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收件人: Weihong Guo <guoweihong@ecust.edu.cn>

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MXene-Based Organic Coatings: Emerging Frontier of Marine Anti-Corrosion Strategies

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Kind regards,
Jordan Emery
Scientific Handling Editor

Surfaces and Interfaces

Editor and Reviewer comments:

Reviewer #3: The authors have addressed all of my concerns, and I recommend that the paper be accepted for publication.

More information and support



MXene-based organic coating: An emerging anti-corrosion strategy for marine engineering

Jiaqi Lin, Jinheng Wang, Yican Wang, Weihong Guo^{*}

Key Laboratory for Ultrafine Materials of Ministry of Education, Shanghai Key Laboratory of Advanced Polymeric Materials, School of Materials Science and Engineering, East China University of Science and Technology, Shanghai, 200237, PR China

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ABSTRACT

Harsh marine environments subject offshore engineering equipment to severe corrosion issues, resulting in substantial economic losses. Traditional organic coatings struggle to meet long-term protection requirements. MXene is a novel two-dimensional material composed of transition metal carbides, nitrides, or carbonitrides, characterized by a high specific surface area, excellent electrical conductivity, good mechanical properties, and a rich variety of surface functional groups. These characteristics provide a new avenue for developing high-performance marine anti-corrosion coatings. This review explores the long-term protective role of MXene-based organic coatings in marine engineering applications. The article focuses on the preparation techniques for fluorinated and non-fluorinated MXene via etching, as well as the mechanisms of action and performance advantages of these coatings in key marine engineering scenarios. It also summarizes the core challenges facing the industrial-scale production of MXene-based organic coatings. The results indicate that establishing a multi-factor, coupled long-term aging evaluation system, developing green and low-cost synthetic routes, and leveraging biomimicry and machine learning technologies are key prerequisites for advancing the engineering applications of MXene-based coatings. Through this review, we aim to provide technical forecasts on the development trends of MXene-based organic coatings in marine engineering, offering scientific guidance.

1. Introduction

Corrosion refers to the process by which materials deteriorate and fail due to external factors. The marine environment, characterized by high salinity, humidity, pressure, and microbial activity, makes marine corrosion an invisible killer that erodes the value of marine equipment and threatens operational safety [1]. Marine corrosion is a complex process involving the synergistic interaction of multiple factors, including chemical, mechanical, and biological elements [2]. It primarily encompasses three major categories: electrochemical corrosion [3], mechanical corrosion [4], and biofouling [5]. Electrochemical corrosion is the primary failure mechanism in marine environments and causes significant damage to steel. As shown in Fig. 1a, when a metal is immersed in seawater, microscopic anode-cathode pairs form on its surface. At the anode, iron atoms undergo oxidation and dissolution, releasing Fe^{2+} ions and free electrons; the electrons are transported through the metal matrix to the cathode, where they participate in an oxygen reduction reaction with dissolved O_2 and H_2O molecules [6]. Dissolved Fe^{2+} further reacts with hydroxide ions and oxygen, ultimately

forming hydrated iron oxide ($\text{Fe}_2\text{O}_3 \cdot x\text{H}_2\text{O}$) deposits on the surface, which manifest as a loose rust layer. High concentrations of Cl^- in seawater can easily penetrate the passivation film and rust layer, forming closed corrosion cells and thereby causing severe localized damage such as pitting corrosion and crevice corrosion [7]. Mechanical corrosion primarily results from the interaction between high-velocity seawater and the surface of the equipment (Fig. 1b). When seawater flows rapidly along the surface of a structure, the local pressure drops below the saturated vapor pressure, resulting in the formation of a large number of microbubbles [8]. The instantaneous collapse of these bubbles generates high-velocity liquid microjets and shock waves that repeatedly impact the material surface, leading to deformation, cracking, and spalling [9]. At the same time, sediment and sand particles carried by the seawater continuously scour the surface, causing abrasion. Mechanical corrosion continuously erodes the surface passivation film and rust layer, exposing fresh metal substrate to the corrosive medium and creating a vicious cycle. Fig. 1c illustrates the failure process of biofouling, which follows a phased pattern [5]. Within seconds, organic substances in seawater (such as proteins and polysaccharides)

^{*} Corresponding author.

E-mail address: guoweihong@ecust.edu.cn (W. Guo).

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