PROTECTIVE IMPACT OF MOLTEN ZINC COATING SHEETS IN CONTAMINATED ENVIRONMENT-REVIEW

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Abstract

Steels are susceptible to degradation orchestrated by the immediate environment which alters their physical, mechanical and electrochemical properties. These challenges have necessitated their protection with molten zinc which solidifies to form protective barrier against external contaminants. Protection of mild steel is a necessity because of its availability and cost effectiveness which has made it the most used metal for structural application in many part of the world. Surface protections of steel incorporate specific properties that enable it to stand a test of time due to the alteration of the surface characteristics. This mini review outlines the impact of molten zinc coating on mild steel and several coating application techniques

Keywords: Surface; Coating; Electroplating; Environment; Morphology.

1.0 Introduction

Coating as a protective covering is applied to the surface of an object in form of a thin film. The coated object is normally referred to as the substrate. Coating is applied for surface morphology improvement, corrosion resistant, thermal stability, fracture toughness and imputation of other desired properties. Various concepts and properties are made reference to in basic coating principles. Surface coatings have been beneficial to many manufacturing industries because of the resistance is able to provide against corrosion and other form of degradation in an aggressive environment. The effectiveness of any coating is a function of the environment where it to be used. This why the chemical composition of the corrosive medium must be studied for optimum performance of the coating [1, 2]. Metallic coatings comprise of a metallic element or alloy. This can be applied electrochemically, chemically, mechanically or via the use of sprayer. Metallic coatings are applied to engineering components that require shiny appearance and protection from the sun ray and corrosion. It is significant to note that metallic coatings enhance the surface properties of the work piece to those of the metal being connected. The work piece turned into a composite material exhibits improved properties better than the base material [3]. Metallic coating promotes solidity of the molten zinc on the substrate and makes the regenerated material erosion safe. The affirmation of metallic coatings was found in the use of nickel chromium, cadmium and copper commonly achieved by wet mixtures that have natural contamination control ability. Metallic coatings are carried out via electroless plating, electroplating, showering, synthetic vapour testimony, hot plunging and particle vapour. Other vital metal coatings such as aluminum, zinc, gold, and silver are moreover utilized in electrical hardware and sometimes strength fastener applications. Copper is employed as a base layer in
various plate electroplating, silver is used for anti-fretting purposes, and both silver and gold have been used to improve electrical conductivity and corrosion resistance by forming a protective layer that can withstand harsh environmental condition [4]. Metallic coatings are usually applied on steel surfaces using one of four common methods:

- **Thermal spraying:** This is a coating process in which finely chopped metallic coating materials are deposited in a molten or semi-molten form on the substrate. The material used for coating is usually in the form of wire, powder or ceramic rod [5].

- **Electroplating:** This involves coating a metal with a thin layer of another metal by electrodeposition or electrolysis to enhance the metal's corrosion resistance of the metal and imputing other properties of interest [6]. Electroplating is one of the surface protection techniques that alter the surface properties of a metal. It may also involve coating a metal with oxide of metal or composites so as to deposit a thin oxide film on it [7]. It has been the objective of many industries to upgrade the surface quality by enhancing their appearance and at the time impacting some desired mechanical and electrochemical properties. As of late surface properties improvement are tailored towards surface treatment and the introduction of specific physical or mechanical properties to the surface of the substrate, for example, wear resistance and hardness. Electroplating basically requires homogeneous distribution of the coating elements on the substrate metal. The crucial components of electroplating include: The plating bath, the substrate to be plated (Cathode), the anode (Zinc or Nickel plate), an inert compartment for steel and a rectifier [8]

- **Galvanizing:** To galvanize steel, it is dipped into bath containing molten zinc or other metallic covering of interest which will be pulled out vertically when the coating is achieved. Excess molten zinc is removed employing high-pressure air so as to obtain a closely controlled coating thickness.

