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A stable hierarchical superhydrophobic coating on pipeline steel surface with self-cleaning, anticorrosion, and anti-scaling properties

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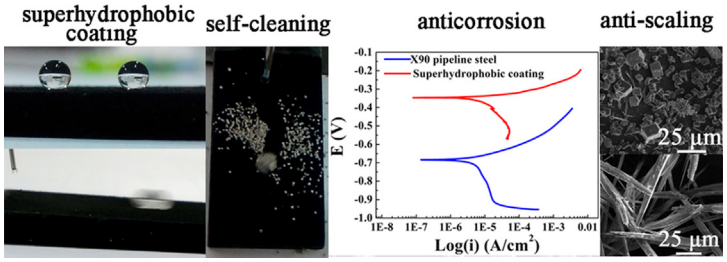
HIGHLIGHTS

- A superhydrophobic coating was fabricated on pipeline steel surface.
- This coating had the hierarchical structure that was self-assembly by nanoflakes.
- This coating had self-cleaning, anticorrosion and anti-scaling properties.
- This coating had long-term, mechanical and thermal stability.

GRAPHICAL ABSTRACT



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ABSTRACT

Superhydrophobic surface has attracted great attention because of its potential applications. In this work, a facile method for fabrication of a superhydrophobic coating on pipeline steel surface is reported. A hierarchical structured coating with nanoflakes was fabricated via electrodeposition and solution-immersion, and then the coating achieved superhydrophobic with water contact angle about 157° and sliding angle around 3° after fluorination modification. The surface morphology and wettability changed with different experimental parameters were also investigated. The prepared superhydrophobic coating exhibited efficient self-cleaning and anticorrosion properties. Furthermore, the anti-scaling property of this superhydrophobic coating was confirmed since the $CaCO_3$ crystals on the superhydrophobic coating were mainly needlelike compared to the rhombohedral $CaCO_3$ crystals on the surface of steel substrate. This superhydrophobic coating maintained good long-term stability in air, and mechanical and thermal stability under certain environment. This superhydrophobic coating provided potential multifunctional applications, such as self-cleaning, corrosion resistance and anti-scaling properties, of deposition metal or alloy coating.

1. Introduction

Wettability is a popular field of research in recent years due to various potential applications of the superhydrophobic surface, which is directly related to our daily life [1]. Inspired by nature, especially the "lotus-effect", it has been well accepted that the combined effect of the surface morphology and the chemical composition contributes to the superhydrophobicity [2]. Fabricating superhydrophobic surface can be mainly classified into two categories, including modifying rough surfaces with low-surface-energy material and preparing rough structures on low-surface-energy material [3]. Meanwhile, appropriate surface morphology plays a crucial role in achieving superhydrophobic property [4]. To date, many methods have been employed to fabricate superhydrophobic surface, such as plasma etching [5], template [6], sol-gel [7], anodization [8], solution-immersion

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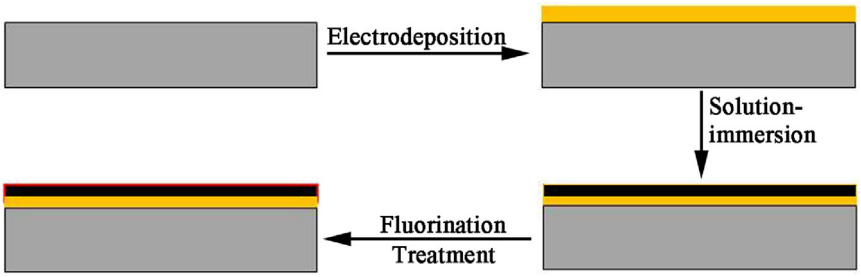

Fig. 1. Scheme of the preparation of the superhydrophobic coating on pipeline steel surface.

