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Surface modification of 5083 aluminum-magnesium induced by marine microorganisms

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ABSTRACT

The influence of microorganisms from a salt marsh in the surface modification of 5083 aluminum alloy (Al-Mg) in seawater was evaluated. An immersion test performed for 50 days in biotic and abiotic conditions, with electrochemical monitoring and surface/cross-section characterization by SEM/EDX and TEM after exposure, showed that microorganisms induced the formation of a homogenous layer on the Al-Mg surface. This layer, which proved to be composed of a double-structure: a dense, amorphous inner layer and a more porous outer layer, was demonstrated to influence the corrosion resistance of the Al-Mg alloy in seawater.

1. Introduction

Aluminum alloys are widely used for marine craft because of their high corrosion resistance, lightness, easy workability and recyclability [1]. The 5000 series Al-Mg alloys are particularly recommended for this purpose. However, the use of aluminum alloy does not make processing and maintenance unnecessary in a marine environment [2]. Under certain circumstances, even the most corrosion-resistant aluminum alloys may develop pitting corrosion as well as galvanic corrosion in seawater. Although a thin protective oxide film forms spontaneously on the surface of the aluminum alloy, chlorides are able to break this layer and thus allow corrosion to spread [3–5].

Furthermore, materials exposed to the natural environment are covered by microorganisms forming a biofilm on their surface. The biofilm is made up of a community of microorganisms embedded in extracellular polymeric substances (EPS), attached to a solid surface [6,7]. In the case of metallic materials susceptible to corrosion, the presence of biofilm can accelerate their degradation. This phenomenon is known as MIC, for Microbiologically Influenced Corrosion [8–11], and is particularly promoted in seawater, which is an aggressive medium due to the high concentration of chloride and the presence of a broad indigenous microbial flora. Numerous microorganisms are known to catalyze corrosion reactions include metal-reducing bacteria, metal-depositing bacteria, acid-producing bacteria, and fungi [8,9]. The most common are mentioned below. Under aerobic conditions, some microorganisms, like *Pseudomonas aeruginosa,* which produces the pyocyanin mediator, are able to catalyze the oxygen reduction [12,13] via direct (DET) or mediated electron transfer (MET) [14]. For oxygen reduction catalysis, it has been shown that a multispecies biofilm is more efficient than a single species [12,15]. Moreover, the diversity of the biofilms that develop in the marine environment depends on the nature of the immersed material. For example, the dominant genera have been shown to differ when samples are made of copper, steel or aluminum [16], which will certainly lead to various MIC mechanisms.

Most MIC studies in an anaerobic environment have focused on Sulfate-Reducing Bacteria (SRB), which lead to the formation of FeS that catalyzes water reduction on steel [9]. In the case of Al alloys, MIC caused by SRB in seawater has been studied on 5052 aluminum alloy. Localized corrosion was observed with and without SRB because of the presence of chloride ions in seawater, but pitting corrosion was greatly enhanced by metabolites (acid or other) produced by the microorganisms [17]. MIC on aluminum alloys has also been reported in other environments, such as aircraft tanks, where the 2024 aluminum alloy was attacked by a fungus, *Hormoconis resinae*, capable of growing on a hydrocarbon-rich substrate [18]. Several studies have pointed out the relevant fact that microorganisms involved in MIC act synergistically in multi-species biofilm, causing more damage than when only a single species is present [9,19,20].

Some microorganisms are also able to inhibit corrosion. This phenomenon is known as MICI, for Microbiologically Influenced Corrosion Inhibition [21–23]. Mechanisms inducing MICI are various, for example, in the formation of a protective layer, *Pseudomonas putida* RSS can produce a stable Fe-EPS complex inducing the formation of a vivianite layer protecting mild steel from corrosion [24]; *Geobacter sulfurreducens* is known to reduce Fe(III) to Fe(II), also leading to the formation of a vivianite layer on steel in a medium containing phosphate compounds

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