state in all surfaces.

For the Cassie state, we have calculated the estimated solid fractions for the respective roughness, which ranged from 0.35 to 0.5 from 1st to 4th cut. It is indicative that the wetting state in the secondary roughness is very stable in the Cassie state. Therefore, we conclude that the possible wetting states in dual-scale roughness are only W-C and C-C in equations (2) and (4).

A further measurement of wetting angles on dual-scale roughness of Al alloy with the 1st cut process is shown in Figure 2A. Here, the creation of microscale sinusoidal patterns with different wavelength on aluminum alloy surface with WEDM show different wetting behaviors. For higher wavelengths (500 and 400 μm) with the 1st and 2nd cuts, the CAs were larger than 150° and contact angle hysteresis was lower than 3°. In contrast, for lower wavelengths (200 and 300 μm) with all cuts and higher wavelengths with the 3rd and 4th cuts show CAs about 140° and high contact angle hysteresis (> 5°). A comparison to theoretical models with composite wetting states is shown in Figure 4B. Here, for higher wavelengths with the 1st and 2nd cuts, the experimental data show very good agreement to

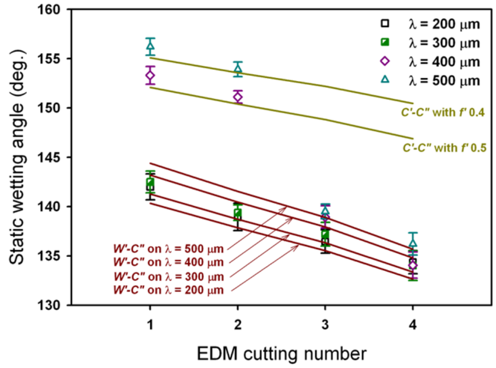

Fig. 2 Static wetting angles on the various samples with comparison to theoretical models.

C'-C'' model. Then, there seems a transition to *W'-C''* model with the 3rd and 4th cuts. In parallel, for lower wavelengths with all cuts the experimental measurements show excellent agreement with *W'-C''* model. This suggests that the WEDM method presented here has designing capability to tune surface texture and wettability.

3. Conclusions

We have presented a simple method to form dual-roughness superhydrophobic metallic surfaces by using WEDM process.

It is envisioned that our WEDM method would find many uses in making superhydrophobic metallic surfaces in more diverse applications with harsh environments.

References

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