### 2.0. **Galvanization Techniques Employed in Coating Industries**

#### 2.1 Flow Galvanizing

Flow galvanizing is a crude way of galvanizing. It is a galvanization method that involves the flow of hot zinc over cleaned steel metal surface so as to achieve adhesion and covering of the steel surface. Excess zinc that flows down is collected and recycled. This method is proper for the galvanization of flat sheet metal only. In this process, the coating thickness can be controlled to a uniform value. Flow galvanizing method was modified to use a metal spraying gun. The gun is connected to a device that provides oxygen flame and through it zinc wire is fed and melted. The molten zinc is sprayed on the surface of the sheet metal via air pressure. The challenges of dipping a large work piece of metal in a coating bath are overcome [ in flow galvanizing. More so, thin and uniform thickness layer is maintained

#### 2.2 Sherardizing

The galvanizing of small intricate shapes can be achieved using the Sherardizing method. In Sherardizing a container is filled with fine zinc powder and parts are placed in the container. The container is then heated in the presence of air. The Zinc powder vaporizes and the vapour comes in contact with the surface of the work piece so as to deposit zinc on it. The work piece is then removed and left to cool to room temperature. [9]
2.3 Electro galvanizing

In the case of electro galvanizing, zinc is deposited on the work piece made the cathode just like an electroplating process. Electrogalvanized of steel sheet have the following advantages over hot dip galvanizing:

- High performance coating with lower thickness is achieved
- Wide range of coating conversion is available with different colour options
- The achievement of brighter and aesthetically appealing coating is possible

2.4 Cold Dip Galvanizing

Cold dip galvanizing is a galvanizing process that involves the use cold bath for the coating process. Polishing, buffing, and removal of grease from the work surface before galvanizing process. This process does not involve the application of heat or flow of current through the electrolyte. Zinc chloride, ammonium chloride, tin chloride, potassium bitartrate etc is dissolved in a metallic tank filled with water. The parts to be galvanized are submerged into the bath. The immersion time is a function of the required thickness. 3 to 12 hours of dipping time is required. Cold Dip Galvanizing is economical because there is no heating or electric current is required. However, Intermittent stirring of the bath is needed. Reduction of metal occurs as the coating process progresses; therefore, more metal salt is required to keep the galvanizing process going.

2.5 Hot Dip Galvanizing

Hot-dip galvanizing process employs continuous zinc coating lines either by hot or cold rolling. The coating of the steel is achieved by passing it through a bath of molten zinc to form of a continuous ribbon. In the molten zinc bath, the zinc adheres to the steel, forming protective barrier of controllable thickness. The steel is allowed to cool so that the molten zinc can become its solid component [10]

2.6 Common Terminologies in Hot Dip Galvanizing

Some very important terminologies are unavoidable in the hot dip galvanization. These terminologies are dross, pickling, fluxing and surface morphology.

2.6.1 Dross

Dross is produced as a result of oxidation and contamination of the zinc bath. When steel is immersed in the Zn, iron dissolves and interacts with the constituents of the bath to produce intermetallic particles of iron alloys known as dross. The dross produced sinks to the bottom of the baths compartment because it has a higher density than the zinc melt. Some dross floats, the floating dross are known as “galvanizing ashes” consisting mainly of chlorides and oxides [11] The presence of dross causes defective coating of the steel. Steel in molten zinc produces dross with a chemical formula FeZn₉ or FeZn₁₃. Zinc bath typically contains 0.025 to 0.06 wt% dross of about twenty microns in diameter, thermodynamic equilibrium. Dross formation is dependent on bath composition, the operating temperature of the bath, stirring rate [12], dipping time and withdrawal speed. It is there imperative to employ the right operating parameters so as to minimize dross formation.

2.6.2 Pickling

This is the process of removing oxide scale on steel before fluxing which is essential for the achievement of high surface quality. The greasy substance on the steel substrate is removed by pickling using HCl and H₂SO₄. However, most researches prefer pickling of steel with HCl
because it can be used at low temperature with less volume. Moreso, it becomes easy to protect the steel surface without any special treatment. H₃PO₄ was reported to have been used to ensure a stable coating [13]. Pickling is carried out after fluxing i.e. after the dissolution of films of oxide formed on the steel surface. Badly covered zinc layers are normally removed in another pickling bath contains the desired concentration of HCl so as to ensure superior surface coating [14].

