

Method for Preparing Surface Microstructures with Special Wetting Properties

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Abstract: In the field of surface engineering of materials, surface wetting properties are one of the key indicators that determine the performance and application scenarios of materials. By precisely controlling the microscopic morphology and elemental composition of the sample surface, researchers have successfully prepared matrix materials with significantly different surface wetting properties. The microscopic morphology of the surface can alter the contact area and contact angle of liquids on the material surface, while the elemental composition of the surface directly affects the surface energy of the material. The combined effect of these two factors enables the directional design of wetting properties, such as the precise transition from super-hydrophilic to super-hydrophobic states. With the continuous advancement of research, the preparation technologies for functional surface materials with extreme wetting properties have formed a diversified system. These technologies not only meet the strict requirements of different application scenarios for the material's wetting properties, but also can achieve functional integration by combining the physical and chemical characteristics of the material itself.

Keywords: surface microstructures; laser etching; electrochemical deposition; anodic oxidation; nickel coating

1. INTRODUCTION

Many scholars have constructed surface microstructures with specific surface wetting properties by adopting different methods for various material applications. Among them, widely used and easily operated methods include electrochemical deposition, laser processing, micro-milling, anodic oxidation.

Electrochemical deposition is one of the most commonly used methods for preparing metal coatings. It has the advantages of high production efficiency, stable process, and high cost-effectiveness. Its application fields are extensive, such as preparing superhydrophobic surfaces, improving the wear resistance and corrosion resistance of metal surfaces, and decorating the surfaces of metal products, etc.

By laser processing techniques, different micro-structural surface patterns can be fabricated, thereby altering the surface wettability of the substrate. The advantages of this method lie in its high processing accuracy, regularity of the processing array, and the micro-controllability of the processing trajectory.

By applying an external power supply to the metal surface, the anode plate undergoes an oxidation reaction and is electrochemically corroded, thereby forming a rough structure with a specific microstructure on the surface. This process is known as anodic oxidation. By adjusting the oxidation time and the external voltage, different surface morphologies and microstructures can be obtained.

2. SURFACE MICROSTRUCTURE PROCESSING METHOD

2.1 Laser etching method

Wang^[1] used the picosecond laser ablation method to fabricate a series of nipple-like textures with different microstructures on the copper surface, as shown in Figure 1. They studied the effects of laser power, scanning speed, and frequency on the surface morphology and hydrophobicity of the nipple-like textures, and analyzed the transformation mechanism of surface wettability. When the laser power was

9 W, the repetition frequency was 2 MHz, the scanning speed was 200 mm/s, and the scanning times were 20s, after the cross-scale nipple-like textured surface was left to stand for 30 days, an ultra-high hydrophobicity could be achieved. After storage for 30 days, the surface hydrophilicity of Ni and CuO transformed into hydrophobic NiO, Ni(OH)₂, and Cu₂O. At the same time, hydrophobic gas-phase particles in the air were adsorbed on the surface, causing the wettability of the nipple-like textured surface to change from super-hydrophilicity to hydrophobicity.

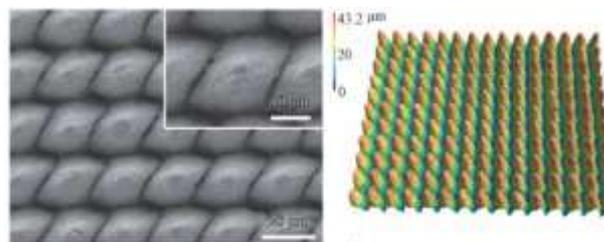


Figure 1. The surface morphology prepared by picosecond laser etching method^[1]

2.2 electrochemical deposition method

Xiang^[2] investigated the influence of current density on the surface morphology and wettability of nickel coatings on low-carbon steel substrates. At current densities of 6 A/dm² and 8 A/dm², the coating surfaces presented micro-nano structures, as shown in Figure 2. After modification with myristic acid, they exhibited superhydrophobicity with a contact angle of 152°. After abrasions, obvious furrows appeared on the surface prepared at high current density. However, the surface contact angle remained at a high level, and the corrosion current density decreased by 60%. Wei^[3] prepared long-term stable Ni-SiC coatings on copper substrates using magnetic field scanning electro-deposition technology. By applying different magnetic induction intensities, two different microstructures of the coating surfaces were obtained, namely rough layered structures and micro-gaps, which significantly enhanced the surface hydrophilicity.

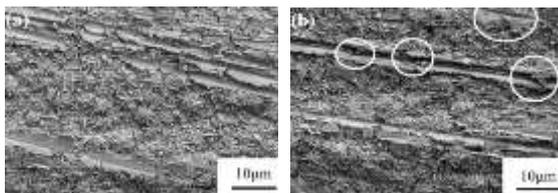


Figure 2. Surface morphology of nickel coating prepared by different current density^[2]: (a) 6 A/dm²; (b) 8 A/dm²

Shen^[4] prepared a superhydrophobic nickel coating by using the scanning electrodeposition technique, as shown in Figure 3. Due to the electrodeposition tip effect, cauliflower-like clusters grew on the surface, and the contact angle of water droplets on this surface reached 155.4°. Hashemzadeh^[5] used different concentrations of NH₄Cl as crystal modifiers to prepare electrochemically deposited nickel coatings as shown in Figure 4. As the concentration of NH₄Cl in the solution gradually increased, the surface morphology tended to be regular, sharp, and presented symmetrical micro-nano cone structures, and the liquid water showed superhydrophobicity on the surface.

