Research Article

High Efficient Construction and Comprehensive Evaluation of Superhydrophobic Filter Screen Coatings

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The preparation of environment-friendly and efficient superhydrophobic filter screen still faces great challenges. Herein, a compact, solid cerium stearate superhydrophobic-coated stainless steel mesh (SSSM) was prepared by a simple, efficient, and environmentally friendly one-step electrodeposition process. Fourier transform infrared (FTIR) spectroscopy, energy-dispersive X-ray spectroscopy (EDS), scanning electron microscopy (SEM), and contact angle measurement were used to characterize the surface coating (composition, morphology, and contact angle) of SSSM. The results show that the SSSM surface is a dense mastoid cerium stearate micronanostructure coating, and its static contact angle with water can reach 162.73°. In addition, it has excellent self-cleaning performance for conventional simulated pollutants, and the contact angle can still reach 161° after 28 days of storage. In the wear resistance and corrosion resistance tests, the contact angle can still be kept above 150° after 600 mm abrasion under the load of 19.6 kPa, the corrosion current of SSSM is reduced by two orders of magnitude, and its corrosion inhibition efficiency reaches 99.74%. In addition, the oil/water separation performance of SSSM is also very good, and the separation efficiency for different oil/water mixtures exceeds 97%. This study will provide important data support and method reference for the preparation of metal anticorrosion superhydrophobic material coating and the development of environment-friendly and efficient oil–water separation materials.

1. Introduction

With the continuous development of economy, oil exploitation, processing and transportation, offshore crude oil leakage, industrial production, and daily life produce a large amount of oily sewage, which will pose a great threat to the ecological environment and human health [1–3]. At present, traditional oil removal methods have many limitations, such as difficult recovery of adsorption materials, poor adsorption performance, low separation efficiency, harming the natural environment, and high cost [4]. Therefore, it is urgent to develop functional materials that can solve the above problems and realize efficient oil/water separation.

Biomimetic superhydrophobic mesh materials have broad application prospects in the field of oil/water separation due to their water-blocking and oil-transferring performances [5–8]. At present, the key to the preparation of special wetting oil/water separation materials is to change the roughness and surface energy of the substrate surface. The main methods are electrospinning [9], coating [10, 11] sol–gel [12], hydrothermal synthesis [13], template method [14], etc. However, most of these preparation methods require special equipment, harsh preparation conditions, and are not conducive to industrial production. Low surface energy materials for modification are generally expensive and involve environmental harmful substances. Therefore, it is of great significance to explore the preparation method of special wettability of oil/water separation materials with simple process, environment-friendly, and easy availability of raw materials, suitable for large-scale production and excellent product performance.

Electrochemical deposition is an effective method for preparing rough surfaces, in which a thin coating is deposited on a conductive surface from a solution containing ioni-

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superhydrophobic films on the substrate surface [17–19]. Compared with postdeposition modification, it not only simplifies the preparation process but also makes the modification of low surface energy materials more compact and uniform. Zhang et al. [17] prepared fluoride-free functionalized superhydrophobic 3D porous copper foam by one-step pulse electrodeposition method, showing excellent corrosion resistance, mechanical strength, and oil/water separation performance. Yang et al. [20] prepared nickel corrosion-resistant superhydrophobic coating on copper by direct current electrodeposition. Zheng et al. [21] constructed magnesium stearate superhydrophobic corrosion-inhibitive coating with microsphere and nanoflake composite structures on the surface of magnesium alloy by one-step electrodeposition. To sum up, one-step electrodeposition cannot only prepare superhydrophobic coatings efficiently and rapidly, but also the coatings generally have good corrosion resistance. Of course, there are other preparation schemes for the preparation of corrosion-resistant superhydrophobic coatings. For example, Yin et al. [22] prepared superhydrophobic double-layered coating on Mg alloy by electrodeposition and dip-coating methods; after electrochemical testing and immersion in 3.5 wt% NaCl solution for 7 days, they all showed excellent corrosion resistance. Li et al. [23] prepared a self-healing superhydrophobic anticorrosion coating on the surface of Mg alloy by combining polydopamine-functionalized Cu$_2$O-doped graphene oxide, octadecylamine, and polydimethylsiloxane, and meanwhile, the coating also showed good mechanical stability, chemical durability, and weather resistance. Ge et al. [24] prepared superhydrophobic Al coatings with excellent self-cleaning performance and corrosion resistance on steel plates by arc spraying and etching with sodium hydroxide solution, and finally passivating with perfluorodecyltriethoxysilane ethanol solution. However, the above preparation process involves multiple steps, and some also involve fluorine-containing hydrophobic agents with higher prices.

