Organic Coatings for Marine Applications

Subjects: Materials Science, Coatings & Films | Engineering, Ocean
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Organic coatings for marine applications must have great corrosion protection and antifouling performance. This review presents an overview of recent investigations into coating microstructure, corrosion protection performance, antifouling behavior, and evaluation methods, particularly the substrate effect and environmental influence on coating protectiveness, aiming to improve operational practice in the coating industry.

Keywords: corrosion ; biofouling ; coating ; surface ; electrochemical technique

1. Introduction

As an effective barrier to corrosion media, organic coating is one of the most popular corrosion protection approaches [1,2,3,4,5,6,7,8]. Since organic coating is usually more protective and relatively low cost, and can be more easily applied to large structures than other coating techniques, it is often the first option, particularly for heavy-duty anti-corrosion [9,10] in marine environments [11,12], where many factors, such as solar radiation, high salinity, hot–cold alternation, wet–dry cycling and micro and macro living species, can significantly exacerbate the environment corrosivity and dramatically accelerate the coating degradation [13,14]. Therefore, coatings used in such an aggressive environment must be extremely robust. For example, an organic coating for marine applications is usually a few hundred micrometers thick (typically around 250 μm), much thicker than a conversional coating [15]. Apart from the essential corrosion protection performance, the coatings for marine applications are usually required to be antifouling [16] or super-hydrophobic [17,18,19] to avoid the attachment of some creatures from sea.

Thus far, tremendous research efforts have been made to improve the corrosion resistance and antifouling performance for organic coatings in marine environments, including the design of new polymer molecules or chains [20,21,22], change in coating constituents or additives [23,24,25], modification of coating micro-structures [26,27], decoration of coating surfaces [28,29], and adjustment of coating layers or composite interfaces [30,31,32], as well as the development of new techniques for coating characterization, evaluation and prediction [33,34,35,36]. Apart from these well-known achievements in the coating field, there are also some fragmentary but important progresses that may fundamentally influence the future research of marine organic coatings. This overview basically summarizes some of these key results obtained mainly in the past 15 years, aiming to illustrate the implications of the new findings and developments in possible marine applications. Since there have been many conferences [37,38,39], articles [40,41,42] and books [43,44,45] on the traditional coating systems for marine engineering, this review tries to look at some specific marine applications of organic coatings differently, aiming to establish a relationship between coating microstructure and marine application performance. Therefore, only a few fundamental issues that have not been reviewed before are addressed for some non-traditional marine coatings, rather than the practical behavior of traditional marine paintings or coating systems. From this perspective, it is expected that new and deepened understandings may be obtained for the behavior of organic coatings in marine environments.

2. Organic Coatings for Marine Applications

Generally speaking, a coating plays two basic roles in protecting its substrate [46,47]: (1) isolating the substrate from the environment and (2) changing the substrate surface to a different one with desired properties. The barrier effect in the first role is responsible for the corrosion resistance of organic coatings, while antifouling coatings are typically dependent on the surface functionality in the second role. These two roles can be combined in practice. For example, an organic coating with Zn powder pigment can serve as a barrier to water permeation to isolate a steel substrate and also act as a sacrificial anode to cathodically inhibit the corrosion of the substrate. When some antifouling additives are mixed in an organic coating, the coating will become anticorrosion and antifouling in the same time.

A marine coating system basically includes at least a pretreated substrate surface, a primer layer and a topcoat [48]. The substrate treatment is to remove contaminants and enhance the coating adhesion. The primer is the barrier against water permeation and the carrier of various species, such as anodic passivators, cathodic protectors, and/or inhibitors with particular functions. Traditionally, Zn epoxy-based and silica-based primers with Zn powder as the pigment have been widely used in marine environments. The topcoat, which is typically an alkyd, vinyl or epoxy film, is normally applied to protect the primer from UV irradiation or accident scratching or for a decoration purpose. To prevent the attachment or growth of a biofilm or some fouling, an antifouling coating may also be coated on the top. It should be noted that to date marine coatings are not simply limited on ships and platforms. Unprecedented and extreme applications, such as polar region navigation, deep sea exploration, navy military, etc., have brought many new materials, system designs, and function requirements into the coating industry. Therefore, the marine coating family is currently growing rapidly. For example, many advanced devices are now being more and more frequently used in marine atmospheric conditions [49,50]. They are usually powder coated or E coated very differently from a traditional marine coating. Therefore, the performance of these non-traditional marine coatings should also be included in the scope of contemporary marine coating research. Additionally, with more new metallic materials being increasingly used in marine environments [51,52], such as Ti alloys for submarines, Al alloys and Mg alloys for helicopters and fighters on warships and aircraft carriers, etc., the substrate in a coating system for marine applications is not limited to the steel anymore. Thus, the pretreatments of these new alloys, the organic coating materials and the corresponding coating processes, as well as the coating performance, will be quite different. These are also important topics.

The performance evaluation or service life prediction of a coating system is always one of the biggest challenges in the coating field [53,54,55], which can be seriously affected by the corrosion of the substrate surface, the permeability of the primer, and the disfunction of the topcoat. More specifically, the defects formed during coating or introduced in service can facilitate the ingress of deteriorating and aggressive species into the primer coating, trigger the corrosion of the substrate and delaminate, and eventually rupture the coating, while the consumption of the antifouling species in the coating or the wearing of the special surface molecular microstructure of the coating can lead to the decay of antifouling performance. An organic coating can degrade or be damaged in some environmental conditions through various mechanisms. The deteriorating rate is critically determined by the microdefects for an anticorrosion coating, or the surface polymer molecular structure for an antifouling film. Therefore, in this review, the defects and polymer modification are focused.