Evaluation of Corrosive Behavior of Zinc Composite Coating on Mild Steel for Marine Applications

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Abstract-
Mild Steel has various forms in which it can be used. It possesses mechanical properties and hence it has found various implementations in many sectors / industries. However, the downside of using mild steel is that it has a high susceptibility to corrosion. There are numerous techniques for protection of mild steel but Zinc electrodeposition techniques is the most preferred method for producing a suitable film coating for the appropriate protection of mild steel. The effect of deposition potential, current, bath composition (including temperature), deposition time and concentration on the structure and crystallinity of the films deposited was systematically studied from various literatures. Introducing zinc into the coating process significantly alters and improves the mechanical and chemical characteristics of mild steel.

Key words: Corrosion, Electrodeposition, Mild steel, Thin film application, Composite materials.

1. Introduction
Corrosion is the natural disintegration of a material as a result of its reaction with agents in the environment of its application [1]. Proper selection of alloys can be employed as a technique for curbing severe corrosion. In order to select an ideal metallic material, intended application such material and the environment should be considered. In summary, material selection is all about minimizing costs and also meeting with the required performance goals. Therefore, the properties and the costs required of the material must be put into consideration. The emphasis on knowing both the alloy as well as the service condition is very important [2].

Of the numerous metals out there, mild steel is mostly used in applications. Mild steel is a carbon steel, which has a carbon amount of about 0.16% - 0.19%. In addition, when heated and cooled with cold water, it does not harden; thereby making further machining easy. This makes it much stronger and harder than iron [3]. However, although the steel alloy has increased carbon content which increases its hardness, it causes a reduction in its ductility. The reason why mild steel is more important than other steels is because it is widely available and not as costly. When compared to other metals, it is quite easy to mould and weld [3]. However, although mild steel is commonly used, it is easily susceptible to corrosion [4-7]. It easily rusts in various media, including moist atmospheres [8]. They are usually selected for their properties such as cost, strength and ease of fabrication, not for their resistance to corrosion. Hence, there is need for proffering solutions to curb or drastically reduce corrosion.

Due to its relatively cheap price and economic usage, Zinc has been generally accepted and used as an electrodeposited metal for protecting various steel from corrosion [9]. However, Zinc
possesses limited resistance to corrosion. In recent years, various resources have been put into trying to improve the corrosion stability of pure zinc coatings by making it alloys with more noble metals (e.g. iron, nickel, cadmium and cobalt) [10]. In addition, numerous organic compounds which have been extensively studied in order to obtain durable, uniform, and compact coatings for corrosion prevention of steels, have been suggested as additives for zinc electroplating. These organic composites added to the electroplating solution were known to have effects on the corrosion characteristics and quality of the deposits. The addition of these organic compounds to the electrodeposition process was reported to affect the mechanical properties of electrodeposits [11].

2. Review on Corrosion Resistant Coatings

A coating is judged by its ability to provide resistance to corrosion in a specific environment. Therefore, varieties of protective coatings for corrosion have been developed due to the many variations observed by the metallic material in the corrosive environment. Because of the various challenges faced by metallic materials in corrosive environments, coatings have become the way out to prevent failure of the metal. In other words, the importance of coatings is to improve the life span, properties and other specialties. Coatings have been proven to be the most appropriate solution for corrosion protection against marine fouling [12]. Protective coatings can be divided into inorganic coatings, organic coatings and metallic coatings [13].

2.1 Inorganic coatings

Inorganic coating is a type of surface protective coating. It is produced with or without the use of electricity by chemical action. This type of coating provides a better resistance to corrosion on the metal’s surface by replacing the immediate surface layer into a metallic oxide film or a compound than the previous layer of natural oxide film making it an effective foundation for additional protection such as paints [14]. Mostly, inorganic coatings serve as pre-coating before proper deposition is carried out.

2.2 Organic Coatings

Organic coatings and paints of high efficiency were established for protection of materials and equipments from deterioration happening to industrial equipments in the environment. Polyvinyl chloride coatings, epoxy coatings are examples or organic coatings that are used widely in manufacturing industries to prevent the metal from attacks such as water, oxygen, cathodic reactions and so on beneath the coating. During advancement of these organic coatings, the petroleum industry was the case study. This is because epoxy coatings, polyurethane coatings contained refined petroleum products. It has been reported that organic coatings offer good corrosion resistance to ionic conductivity thereby offering good barrier properties [15].

2.3 Metallic Coatings

Metallic coatings are involved with depositing metal coatings through the process of electrodeposition, vapour deposition, electroless plating, and hot dipping. Materials (metallic) mostly used for these coatings include zinc, aluminium, chromium and more. Metallic coatings change the work-piece surface layer properties that of the metal being applied. The coatings give a corrosion resistant layer that is also durable. Metallic coatings are known for their texture
properties [16]. A research showed that there was an improvement in composite properties of metals having low porosity and other good properties [17].

2.4 Electrodeposition
Electrodeposition is a coating process which involves the addition of metal alloy, composite or oxide film of another material from electrolyte to get desired surface properties on the metal. Metal finishing is important in the modification of surface characteristics. Deposition practices have been employed over the years to achieve improved functionalities [18]. It is a good plating practice producing good coatings of desired thickness and fine aggregate size. In most industries, electroplating has been employed to improve the surface of a metal, the properties (both mechanical and electrochemical), characteristics which they possess and resist corrosion as much as possible [19].

Properties of a coating are designed to a desired prerequisite or intended characteristics to which you want to achieve. Therefore, metals are reliant on bath formulation and the conditions for depositions for the required properties. Conditions for electroplating include the bath formulation and concentration, current, voltage, temperature and the anode [20]. For effective deposition, factors like current density, careful anode selection and other conditions must be considered to achieve excellent properties.

3. A Review of Electro-Deposition of Zinc on Mild Steel
The characteristics of a metal’s surface can be physically altered through various methods. As discussed above, an example is through electrodeposition. Steels are majorly protected from corrosion through the electrodeposition of zinc coatings [21]. Incorporating substances such as Micropogonias Undulatus scales into the electroplating solution can be used produce micro patterns. This is because micro patterns can imitate marine creatures (sharks and fish) skin’s surface topography [22]. Since electrolytic deposition process has proven to be successful in boosting the physical properties of diverse materials and protecting them from corrosion [23], it can be assumed that the inclusion of Micropogonias Undulatus scales will further enhance and improve the corrosion resistance of the mild steel material. A number of researchers have leveraged the benefits of electrodeposited zinc coating for corrosion resistance.

A group of researchers investigated the behaviour of mild steel samples plated with zinc with and without inhibitor, in HCl acid solution. This study used Zinc Oxide as inhibitor retardant against acid variation using electrochemical polarization and weight loss methods. Investigational findings showed that zinc-plated mild steel layers that lack inhibitor, which got corroded, has elevated content of corrosivity that relates to the presence of cracks as a result to the mild steel getting dissolved in the acidic medium. Nevertheless, electro-deposition of zinc with Zinc Oxide in the test medium as an inhibitor showed a solid film layer to be formed because of the complex ions that are insoluble. By doing this, the stability of mild steel in less aggressive acidic medium is improved, therefore alleviating the occurrence of any severe corrosion attack. It was observed that the coatings made of Zinc possessed some products of corrosion not soluble that served as a barrier to corrosion; however, deformation may emerge within the surface boundary if the zinc-plated steel is subjected to an environment of aggressive corrosion having acidic or oxides films [24].
Another research team studied the effect that glycerol had in a bath made of Zn–Ni, the coating was done of carbon steel, in order to improve its resistance to corrosion, in many applications, including marine application. The galvanostatic and Potentiodynamic deposition was used to analyze the efficiency of deposition. Also, electrochemical tests and mass loss measurements was used to estimate the corrosion resistance. SEM, XRD and X-ray fluorescence were used to characterize the deposits. The result from the investigation indicated that the corrosion resistance and deposition efficiency increased substantially when using glycerol concentrations of up to 0.07mol/L. For glycerol concentrations ranging from 0.14 to 0.34mol/L, reduction in the efficiency of deposition was observed, and no clear increment in the Zn–Ni deposit’s corrosion resistance was reported with these concentrations. Analysis done to understand glycerol impact in the deposition bath indicated that this effect on corrosion resistance and deposition efficiency is linked to the morphology of the deposit. That is, adding glycerol to the solution in the deposition bath led to grain refinement in which additional compact deposits were formed [25].

According to another report, an improved surface finished and homogenous layer of well deposited zinc on mild steel is a function of varying distance between the anode to cathode, depth of immersion and applied voltage. The authors evaluated the plating thickness by varying the plating parameter using a simple hull set apparatus. Deposition was made on mild steel from zinc bath at varying voltage between 0.5 and 1.0 V. It was observed that the sample plated at 0.8 46V for 15 minutes gave the best plating deposition and a crack free appearance from the surface morphological study using SEM [26].

In another study where multi-layered composite coatings were used on substrates made of mild steel, all multilayered coatings used led to an increment in the substrate’s corrosion resistance. Composite coating containing multiple layers (electrodeposited Zn–Fe alloy layer, zinc phosphate conversion layer and up to three organic layers) was deposited on a mild steel substrate. A study was done on the multilayered coating and mild steel substrate adhesion with each other using scratch testing method. In addition, metallurgical microscopy was used to examine the different multilayered coatings’ worn surfaces. The same multilayered coatings were examined with FTIR spectroscopy and X-ray diffraction techniques. The experiment showed that multilayered coatings seemed to be without cracks or flaws, uniform in thickness and continuous. The cohesion and adhesion of the multilayered coating with organic layers was higher when compared to the to the steel substrate. The corrosion resistance of the mild steel substrate was enhanced because of all multilayered coatings [27].

Another group of researchers attempted to deliver improved corrosion protection via electro-deposition (by pulse current) of Zn-Ni alloys on steel. Electric variables such as pulse cycle and average current density, sizes of the coating’s grains, and the temperature and chemical compositions of baths were studied. Furthermore, SEM (scanning electron microscope) combined with EDS (energy dispersive X-ray spectroscopy) and scanning probe AFM (atomic force microscope) were used to ascertain the chemical compositions and the coating’s grain size. The key component that influenced nickel % in the deposits was the plating bath temperature. Yet, there was only minor effect of the pulse cycle and plating current densities on the Nickel’s compositions of deposits. Moreover, the rust layers were confirmed to constitute Zn(OH)2 and ZnCl2 that validated the corrosion products from the corrosion mechanisms [28].
4. Conclusion
The world continues to encounter critical challenges in materials degradation and failures of component during service. Life threatening environments in which materials developed are expected to function as necessitated by recent technological development is of great task to engineers. The conflicting choice of a suitable material intended for a specific use and environmental hazards’ control lies with Materials and corrosion experts. Therefore, electrodeposited zinc coating technique has been employed to proffer solutions to surface degradation of mild steel in the marine environment.

The improved hardness, corrosion and wear resistances of mild steel after electro-deposition rest on the weight gain of deposited particles and the coating structure. The applied voltage, bath composition and concentration affects the morphology of deposited Zn (uniformity, grain size, porosity on the coating and stresses built up). This becomes the foundation for surface adhesion and corrosion property enhancement.

5. Recommendation
Ultimately, more work needs to be done using nano-composite coatings, which appears to be a more sustainable solution to corrosion prevention. This will be highly effective especially if the composite constitutes natural products such as Micropogonias Undulatus. The is basically because they have large definite surface area that is usually inversely proportional to the nanoparticle’s size [29-30], making them excellent constituents of Zinc electrodeposited composite coating for mild steel when needed for marine applications.

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