Stainless steel mesh is a common metal material, which has the advantages of stable physical and chemical properties, independent control of mesh size, wide application, and low cost. Therefore, the study of its surface modification plays a great role in promoting the development of oil/water separation materials and even its existing applications. However, there are few reports on the comprehensive properties of self-cleaning, durability, corrosion resistance, and oil/water separation of superhydrophobic stainless steel mesh (SSSM) prepared by one-step electrodeposition, which has an important impact on the popularization and application of superhydrophobic mesh membrane. To sum up, this study intends to prepare uniform cerium stearate micro/nanostructure superhydrophobic coating on the surface of stainless steel mesh by a simple and environment-friendly one-step electrodeposition method with cheap and environment-friendly stearic acid as the hydrophobic agent. Through the comprehensive performance test and evaluation of the prepared superhydrophobic filter screen, the research shows that the prepared SSSM samples have excellent self-cleaning, durability, corrosion resistance, and oil–water separation functions.

2. Materials and Methods

2.1. Materials. Stearic acid, anhydrous ethanol, sodium chloride, and methyl violet were purchased from Tianjin Kemji Chemical Reagent Co., Ltd. Sulfuric acid and chloroform were provided by Luoyang Chemical Reagent Factory. Cerium nitrate was purchased from Shanghai Sanpu Chemical Co., Ltd. All the reagents used above are analytical pure reagents and have not been further purified. 93# gasoline and 0# diesel oil were purchased from Sinopec gas station. The base material used in this research is 400 mesh stainless steel mesh purchased from Taobao. Sandpaper was purchased from Wuxi Gangxia Precision Sandpaper Factory. Deionized water was self-made.

2.2. Preparation of Superhydrophobic Micronanostructure Coating. The stainless steel mesh was cut into 1.0 cm × 5.0 cm rectangular strip, polished with 600 mesh sandpaper, and ultrasonically cleaned in anhydrous ethanol and deionized water for 15 min, respectively. The stainless steel mesh was soaked with 10% sulfuric acid solution for 20 min to remove the oxide layer and residual oil on the surface [25]. Then, it was taken out, washed with deionized water, and dried at 80°C for standby. 5.43 g of cerium nitrate and 7.11 g of stearic acid were weighed, respectively and dissolved in 250 ml of absolute ethanol to prepare the electrodeposition solution. The electrodeposition process adopted a double electrode system, with the pretreated stainless steel mesh as the cathode, and the graphite electrode as the anode, which were, respectively, inserted into the above solution and kept at a certain distance. The constant temperature electrodeposition was carried out for a period of time under the voltage of 32.5 V by the DC stabilized voltage power supply (PS-A305D, China). Finally, rinsed with absolute ethanol for several times and dried naturally to obtain the sample.

2.3. Characterization Techniques. The chemical composition of the as-received SSSM was investigated by infrared spectrum (FTIR-650) and energy-dispersive X-ray spectroscopy (EDS) (Nova NanoSEM 450). The morphology of SSSM surface was characterized by field-emission scanning electron microscope (FE-SEM) (Nova NanoSEM 450). A contact angle (CA) measuring instrument (C601 solid–liquid interface analyzer, China) was used to measure the static CA of the prepared sample surface to 3 ml deionized water droplets at room temperature. At least three different positions were measured for each sample to determine the average value of CA. The static CA was an average value obtained by measuring at least three different points on the surface of each sample using about 3 μl of deionized water droplets. The corrosion resistance of the samples was measured by electrochemical workstation (CH1660E), and the polarization (Tafel) curve and electrochemical impedance spectroscopy (EIS) of the sample were measured, respectively, in 3.5 wt% NaCl solution. The platinum sheet was used as the counter electrode, and the saturated calomel electrode was used as the reference electrode. SSSM was used as the working electrode. EIS was performed at a frequency range of 100 kHz to 10 MHz with an amplitude of 50 mV. The polarization curve (Tafel) was tested.
at 0.01 V/s scanning speed in the recording range of −800 to 0 mV.