2.6.3 Fluxing
Fluxing is the process by which the base metal is protected against oxidation. In a standard hot dip galvanizing process, the steel substrate is cleaned, fluxed and then dipped into a molten zinc bath at a temperature of about 450 °C [15]. This is the surface preparation that is carried out after pickling. Fluxing involves dissolution of oxide films formed on the steel surface after pickling. Fluxing treatment enables proper adherence of liquid zinc on the steel surface and provides enough metallurgical interaction between zinc and steel. It also minimized the oxidation of steel surface on exposure to atmosphere. Alkali and alkali earth metal chlorides are some of the known fluxing solutions.

2.6.4 Surface morphology of Hip dip galvanized Steel
The hot galvanizing process formed a protective coating between 450 and 480 °C. The coating was made up of intermetallic layers of Fe–Zn, identified as gamma (Γ), delta (δ), zeta (ξ) and an outer eta (η) layer, highly rich in zinc. The formation of ξ or δ phases was without delay in the pure and commercial grade zinc baths. Formation of the Γ phase after the waiting time of about 30 s when the bath temperature was 470°C in the pure zinc bath but this was delayed in the commercial grade zinc bath. The formation of a second ξ layer at the ξ/δ interface in the pure zinc bath is the last morphological feature. In the case of the commercial grade zinc bath two distinct ξ phases was observed within the short dipping period. The coating was thicker as a result of Fe-Zn intermetallic leading to reduced ductility and degraded external appearance. Presence of cracks and dross entrapment in the coating was attributed to the less compact coating that was produced in the commercial grade zinc bath [16-17].

Hot-dipped coating with spangles has been of tremendous interest in recent. The shift of attention towards it have been as a result of its beautiful appearance which has made many galvanizers devoted themselves to the development of alloy for ornamental galvanizing of steel [18].

3.0 Broad Classification of Coatings
Coatings can be broadly classified as organic and inorganic coating. Organic coatings are paints or powders applied on metals in multiple layers before a thicker and satisfactory coating is achieved to repress corrosion. The coating must be impervious and durable. Paints and superior natural coatings have been produced to shield metals from environmental deterioration. Gum polymers such as vinyl and acrylics are good examples of organic coating materials. Epoxies and present-day polyurethane coatings are also organic. [19]. An organic coating method protects metal substrates against corrosion by means of one or more mechanisms:

- Lowering the rates of anodic (oxidation) and/or cathodic (reduction). These are corrosion half-reactions that occur on the metal/paint interface.
- Introduction of high electrical resistance into the circuit of the metal/electrolyte corrosion cell that is caused by the nonconductive organic film applied on the metal substrate which
act as a barrier against the transport of aggressive species, such as water, which is the basis of the electrolyte/humidity conditions; oxygen, which is the oxidizing agent; and various corrosion ions (Cl\textsuperscript{\textdaggerright}, SO\textsubscript{4}, etc.) to the metal surface. [20]

In general, the anti-corrosion efficiency of an organic primer film is a function of four factors:

- The nature of the metal substrate, that is, its susceptibility to oxidative corrosion.
- The state of the metal/primer interface—for example, its electrical resistance and capacity, the nature of ions or molecules present in this region, etc.
- The composition of the primer film and efficiency of the anti-corrosion pigments and any other inhibitors.
- Corrosion aggressiveness of the environment and the characteristic nature to which the coated metal is exposed. [21], [22]

Inorganic coatings can be performed with or without the use of electricity. It involves surface conversion, anodizing, enameling, metallic coatings and more. Inorganic coatings are created via chemical action that transforms the metal substrate surface into a metallic oxide film or compound that inhibits corrosion. The thin film oxide acts as an obstacle to the erosion of the metals top layer. For example, paints, in a few occasions, are used as preliminary advance before painting [23].

