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Recent progress in marine foul-release polymeric nanocomposite coatings

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ABSTRACT

Progress in materials science is associated with the development of nanomaterials in terms of energy-saving, environmentally friendly, and low-cost methods. Since the use of tributyltin compounds in antifouling coatings was banned in 2003, the search for ecofriendly alternatives has been promoted. Foul-release (FR) nanocoatings have been extensively investigated because of their non-stick, ecological, and economic advantages. Such nanocomposite systems are dynamic non-stick surfaces that deter any fouling attachment through physical anti-adhesion terminology. Instead of biocidal solutions, several functional FR nanocomposite coatings have been developed to counter biofouling and biocorrosion with ecological and ecofriendly effects. Selected inorganic nanofillers have been incorporated because of their enhanced interaction at the filler-polymer interface for nanocomposites. Metallic nanoparticles and their oxides have also been widely explored because of their unique morphological characteristics and size-dependent, self-cleaning properties. In modeling a novel series of FR nanocoatings, two modes of prevention are combined: chemical inertness and physical microfouling repulsion for maritime navigation applications. Long-term durability and self-cleaning performance are among the advantages of developing effective, stable, and ecofriendly modeling alternatives. This review provides a holistic overview of nano-FR research achievements and describes recent advancements in non-stick marine nanocoatings for ship hulls. This review highlights the key issues of nanocomposite structures and their features in improving the biological activity and surface self-cleaning performance of ship hulls. This review may also open new horizons toward futuristic developments in FR nanocomposites for maritime navigations.

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Contents

1. Introduction

Nanocomposites constitute a class of materials that exhibit advanced properties at low nanoparticle (NP) concentrations in comparison with conventional filler contents in coatings [1]. Selected NPs in coating formulations can enhance various properties, including antifouling (AF), mechanical and optical characteristics, permeability, and wettability [2]. Biofouling is a complex issue that causes serious economic casualties and unfavorable ecological impacts on maritime ecosystems. Marine fouling costs about US$ 150 billion every year in transportation [3]. As such, fouling control through ecofriendly and economic AF paint solutions is of great importance because the annual consumption reaches 80,000 tons [3]. Fouling layers increase friction drag and hydrodynamic weight and thus decrease shipping speed and maneuverability [4]. For this reason, high fuel consumption is necessary to maintain the required speed and navigation setting; as a consequence, financial costs are increased and harmful compounds are emitted into the environment. This action also requires personnel resources, entails machinery effort, consumes time, and generates wastes that pose harmful effects on health and environment [5]. Therefore, these problems have prompted researchers to develop coatings that prevent ship hull biofouling caused by commercial biocidal AF coatings [6,7]. With environmental toxicity issues related to the use of toxic AF coatings, modern research has focused on environmentally friendly alternatives, such as foul-release (FR) technology [8]. This review discusses the advanced ecofriendly technologies for AF coatings and focuses on the modern streams achieved in FR coatings for maritime applications.

Non-stick FR coatings, which include fluoropolymers and silicon compounds, offer an ecofriendly alternative that can be used for prolonged periods [9]. FR coating technology acts by preventing fouling settlements and providing extremely smooth self-cleaning surfaces [10]. Organo-silicone polymers, particularly polydimethylsiloxane (PDMS), are more efficient than fluoropolymers and thus are considered the most promising FR coating systems [4–6,8,11,12]. As a non-stick FR layer, PDMS with a Si-O backbone and a CH_3 side chain possesses excellent properties, such as high level of smoothness, hydrophobicity, and mobile molecular structure; however, surface tension and porosity are low [12,13]. In addition, PDMS exhibits excellent heat resistance, anti-oxidation and anti-ozone properties, and durability against ultraviolet (UV) irradiation [14]. Although PDMS coatings show inherently superior FR attributes, its combination with inorganic nano-additives has become necessary. An enhanced matrix-nanofiller interaction provides a cost-effective method and improves some characteristics of nanomaterials. Several characteristics can influence the nanocomposite FR features, such as filler type, size, shape, dispersion percentage, and compatibility with matrix segments [15–17]. Reduced surface tension and increased contact angle (CA) are also major factors that diminish fouling settlements and bacterial cohesion [18]. Coating techniques with noble metal NPs and metal oxides are possibly effective methods to prevent fouling because of their stability against microbial attacks [18–20]. Among these materials, Cu_2O, ZnO, TiO_2, and Ag NPs are easily prepared from low-cost, highly secured natural sources and thus are applicable to feasibility and advanced studies [20]. A series of uniform in situ, ex situ, and sol-gel FR polymer nanocomposites with varying degrees of hydrophobicity and hydrophilicity has been investigated in micro- and macro-biofouling assays and in field tests [5,21]. In addition to surface chemistry, surface free energy and surface topologies affect adhesion mechanism, biofouling, and self-cleaning performance [22]. Considering the high costs associated with fouling