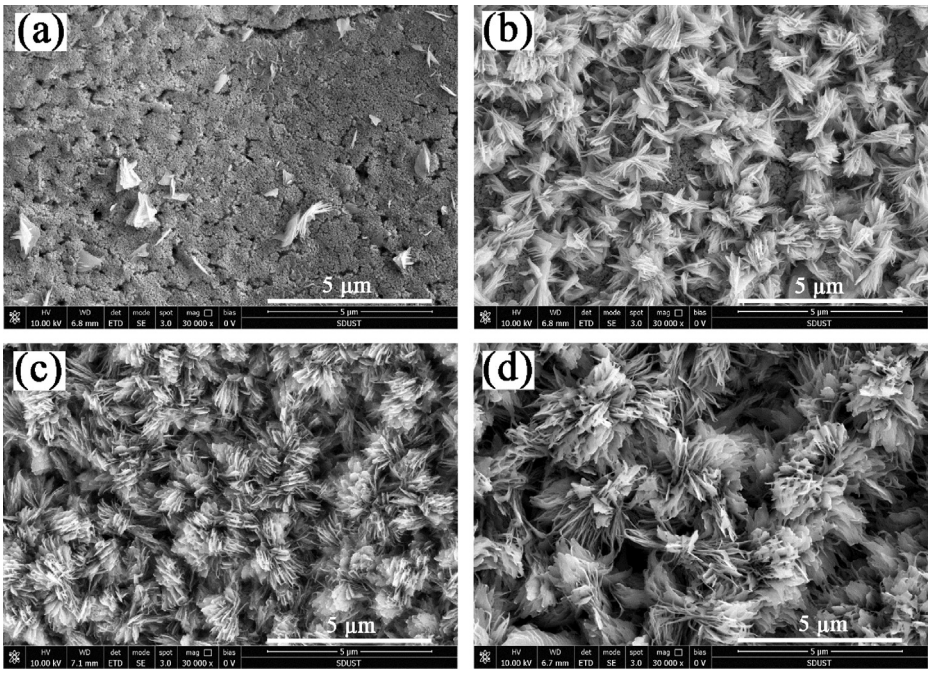

Fig. 2. Surface morphology of the coating changed with the solution-immersion times. (a) 5 min; (b) 15 min; (c) 30 min; (d) 40 min.

[9], and electrodeposition [10]. Among these methods, electrodeposition and solution-immersion are facile, inexpensive, and appropriate for large-area surface [11,12].

In the field of industrial production, pipeline steel is an essential metal. However, the adhesion of the aqueous mixture to the pipe wall could result in the phenomenon of scaling, which resulted in equipment damage and the waste of energy. Therefore, fabricating a superhydrophobic coating on pipeline steel surface is necessary.

Recent years, superhydrophobic surface with self-cleaning property [13] has been fabricated to keep the surface cleaning. It also has been considered as one of the effective ways to improve the corrosion resistance of the substrate material because the water in air is difficult to contact the substrate surface [14,15]. In addition, the electrodeposition metal or alloy coating is mainly used to protect the substrate material [16]. Cu-Zn alloy has got rapid development and application due to the anti-scaling property [17]. Hence, preparing a superhydrophobic Cu-Zn coating with self-cleaning, anticorrosion, and anti-scaling properties on pipeline steel substrate is feasible.

In this paper, we describe the fabrication of superhydrophobic coating with hierarchical structures on pipeline steel surface. It was achieved by a simple method involving electrodeposition of Cu-Zn coating, solution-immersion for in situ growth of CuO hierarchical structures, and fluorination modification with low-surface-energy material. Meanwhile, the surface morphology was controllable by varying the experimental parameters including solution-immersion time, current density in the electrodeposition process, fluorination modification time, the mole ratio of Zn^{2+} to Cu^{2+} in the electrodeposition process, and the influence of these experimental parameters on water contact angle was also investigated. It showed that the prepared superhydrophobic coating showed excellent self-cleaning, anticorrosion, anti-scaling properties, and good mechanical and thermal stability under certain environment.

2. Experimental

2.1. Materials and reagents

X90 pipeline steel (composition: ≤0.1 wt.% of C, ≤0.55 wt.% of Si, ≤2.0 wt.% of Mn, ≤0.4 wt.% of Cr, ≤0.5 wt.% of Mo, ≤0.5 wt.% of Ni, ≤0.5 wt.% of Cu, ≤0.15 wt.% of V + Nb + Ti, and the balance was Fe) was used as the substrate and cut into rectangle sample (20 × 50 × 3 mm). The rectangle brass sample (Cu ~ 60.5–63.5 wt.%, 20 × 50 × 5 mm) was set as counter electrode in the electrodeposition process. Moreover, the pentadecafluorooctanoic acid (90%, Aladdin Industrial Inc.) was used for fluorination modification. Other chemical reagents were all analytical grade and without further purification.