3.1 Characteristics and Functions of Metallic Elements used for Protective Coating

Mild Steel is a strong, versatile and relatively inexpensive material commonly used for several industrial applications. The major drawback of steel is corrosion. Protection of steel from the attack of corrosion is vital so as to provide structures that are economical. Long-term savings due to minimal maintenance cost have been discovered possible with the use long lasting protective techniques. The uniform zinc coating improves the corrosion resistance of base steel when they come in contact with moisture in the air. This can be prevented by applying chromate-free and other unique treatments on the galvanized sheet. Mild steel is commonly used for engineering applications due to their low cost, high tensile strength and ease of fabrication. However, their major limitation is corrosion [24]. Corrosion causes huge economic losses which accounts for a quarter of the world’s production annually. Corrosion causes severe structural damage to metal structures, and impacts on public safety, maintenance plans and requires extensive repair and replacement of corroded structures or parts. Since corrosion is thermodynamically spontaneous, it can only be reduced but not prevented. Different metallic materials will either corrode slowly or faster, depending on the corrosive environment in which they are used. For instance, aluminum coated steel corrodes faster in severe marine environment conditions, while galvanized sheets corrode faster in industrial environments. Several attempts have been made to reduce corrosion for economic, industrial production and public safety [25].

3.2 Electrochemical Behaviour of Zinc Coated Steel in Different Environment

In an attempt to optimize the corrosion resistance and mechanical properties of zinc coated steel, a lot of investigations have been carried out by author in naturally corrosive and simulated environment. [26] investigate the effect of 5\% NaCl solution, sea water and rainwater on the corrosion resistance of galvanized steel and copper (Cu) by immersion test technique. The examination of Corrosion characteristics was carried out employing XRD, XRF and SEM. Copper sample was found to displayed superior corrosion resistance than galvanized steel in
5% Sodium chloride and rainwater [27]. However, galvanized steel exhibits better corrosion resistance than Cu within the 5 days of exposure to seawater. The author concludes that Cu might possess better corrosion resistance than steel in seawater over a long range of immersion. [28] carried out corrosion resistance evaluation of bare galvanized steel and 55% Al-Zn alloy coated steel sheets. Similar painted samples of the galvanized steel and 55% Al-Zn alloy coated steel sheets which has been exposed for 12 years in urban atmosphere were subjected to the same examination. The exposed surface of the sample was evaluated using the occasional visual examination, standard adhesive tests and electrochemical impedance measurements. The variables monitored were the temperatures, average annual temperatures, sulphur and chloride concentration, speed and direction of wind and relative humidity. The corrosion resistance of 55% Al-Zn/steel sheets was discovered to be higher than the galvanized steel sheet in the testing atmosphere [29]. The polyurethane painted steel sheet was also discovered to be more protected than the alkyl and epoxy painted sheet on exposure to external contaminants. [27] investigate the electrochemical properties and porosity of epoxy coatings electrodeposited on hot-dip galvanized steel (ECGS) and epoxy coated steel modified by Zn–Ni alloys (ECZN). The electrochemical experiments were carried out in 3% NaCl solution. The corrosion resistance of ECZN was discovered to be better. The author attributed the corrosion resistance of ECZN to the presence of Zn–Ni alloys leading to the enhancement of epoxy stability [30]. Moreover, the ECGS sample was found to exhibit reduced porosity and improved coating capacitance and permittivity relative to the ECZN at the initial period of exposure to 3% NaCl which was attributed to the partial dissolution of zinc due to high pH close to the cathode and the heat generated via the epoxy deposition on the galvanized steel. The lower porosity of ECGS was confirmed via the smaller diffusion of water through the samples when compared to ECZN.

[31] compared the corrosion resistance of galvanized steel and aluminum in three different corrosive environments, sea water, 5% NaCl solution, and rain water, via the immersion techniques. The test samples were analyzed using by XRD, XRF and SEM. Although all the analysis pointed to the fact that aluminum possess a more superior corrosion resistant than galvanized steel in the testing aqueous environments. However, the corrosion resistance of galvanized steel might be better than that of Aluminum after a long period of exposure to rain water. The corrosion resistance of Al made the author to a conclusion that aluminum can be substituted for galvanized steel in industrial structures (roofing sheets) not taken cost into account. [32] investigate the performance characteristics of different coated and uncoated corrugated roofing Sheets in Nigeria. The samples were coated and uncoated galvanized steel and aluminum roofing and plastic sheet of various grades. The gravimetric experiment was carried out by cutting the samples to the desired sizes and immersed in H2SO4, NaOH, sea water, and rain water for 70 days. Each of the samples were removed and weighed after every 5 days. Generally, the coated or painted samples displayed higher resistance to corrosion compared to the uncoated samples [33]. However, based on the experimental result, aluminum was recommended for roofing sheet manufacturers in Nigeria. Although the plastic sample did not corrode in the course of the experiment but its low resistance to temperature which could lead to brittle fracture on continuous expansion and contraction makes it unsuitable for roofing in Nigeria. More so, plastic is not fire proof. The Comparative tribological and corrosion resistance behaviour of galvanized and zinc-iron coated steels was investigated by [30]. The comparison of the electrochemical behaviour of the coating samples were carried out using polarization tests, open circuit potential and mass loss after sliding in 3% NaCl. The vivid examination of the samples using SEM after various experiments shows that the tribocorrosion
behaviour of the hot-dip galvanized coatings is superior to that of zinc-iron coated steel samples. [34-36] investigate the corrosion behaviour of galvanized steel in chloride surrounding environment. 0.5M NaCl solution was the medium for dissolution of galvanized steel to result in Fe-Zn alloy layer on the base steel by galvanstatic dissolution. The aim of the study was to ascertain the internal effect of the alloy layer (Fe-Zn) created as result of process of hot-dip galvanizing on the corrosion resistance of galvanized steel in a surrounding marine environment making use of photodynamic polarization, surface potential measurement methods. It was critically clear that this research was not aimed at preparing the alloy layer rather the effect of alloy layer (Fe-Zn) on the corrosion resistance of galvanized steel. It was observed that the alloy layer (Fe-Zn) was of the same cathodic polarization behaviour to that of galvanized steel but of different anodic polarization behaviour to the rate of 100 times lower than that of the galvanized coating. The result extract shows that from the surface potential measurement the alloy layer (Fe-Zn) has been confirmed to protect both the galvanized steel itself and base iron over the initial stage of atmospheric corrosion[37].

4.0 Conclusion
Deterioration of steel is inevitable in the presence of contaminants. This has caused huge economic losses annually. However, coating of steel with molten zinc provides some degree of protection. Although white rust sets in over a period of time which could mandate the employment of multilayer coating, depending on the area of application.

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References

[1] Wang, D., & Bierwagen, G. P. (2009). Sol–gel coatings on metals for corrosion protection. Progress in organic coatings, 64(4), 327-338.
[2] Fayomi, O.S.I., & Popoola, A.P.I. (2012). An Investigation of Properties of Zn Coated Mild. International Journal of Electrochemical Science, 7, 6555-6570
[3] Milton, G. W. (2002). The theory of composites. The Theory of Composites, by Graeme W. Milton, pp. 748. ISBN 0521781256. Cambridge, UK: Cambridge University Press, May
[4] Gray, J., & Luan, B. (2002). Protective coatings on magnesium and its alloys—a critical review. Journal of alloys and compounds, 336(1-2), 88-113.
[5] Afolalu, A. S., Enesi, Y. S., Kehinde, O., Samuel, U. A., Ikechi, V. I., & Remilekun, R. E. (2018). Failure Mode and Effect Analysis a Tool for Reliability Evaluation. European Journal of Engineering Research and Science, 3(4), 65-68.
[6] Mizushima, I., Tang, P. T., Hansen, H. N., & Somers, M. A. (2005). Development of a new electroplating process for Ni–W alloy deposits. Electrochemical Acta, 51(5), 888-896.
[7] Fayomi, O. S. I., Popoola, A. P. I., & Daniyan, A. A. (2017). Hybrid effect of an in situ multilayer Zn–ZnO–Cr2O3 electrodeposited nanocomposite coatings for extended application. Particulate Science and Technology, 35(4), 418-425.
[8] Durodola, B.M., Olugbuyiro, J.A., Moshood, S.A., Fayomi, O.S.I., Popoola, A.P.I. (2011). Study of influence of zinc plated mild steel deterioration in seawater environment. International Journal electrochemical science, 6, 5605-5616
[10] Lee, S. J., Kim, S., Koh, M. S., & Choi, J. H. (2002). Flow field analysis inside a molten Zn pot of the continuous hot-dip galvanizing process. *ISIJ International*, 42(4), 407-413.

[11] Zhang, J., Yang, X. Q., Jinag, H. L., & Sun, L. (2005). Investigation on Sherardizing Process Using Nano Zinc Powder and Nano Rare Earth [J]. *China Surface Engineering*, 3, 010.

[12] Li, Q., Lu, H., Cui, J., An, M., & Li, D. Y. (2017). Improve the performance of Cr-free passivation film through nano electrodeposition for replacement of toxic Cr6+ passivation in electro galvanizing process. *Surface and Coatings Technology*, 324, 146-152.

[13] Pichler, A., Traint, S., Pauli, H., Mildner, H., Szinyur, J., Blaïmschein, M., ..., & Werner, E. (2001). Processing and properties of cold-rolled TRIP steels. In *43rd Mechanical Working and Steel Processing Conference* (pp. 411-434).

[14] Ooi, T., Sato, Y., Tobiyama, Y., Okuma, T., Furuta, A., Yoshida, M., & Matsuzaki, A. (2018). "Hot-Dip Al-Zn-Mg-Si Coated Steel Sheet and Method Of Producing Same." *U.S. Patent Application No. 15/553,658*.

[15] Szafranek, M., Michalski, R., & Wiechek, L. (2016). Information Systems for Supporting Production Processes in a Company Manufacturing Roof Metal Sheets-A Case Study. In *Managing Innovation and Diversity in Knowledge Society Through Turbulent Time: Proceedings of the Make Learn and TIM Joint International Conference 2016* (pp. 1023-1031). To Know Press.

[16] Afolalu, S. A., Asonaminasom, E. H., Ongbali, S. O., Abioye, A. A., Udo, M. O., & Salawu, E. Y. (2018). Dataset on experimental investigation of optimum carburizing temperature and holding time of bi-nano additives treatment of AISI 5130 steel. *Data in Brief*, 19, 2279-2283.

[17] Stieglitz, U., Schulz, W. D., Kulker, H., Fleischer, W., & Brucken, V. (2002). Acid matter. Phosphoric acid cleaners for hot galvanizing reduce use of chemicals. *Metalloberflache*, 56(6), 11-17.

[18] Regel-Rosocka, M. (2010). A review on methods of regeneration of spent pickling solutions from steel processing. *Journal of Hazardous Materials*, 177(1-3), 57-69.

[19] Sa-nguanmoo, R., Nisaratanaporn, E., & Boonyongmaneerat, Y. (2011). Hot-dip galvanization with pulse-electrodeposited nickel pre-coatings. *Corrosion Science*, 53(1), 122-126.

[20] Mandal, G. K., Mandal, D., Das, S. K., Balasubramaniam, R., & Mehrotra, S. P. (2009). Microstructural study of galvanized coatings formed in pure as well as commercial grade zinc baths. *Transactions of the Indian Institute of Metals*, 62(1), 35-40.

[21] Peng, S., Lu, J., Che, C., Kong, G., & Xu, Q. (2010). Morphology and antimony segregation of spangles on batch hot-dip galvanized coatings. *Applied Surface Science*, 256(16), 5015-5020.

[22] Holness, R. J., Williams, G., Worsley, D. A., & McMurray, H. N. (2005). Polyaniline inhibition of corrosion-driven organic coating cathodic delamination on iron. *Journal of The Electrochemical Society*, 152(2), B73-B81.

[23] Grundmeier, G., Schmidt, W., & Stratmann, M. (2000). Corrosion protection by organic coatings: electrochemical mechanism and novel methods of investigation. *Electrochimica Acta*, 45(15-16), 2515-2533.

[24] Raps, D., Hack, T., Wehr, J., Zheludkevich, M. L., Bastos, A. C., Ferreira, M. G. S., & Nuyken, O. (2009). Electrochemical study of inhibitor-containing organic–inorganic hybrid coatings on AA2024. *Corrosion Science*, 51(5), 1012-1021.
[25] Mathiazhagan, A., & Joseph, R. (2011). Nanotechnology-a New prospective in organic coating-review. *International Journal of Chemical Engineering and Applications*, 2(4), 225.

[26] Batis, G., Pantazopoulou, P., & Routoulas, A. (2003). Corrosion protection investigation of reinforcement by inorganic coating in the presence of alkanolamine-based inhibitor. *Cement and Concrete Composites*, 25(3), 371-377.

[27] Eduok, U., Suleiman, R., Khaled, M., & Akid, R. (2016). Enhancing water repellency and anticorrosion properties of a hybrid silica coating on mild steel. *Progress in Organic Coatings*, 93, 97-108.

[28] Moniruzzaman, M., & Haseeb, A. S. M. A. (2009). Investigation into the Causes of Premature Corrosion of Pre-Fabricated Steel Factory Building. *Journal of Mechanical Engineering*, 40(2), 90-94.

[29] Haque, M. M., Limon, S. A., Moniruzzaman, M., & Bepari, M. M. (2014). Corrosion comparison of galvanized steel and aluminum in aqueous environments. *International Journal of Automotive and Mechanical Engineering*, 9, 1758.

[30] Ujam, A. J., Egabana, S. O., & Idogwu, S. (2014). Performance Characteristics of various Corrugated Roofing Sheets in Nigeria. *International Journal of Computational Engineering Research*, 4, 27-.

[31] Souza, M. E. P., Ariza, E., Ballester, M., Rocha, L. A., & Freire, C. (2007). Comparative behaviour in terms of wear and corrosion resistance of galvanized and zinc-iron coated steels. *Material (Rio de Janeiro)*, 12(4), 618-623.

[32] Yadav, A. P., Katayama, H., Noda, K., Masuda, H., Nishikata, A., & Tsuru, T. (2007). Effect of Fe-Zn alloy layer on the corrosion resistance of galvanized steel in chloride containing environments. *Corrosion Science*, 49(9), 3716-3731.

[33] Abioye, A. A., Atanda, P. O., Abioye, O. P., Afolalu, S. A., & Dirisu, J. O. (2017). Microstructural Characterization and Some Mechanical Behaviour of Low Manganese Austempered Ferritic Ductile Iron. *International Journal of Applied Engineering Research*, 12(23), 14435-14441.

[34] Ajayi, O. O., Omowa, O. F., Abioye, O. P., Omotosho, O. A., Akinlabi, E. T., Akinlabi, S. A., ... & Afolalu, S. A. (2018, March). Finite Element Modelling of Electrokinetic Deposition of Zinc on Mild Steel with ZnO-Citrus sinensis as Nano-Additive. In *TMS Annual Meeting & Exhibition* (pp. 199-211). Springer, Cham.

[35] Adetunji, O. R., Musa, A. A., & Afolalu, S. A. (2015). Computational Modelling of Chromium Steel in High Temperature Applications. *International Journal of Innovation and Applied Studies*, 12(4), 1015.

[36] Oyinbo, S. T., Ikumapayi, O. M., Ajiboye, J. S., & Afolalu, S. A. (2015). Numerical Simulation of Axisymmetric and Asymmetric Extrusion Process Using Finite Element Method. *International Journal of Scientific & Engineering Research*, 6(6), 1246-1259.

[37] Adetunji, O. R., