A Review on Some Effects of the Electrolytic Deposited Zinc Oxide Multilayered Composite Coatings on Mild Steel

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Abstract
Corrosion is a major problem in engineering because of its adverse effects involving the deterioration of materials as well as the destruction of such materials. Corrosion of mild steel causes excessive damage in terms of material loss and reduced efficiency. This imposes attention from researchers worldwide for novel literature review. This study presents a review on the effects that zinc oxide multilayered composite coatings have on the mechanical properties of mild steels. These mechanical properties include hardness, corrosion resistance, wear resistance, impact strength, tensile strength, and flexural strength. It was reported by various researchers that coating with multilayered composite of zinc oxide gave a better result as compared to coating with Zinc alone. From the literature studied, it was noticed that more work is still required to identify and use more natural products as constituents of these multilayered composite.

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

1. Introduction
Corrosion has proven to be one of the unfavorable conditions experienced by metal structures in aggressive environments mostly marine environment. Aside this, corrosion diminishes the execution and strength of parts or foundations with an exceptionally high economic cost, evaluated to 3% of the yearly total national output (GDP) [1-3]. In meeting product performance goals in corrosive environments, material selection is an important tool in minimizing or reducing cost. Specifications required for metal/alloy need careful consideration. The emphasis on knowing both the alloy as well as the service condition is very important [4-9].

Mild steel has the largest share of the global steel applications, as it is being used in about 85% of these applications. The major reasons for this is that it can be easily heat-treated to achieve desired properties, and it can be machined and fabricated easily [10]. A steel alloy with a high carbon content possesses much more hardness and strength than iron. Many metals experience a type of corrosion called pitting corrosion (creating holes and deep pits in the metal) which destroys the life of the metal in no time. If pitting corrosion is left on a metal structure for a long time, serious damages to lives and properties can occur [11-12]. Pitting corrosion is also a disease of metals and can be seen in the figure 1.
Through profound methods of corrosion control, the economic limitations have been reduced thereby keeping less corrosion attacks [14]. Investigations confirm that through the use of corrosion resistant material, protective systems and mechanisms; corrosion control is achievable.

![Figure 1: Effect of pitting corrosion on a metal structure [13]](image1)

Natural products such as shell of groundnut (*Arachis Hypogea*), which is also known as groundnut husks is a natural fiber can be used as reinforcements in composites. Groundnut shell poses as a waste material acquired after removing the groundnut seed from the pod. They are rich in aluminum oxide, calcium oxide, magnesium oxide, potassium oxide, and silicates, which have proven to be resistant to corrosion when used as composite coatings with other compounds such as Zinc oxide [15-17].

This review aims at studying the effects of the Zinc Oxide Multilayered Composite Coatings on Mild Steel. The scope of this work is limited to electrolytic deposition method of coating, used to protect metals from corrosion.

2. **Review on Electrolytic Deposited Zinc-based Coatings**

Metal finishing is important in the modification of surface characteristics. Deposition practices have been employed over the years to achieve improved functionalities [8]. It is a good plating practice producing good coatings of desired thickness and fine aggregate size. In most industries, electroplating is 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 [18].
2.1 Electrodeposition of Zinc Coating

In a study where zinc was deposited on some samples made of mild steel, it was that the electrode potential of the sample that was not plated was low, whereas the electrode potential of the zinc sample that was plated at 0.8 V, 1.0 V and 1.5 V for 20 minutes was high. After immersing for 23 days, the sample that was plated at 0.6 V, 0.8 V, 1.0 V and 1.5 V for half an hour demonstrated a high electrode potential, this implies a high resistance to corrosion. The high electrode potential that was recorded in the plated samples were ascribed to be the result of the zinc coating on the mild steel that served as protective film. However, a reduction in electrode potential was observed in un-plated sample, this was because of the breakdown of the film. Tests carried out confirmed the feasibility of using zinc coatings as a prospective protective coating. Coatings of thick zinc was reported to offer protection, whereas protection from coatings with low thicknesses were definitely marginal [4,32].

2.2 Electrodeposition of Composite Multilayer Coating of Zn–Fe alloy layer and zinc phosphate on Mild steel

A study has been done in the electrodeposition of composite multilayer coating of Zn–Fe alloy layer and zinc phosphate on Mild steel. In this work, all multi – layered coatings expanded the erosion obstruction of mild steel substrate. Composite multilayered covering which comprised of an electrodeposited Zn-Fe amalgam layer, a zinc phosphate change layer and one, a few natural layers was saved on a gentle steel substrate. The bond between these multilayered covering and the mild steel substrate was contemplated with the guide of a scratch testing procedure [19]. The possibility of increasing the corrosion resistance of sheet steel by electrodepositing will depend on the admixed alloy particle and the process variables. Within proper electrodeposition parameters like the current density, I, electrolyte flow rate, and pH, deposited steel tends to provide high mechanical and chemical resistance to both deformation and corrosion attack [20].