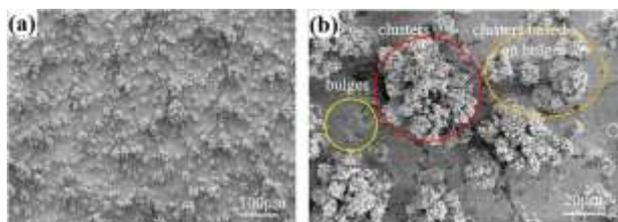


Figure 3. Cluster structure on the surface of hydrophobic nickel coating^[4]

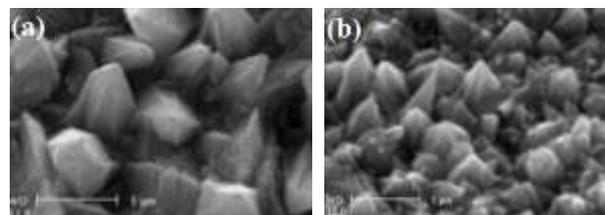


Figure 4. Surface morphology of nickel coating with different concentration of crystal improver^[5]

Yue^[6] prepared a surface morphology with a pyramid-like structure, where the larger-sized layered microstructure at the top was formed after chemical etching for 5 to 10 minutes, as shown in Figure 5. The surface coated with nickel was etched using a mixture of ferric chloride, hydrochloric acid and hydrogen peroxide at different times to obtain different surface morphologies and special microstructures. It still maintained a high surface free energy after exposure to air. The contact angle of the metal solution on this surface was less than 30°, demonstrating excellent hydrophilicity.

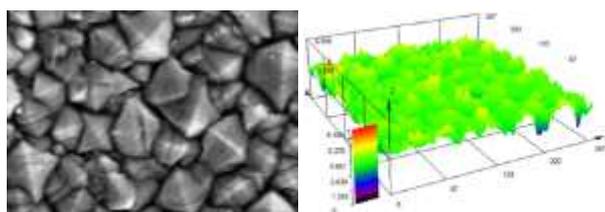


Figure 5. larger-sized layered microstructure and its 3D surface image^[6]

2.3 Anodic oxidation method

Zhang^[7] used anodic oxidation technology to fabricate depressions with a size of approximately 10 µm (see Figure 6a), and used Na₂B₄O₇ electrolyte to prepare micro-nano hierarchical structures, thereby giving the surface greater roughness and excellent hydrophilic properties. Zhang^[8] used micro-arc oxidation process, changed the forward voltage and reduced the duty cycle, which reduced the porosity of the film layer and the corrosion rate. The hydrophilicity of the sample surface was significantly improved, and a surface morphology with excellent wetting property and corrosion resistance was obtained (see Figure 6b). Li^[9] used calcium acetate and sodium dihydrogen phosphate as electrolyte, and by adjusting the power supply voltage and current of micro-arc oxidation, they fabricated rough surface morphology on pure titanium (see Figure 6c). When the voltage was 360 V and the current was 0.6 A, an ultra-hydrophilic surface was prepared, and the contact angle was close to 0°.

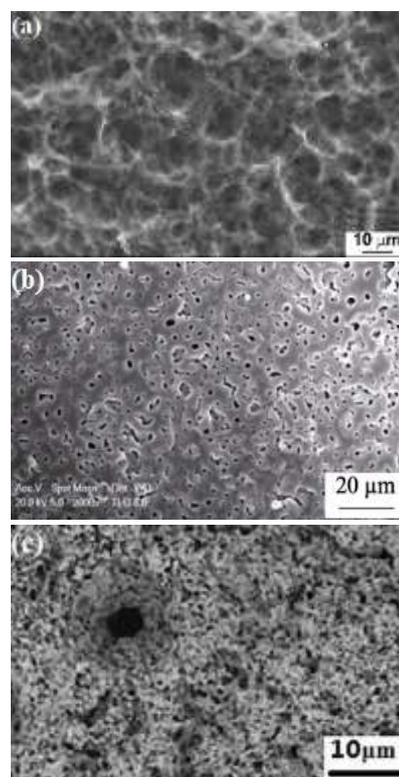


Figure 6. Rough surface morphology prepared by micro-arc oxidation: (a) Micro-nano layered structure^[7]; (b) Hydrophilic surface with high porosity^[8]; (c) Superhydrophilic surface morphology^[9]

3. CONCLUSION

In conclusion, there are numerous methods for preparing special wetting surfaces. By adjusting process parameters, one can obtain surface morphologies with different microscopic characteristics. Electrochemical deposition is a type of additive manufacturing method. By adjusting the solution composition and preparation parameters, microstructures with different surface wetting properties can be generated on the substrate surface, which is suitable for preparing one or more layers of materials with completely different properties on the substrate surface, thereby filling certain performance deficiencies of the substrate. By adjusting the laser beam energy and its moving speed, different material surface features can be directly obtained, especially effective for processing high-hardness, high-fragility and high-melting-

point materials. Anodic oxidation is a method of preparing oxide films on the original metal surface through electrochemical oxidation, thereby changing the surface state and properties, significantly improving the hardness, wear resistance and corrosion resistance of the material. However, its reaction time is long, the preparation process is complex, and the solution concentration is difficult to control. Chemical etching is a flexible and easy-to-operate surface modification method.

4. REFERENCES

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