3. Results and Discussion

3.1. Chemical Compositions of the Superhydrophobic Surface.

The chemical composition of SSSM was analyzed by FTIR spectra and EDS spectra, respectively. Figure 1(a) shows the FTIR spectra of pure stearic acid and SSSM in the wavelength range of 4,000–3,200 cm\(^{-1}\). It can be seen that in the infrared spectrum of stearic acid, 2,916 and 2,849 cm\(^{-1}\) correspond to –CH\(_3\) and –CH\(_2\) stretching vibration absorption peaks, respectively [26], and the peak at 1,701 cm\(^{-1}\) corresponds to the absorption peak of carboxyl group. In the infrared spectrum of SSSM, the other peaks are roughly the same, except that the absorption peak of carboxyl group disappears, and new absorption peaks appear at 1,546 and 1,447 cm\(^{-1}\), which are attributed to the vibrations of the carboxylate (–COO\(^{-}\)) [27]. This redshift and peak splitting confirmed the chelation between stearic acid and cerium ion, and the formation of long-chain carboxylates on the surface of the substrate [28].

In order to confirm the electrodeposition products, EDS was carried out. Figure 1(b) shows the EDS spectrum of the SSSM. The results showed that the coating surface is mainly composed of Ce, O, and C elements, and the contents of C, O, and Ce were 63.1, 8.8, and 28.1 wt%, respectively. The results show that cerium stearate is successfully deposited on the stainless steel mesh substrate [28].

3.2. Morphologies and Wettability of the Superhydrophobic Surface.

To discuss the influence of sample morphology on superhydrophobic property, the stainless steel meshes before and after electrodeposition were characterized by scanning electron microscope (SEM). The results are shown in Figure 2. It can be seen that before electrodeposition, the stainless steel mesh surface was almost smooth except for some scratches polished by sandpaper. After electrodeposition, the SSSM surface was coated with dense papillary structure coating (see Figure 2(b)–2(d)). In addition, the surface of mastoid and between mastoids were also covered with irregular rough structure (see Figure 2(d)). It can be seen that the perfect construction of micro/nanorough structures on the surface of stainless steel mesh had been achieved through certain conditions of electrodeposition treatment.

Figure 3 shows the CA between the stainless steel mesh surface and water droplets before and after electrodeposition. The static CA between the stainless steel mesh surface and water before electrodeposition is about 133.4°, which indicates that the surface before electrodeposition is not superhydrophobic (see Figure 3(a)). However, after electrodeposition, the water droplets on the surface are perfectly spherical, and the CA is about 162.7° (see Figure 3(b)), showing good superhydrophobicity property. According to the previous composition analysis, the chelation between stearic acid and cerium ions generated long-chain cerium stearate carboxylate on the substrate surface. Due to the synergistic effect of rough papillary structure and hydrophobic long-chain branches, the substrate surface showed superhydrophobicity. When the water droplet contacts with the sample surface (which can be regarded as the composite interface between the surface of cerium stearate micro/nanomastoid structure and the air), in addition to the liquid–solid interface, there is also a large area of liquid–gas interface. The area of the liquid–gas interface is calculated by Cassie–Baxter formula [29, 30]:

\[
\cos \theta_i = (1 - f) \cdot (\cos \theta_s + 1) - 1, \tag{1}
\]

where \(\theta_i\) and \(\theta_s\) are the water CA of rough surface and smooth surface, respectively, and \(f\) is the area fraction of...
During the calculation, θ_r and θ_s were assigned the values of 162.7° and 133.4°, respectively. According to Formula (1), f = 0.8555 can be obtained, which indicates that the liquid–gas interface between the SSSM sample surface and water accounts for 85.55% of the gas–liquid–solid composite interface. This shows that the electrodeposited micro/nanopapillary cerium stearate rough structure coating on the surface of stainless steel mesh can store a lot of air to reduce the contact area between its surface and water droplets, thus showing superhydrophobic performance.

3.3. Formation Mechanism of Coating. The growth mechanism of electrodeposited coating is shown in Figure 4. When DC voltage is applied to the electrodes, part of stearic acid combines with free Ce^{3+} ions near the cathode to form cerium stearate complex and hydrogen ions (H^+). With the progress of electrodeposition, the concentration of free hydrogen ions around the cathode plate increases, some of which obtain electrons to form hydrogen gas, while cerium stearate complex is deposited on the surface of the cathode filter screen [17, 31]. The reaction process is described by the following formulae:

\[
\text{Ce}^{3+} + 3\text{CH}_3\text{CH}_2\text{COOH} \rightarrow \text{Ce(CH}_3\text{CH}_2\text{COO})_3 + 3\text{H}^+ \tag{2}
\]

\[
3\text{H}^+ + 3\text{e}^- \rightarrow \frac{3}{2}\text{H}_2 \tag{3}
\]

3.4. Self-Cleaning Property of the Superhydrophobic Surface. Superhydrophobicity can be achieved by tilting water droplets
at a certain angle to achieve free fall. Self-cleaning means that water drops on the surface of superhydrophobic material and rolls down fully after tilting to take away the dust and other particles on the surface to achieve self-cleaning. In order to carry out self-cleaning test, chalk powder, coffee powder, milk, and coke commonly used in life are used to simulate pollution sources. As shown in Figure 5(a)–5(d), the prepared samples were placed obliquely on the glass plate, and chalk powder and coffee powder were sprinkled on the sample surfaces, respectively. The dripping water droplets could easily take away the above powder and formed a clear contrast with the surroundings (see Figures 5(a) and 5(b)). At the same time, milk and coke were rolled directly on the sample surface without polluting the surface (see Figures 5(c) and 5(d)). Obviously, this superhydrophobic coating had a good self-cleaning effect.
3.5. Durability of the Superhydrophobic Surface. In this study, two evaluation methods of weather resistance and wear resistance were used to study the durability of the SSSM surface.

In the study of weather resistance, changes in the wettability of the SSSM surface were observed during 28 days of air exposure at room temperature. During the exposure period, the CA was observed every 7 days, and finally the data points were drawn according to the average values of CA and their error bars. The drawing results are shown in Figure 6. It can be seen that after continuous monitoring of the wettability of the prepared sample exposed to air, its CA to water has changed slightly, and the average CA could still reach up to 161° after being placed for 28 days, which shows that the SSSM surface has good weather resistance.

Sandpaper abrasion test was used to evaluate the mechanical durability of the SSSM surface. The schematic diagram of wear resistance test is shown in Figure 7. Under the load of 19.6 kPa (200 g, 1 cm²), pulled the 600 grit sandpaper pressed above the sample at the speed of 2.0 cm·s⁻¹ (see Figures 7(a) and 7(b)), and observed the CA of the superhydrophobic sample every certain distance. The data points were drawn according to the average values of CA and their error bars, and the drawing results are shown in Figure 7(c). It can be seen that the nonwetting characteristics of the sample surface
have gradually weakened due to mechanical wear. When the wear distance reaches 600 mm, CA still remains above 150°, which is much better than the wear test results reported in literature [18, 19]. This shows that the superhydrophobic sample has good mechanical durability.

3.6. Corrosion Resistance of the Superhydrophobic Surface. The corrosion resistance was evaluated by the polarization (Tafel) curve and EIS in 3.5 wt% NaCl solution. Tafel plots of the blank substrate and the prepared superhydrophobic sample are shown in Figure 8, which are used to derive the corrosion potential ($E_{\text{corr}}$), corrosion current density ($I_{\text{corr}}$), and polarization resistance ($R_p$), as shown in Table 1. The corrosion inhibition efficiency ($\eta$) [32] is calculated according to the following formula:

$$\eta (%) = \left( \frac{I_{\text{corr}}^0 - I_{\text{corr}}}{I_{\text{corr}}^0} \right) \times 100\% \quad (4)$$

where $I_{\text{corr}}^0$ and $I_{\text{corr}}$ are the corrosion current density of the blank substrate and superhydrophobic sample, respectively. Generally, higher the corrosion potential lower the corrosion current density, and greater the polarization resistance better the corrosion resistance [33, 34]. Compared with blank substrate, the corrosion current of the superhydrophobic sample decreased by two orders of magnitude, and the corrosion potential also shifted to the right, which directly leads to the significant increase of polarization resistance by two orders of magnitude, and its corrosion inhibition efficiency was up to 99.74%. The results indicated that the superhydrophobic surface effectively prevented the direct contact between the corrosive medium and the substrate surface and significantly improved the corrosion resistance of the substrate material.

In order to better evaluate the corrosion behavior, EIS is usually used as a supplement to potentiodynamic polarization. The EIS results and corresponding equivalent circuits are shown in Figure 9 to further explore the corrosion resistance of as-prepared samples. The fitting results of electrochemical impedance test are shown in Table 2. According to the EIS diagram and the fitted resistance values, it can be seen that the $R_{\text{ct}}$ (2.8 × 10$^7$ Ω) of the superhydrophobic sample is much greater than that (572,990 Ω) of the blank substrate, which means that the cerium stearate SSSM surface formed a strong barrier to inhibit the corrosive medium transfer among the superhydrophobic interface. The excellent anticorrosion performance of the prepared superhydrophobic sample is attributed to the micro/nanomastoid rough structure on the surface, which helps to intercept a large number of cavitation [35].

3.7. Oil/Water Separation. Superhydrophobic network material has the characteristics of blocking water and oil transportation, so it can be used to separate oil/water mixture. Here, gasoline, diesel, chloroform, and deionized water (dyed with methyl violet) with equal volume ratio were used as the separation objects, respectively, and self-made oil/water separation

![Figure 8: Tafel plots of different samples in 3.5 wt% NaCl solution: (a) blank substrate; (b) superhydrophobic sample.](image-url)
FIGURE 9: Electrochemical impedance spectra and equivalent circuits for blank substrate and superhydrophobic samples in 3.5 wt% NaCl solution: (a) blank substrate; (b) superhydrophobic sample; (c) equivalent circuits.

TABLE 2: The electrochemical parameters of blank substrate and superhydrophobic samples were fitted according to the electrochemical impedance spectrum of the equivalent circuit.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Solution resistance $R_s$ ($\Omega$)</th>
<th>Charge transfer resistance $R_{ct}$ ($\Omega$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blank substrate</td>
<td>3.147</td>
<td>572.990</td>
</tr>
<tr>
<td>Superhydrophobic samples</td>
<td>4.039</td>
<td>$2.8 \times 10^7$</td>
</tr>
</tbody>
</table>

FIGURE 10: Oil–water separation test process and results: (a–c) photos of oil/water separation experiment process; (d) separation effect of different oil/water mixtures.
device was used for separation test. The oil–water mixture was slowly poured from the upper part of the separation device. Due to the characteristics of the superhydrophobic network material, the oil in the mixture freely passes through the superhydrophobic filter and then flows into the collector below the device, while the water was trapped on the surface of the screen and finally poured into another collector. Separation efficiency ($\eta$, %) is calculated by the following formula:

$$\eta \ (\%) = \frac{m_1}{m_0} \times 100\%,$$

where $m_1$ and $m_0$ are the weight of separated oil and initial oil, respectively.

The separation experiment process is shown in Figure 10(a)–10(c). According to the above formula, the separation efficiencies of three different oil/water mixtures are calculated, respectively, and the results are shown in Figure 10(d). It can be seen that the water dyed with methyl violet can be completely separated from gasoline, diesel, and chloroform, and the separation efficiencies of different oil/water mixtures are all above 97%, which shows that the prepared cerium stearate stainless steel mesh has excellent oil/water separation performance.

4. Conclusion

A dense superhydrophobic coating was prepared on the surface of stainless steel mesh by one-step electrodeposition process with high efficiency, low cost, and environmental protection. Its self-cleaning, durability, corrosion resistance, and oil–water separation performance are excellent. It is worth noting that the corrosion current after electrodeposition is reduced by two orders of magnitude compared with that before electrodeposition, and the corrosion inhibition efficiency is 99.74%, indicating that the corrosion resistance of the sample is strong. In addition, the prepared superhydrophobic filter screen also shows good oil/water separation performance, and the separation efficiency of different oil/water mixtures is more than 97%. The method of preparing superhydrophobic filter screen in this research is green and efficient, which is of great value for large-scale industrial preparation and even engineering application of anticorrosion superhydrophobic surface.

Data Availability

This paper contains all the data and information recorded or analyzed in the whole research process.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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