2.3 Electrodeposition of Natural Fiber Composite on Mild Steel

An experimental investigation on electrodeposition of natural fiber composite on mild steel. This investigation revealed that some mechanical properties for groundnut shell that is reinforced with composites of epoxy material, and rice husk that is reinforced epoxy composite, are greatly influenced by the reinforcement’s percentage in the natural fiber composite. These mechanical properties include flexural strength, impact strength, tensile strength, and hardness. As the fiber content increases for both composites, there was a steady increase in the hardness of the composite and its impact strength; however, it was observed that the flexural and tensile strengths decreased as the fiber percentages increases [21]. The reason for this is the fiber misalignment challenges and issues in delamination, which were noticed in the course of the experimental work. The optimal composite, which was developed was used for a Bajaj tricycle rear bumper’s production. The bumper has favorable mechanical properties versus the one produced with E-glass fiber and steel in composite of Epoxy. Also, the mechanical properties of the natural reinforcements in epoxy matrix relates positively with the results that were obtained when other natural reinforcements such as coconut fiber, palm kernel fiber as reinforcement in epoxy, were used. This is in agreement with some other works [22-24].
2.4 Electrodeposition composite coatings made of Zn-Nanosized TiO$_2$

By incorporating TiO$_2$ in zinc coating, a significant improvement of the size of the crystals was observed, likewise the resistance to corrosion was enhanced; in addition, the wear resistance property and micro hardness of the composite coating improved, versus using a coating made of pure zinc. The reason for the enhancement in the resistance is that the physical barriers which is produced by TiO$_2$ prevents the corrosion process by filling gaps, crevices and the micron holes that exists on the zinc coating’s surfaces. This excellent resistance to corrosion, resistance to wear and improved micro hardness, of the composite coatings made it more useful for extensive applications in the modern industry [29].

2.5 Electrodeposition of ternary Zn-ZnO-Y$_2$O$_3$ coatings.

One other study also reported that the hardness of mild steel increased as the weight percentage content of Yttria increased. The hardness value that was attained for mild steel was originally 115Hv, the average hardness values of 155.76 and 156.4 Hv were then obtained for zinc-yttrium deposited samples. The hardness values are respectively before heat treatment and after heat treatment. The main reason for the hardness improvement is the finer microstructure that was formed as a result of adding Yttria and the numerous phases, which were formed at the end of the coating process. [33]. Thus, it was concluded that the presence of Yttria in the coating caused a shift in the steel’s corrosion potential towards the positive direction. The improvement of the steel’s corrosion stability is due to the action of the effective Yttria cathodic coating in the stabilization of the passive state of the steel. This proved that the mild steel coated is more resistant to corrosion compared to the mild steel that was not coated. The order for the corrosion resistance, from minimum to maximum is: control, N Zn-10ZnO, N Zn-10ZnO- 5Y$_2$O$_3$, N Zn-10ZnO-10Y$_2$O$_3$, N Zn-10ZnO-15Y$_2$O$_3$.

3. Review on Electrolytic Deposited Nickel-based Coatings

3.1 Electrodeposition of Zn–Ni–CNT composite coatings

Newer materials and coatings are usually developed mainly for the purpose of mechanical properties improvement and corrosion resistance enhancement [25-27]. This was also the goal in the study done by depositing Zn–Ni–CNT composite coatings. In that study, it was observed that Zn–Ni–CNT composite coating possessed high corrosion resistance when compared to coatings made of only Zn–Ni coatings [28]. The inclusion of carbon, which is non-metallic in nature, improved the substrate’s resistance to corrosion, specifically in aqueous medium. Also, some mechanical properties, such as the coating’s wear resistance and micro hardness were improved, which inferred that the composite coating further improved the mechanical properties [28].

3.2 Electrodeposition of nanocomposite of Ni-Cr$_2$O$_3$ nanocomposite

In another work using Ni-Cr$_2$O$_3$ nanocomposite anodes, which also led to corrosion resistance as a result of incorporated Cr$_2$O$_3$. This is majorly because of the adsorption of suspended particles which exists on the surface of the cathode. As suggested by Guglielmi’s two-step adsorption mode, a metal will start building round about the cathode in a steady manner, on adsorption of the particles occurred, and then encapsulates and incorporates the particles [30]. In addition, by stirring mechanically, transmission of the particles tends to occur at the surface of the cathode through the fluids flowing in order make a contact with the cathode. At that point, they tend to stay on the
surface of the cathode by the means of the external force, and thus gets captured by the metal deposited. In contrast, the intensity of the field existing in-between the electric charges of the particle surface, and interface of electrodes and solution usually plays a substantial role during co-deposition [31]. It was then confirmed that by incorporating Cr₂O₃ nanoparticles, the surface morphology of nickel matrix can be modified [31].

4. Conclusion
The review has been able to study some key ways where electrodeposition of multilayered zinc oxide composite had affected the mechanical properties of mild steel. These mechanical properties include hardness, corrosion resistance, wear resistance, impact strength, tensile strength, and flexural strength. It could be concluded that the application of zinc oxide multilayered composite coatings has proven to be successful in several applications. That being said, few works have been done on this topic using natural products, thus, it is highly important for researchers to incorporate more agriculture-based products to these zinc oxide composites, so as to have the benefits of reduced costs, availability, sustainability, environmental friendliness and ease of production.

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REFERENCES
[1] Babar, S., Gavade, N., Shinde, H., Mahajan, P., Lee, K. H., Mane, N., Deshmukh, A., Garadkar, K. & Bhuse, V. (2018). Evolution of Waste Iron Rust into Magnetically Separable g-C₃N₄–Fe₂O₃ Photocatalyst: An Efficient and Economical Waste Management Approach. ACS Applied Nano Materials, 1(9), 4682-4694.
[2] Devereaux, B. C. (2018). The Material and Social Costs of Roman Warfare in the Third and Second Centuries BCE (Doctoral dissertation, The University of North Carolina at Chapel Hill).
[3] Archibald, Z. H., Davies, J., Gabrielsen, V., & Oliver, G. (Eds.). (2006). Hellenistic economies. Routledge.
[4] Popoola, A. P. I., Aigbodion, V. S., & Fayomi, O. S. I. (2016). Anti-corrosion coating of mild steel using ternary Zn-ZnO-Y₂O₃ electro-depositon. Surface and Coatings Technology, 306(May), 448–454.
[5] Popoola A. P. I., Aigbodion V. S., & Fayomi O. S. I. (2016). Surface characterization, mechanical properties and corrosion behaviour of ternary based Zn - ZnO - SiO₂ composite coating of mild steel. Journal of Alloys and Compounds, 654:561–566.
[6] Loto C. A., Loto R. T. & Joseph O. O. (2017). Effect of benzamide on the corrosion inhibition of mild steel in sulphuric acid. South African Journal of Chemistry, 70:38-43.
[7] Abioye, O. P., Loto, C. A., & Fayomi, O. S. I. (2019). Evaluation of Anti-biofouling Progresses in Marine Application. Journal of Bio-and Tribo-Corrosion, 5(1), 22.
[8] Fayomi, O. S. I., Kanyane L., Popoola, P., Oyedepo, S. (2018). Electrolytic deposition of
super-smart composite coating of Zn-V$_2$O$_5$-NbO$_2$ on low carbon steel for defence application. Defence Technology, 10.1016/j.dt.2018.07.002.

[9] Ajayi O. O., Omowa O. F., Omotosho O. A., Abioye O. P., Akinlabi E. T., Akinlabi S. A., Abioye A. A., Owoeye F. T., & Afolalu S. A. (2018). Experimental Investigation of the Effect of ZnO-Citrus sinensis Nano-additive on the Electrokinetic Deposition of Zinc on Mild Steel in Acid Chloride. In TMS Annual Meeting & Exhibition, Springer, Cham, 35-40

[10] Loto, C. A. (2011). Inhibition effect of tea (Camellia Sinensis) extract on the corrosion of mild steel in dilute sulphuric acid. Journal of materials and environmental science, 2(4), 335-344.

[11] Sahin, Y., & Motorcu, A. R. (2005). Surface roughness model for machining mild steel with coated carbide tool. Materials & design, 26(4), 321-326.

[12] Melchers, R. E. (2004). Pitting corrosion of mild steel in marine immersion environment—part 1: maximum pit depth. Corrosion, 60(9), 824-836.

[13] Nandu River Iron Bridge. https://en.wikipedia.org/wiki/Pitting_corrosion. Retrieved on 31st May, 2019

[14] Roberge, P. R. (2008). Corrosion engineering (p. 708). New York, NY, USA:: McGraw-Hill.

[15] Fatoba, O. S., Fedotova, T., & Pityana, S. L. (2015). Electrochemical studies on the corrosion behaviour of laser alloyed Zn-Sn coatings on UNS G10150 steel in 1M HCl solution. Silicon, 7(4), 357-369.

[16] Fayomi, O. S. I., Atayero, A. A., Mubiayi, M. P., Akande, I. G., Adewuyi, P. A., Fajobi, M. A., & Ayara, W. A. (2019). Mechanical and opto-electrical response of embedded smart composite coating produced via electrodeposition technique for embedded system in defence application. Journal of Alloys and Compounds, 773, 305-313.

[17] Srivastava, M., Balaraju, J. N., Ravishankar, B., & Rajam, K. S. (2010). Improvement in the properties of nickel by nano-Cr2O3 incorporation. Surface and Coatings Technology, 205(1), 66-75.

[18] Schlesinger, M., & Paunovic, M. (Eds.). (2011). Modern electroplating (Vol. 55). John Wiley & Sons.

[19] Panagopoulos, C. N., Georgiou, E. P., Tsoutsouva, M. G., & Krompa, M. (2011). Composite multilayered coatings on mild steel. Journal of Coatings Technology and Research, 8(1), 125-133.

[20] Lima, W. M., Velasco, F., & Torralba, J. M. (1999). Stainless steel matrix composites reinforced with AlCr$_2$. In Materials science forum (Vol. 299, pp. 431-438). Trans Tech Publications.

[21] Olaitan, A., Terhemen, A., King, G., & Oluwatoyin, O. (2017). Comparative Assessment of Mechanical Properties of Groundnut Shell and Rice Husk Reinforced Epoxy Composites. American Journal of Mechanical Engineering, 5(3), 76–86.

[22] Sreenivasulu, G., Qu, P., Petrov, V. M., Qu, H., & Srinivasan, G. (2015). Magneto-electric interactions at bending resonance in an asymmetric multiferroic composite: Theory and experiment on the influence of electrode position. Journal of Applied Physics, 117(17), 174105.

[23] Mair, L. O., Weinberg, I. N., Nacev, A., Urdaneta, M. G., Stepanov, P., Hilaman, R., ... & Superfine, R. (2015). Analysis of driven nanorod transport through a biopolymer matrix. Journal of magnetism and magnetic materials, 380, 295-298.

[24] Santana, R. A. C., Campos, A. R. N., Medeiros, E. A., Oliveira, A. L. M., Silva, L. M. F., & Prasad, S. (2007). Studies on electrodeposition and corrosion behaviour of a Ni–W–Co
Amorphous alloy. Journal of Materials Science, 42(22), 9137-9144.

[25] Hosking, N. C., Ström, M. A., Shipway, P. H., & Rudd, C. D. (2007). Corrosion resistance of zinc–magnesium coated steel. Corrosion science, 49(9), 3669-3695.

[26] Szczygiel, B., & Kołodziej, M. (2005). Composite Ni/Al2O3 coatings and their corrosion resistance. Electrochimica Acta, 50(20), 4188-4195.

[27] Shi, L., Sun, C., Gao, P., Zhou, F., & Liu, W. (2006). Mechanical properties and wear and corrosion resistance of electrodeposited Ni–Co/SiC nanocomposite coating. Applied Surface Science, 252(10), 3591-3599.

[28] Praveen, B. M., & Venkatesha, T. V. (2008). Electrodeposition and properties of Zn-nanosized TiO2 composite coatings, 254, 2418–2424.

[29] Praveen, B. M., & Venkatesha, T. V. (2009). Electrodeposition and properties of Zn–Ni–CNT composite coatings, 482, 53–57.

[30] Guglielmi N. Kinetics of the deposition of inert particles from electrolytic bath. Journal of Electrochemical Society 2002; 119: 1009-12.

[31] Hassan, H. B., & Hamid, Z. A. (2011). Electrodeposited Ni-Cr2O3 nanocomposite anodes for ethanol electrooxidation. International Journal of Hydrogen Energy, 36(8), 5117–5127.

[32] Durodola, B. M., Olugbuyiro, J. A. O., Moshood, S. A., Fayomi, O. S., & Popoola, A. P. I. (2011). Study of influence of zinc plated mild steel deterioration in seawater environment. International Journal of Electrochemical Science, 6(11), 5605–5616.

[33] Popoola, A. P. I., Aigbodion, V. S., & Fayomi, O. S. I. (2016). Anti-corrosion coating of mild steel using ternary Zn-ZnO-Y2O3 electro-deposition. Surface and Coatings Technology, 306(May), 448–454. https://doi.org/10.1016/j.surfcoat.2016.05.018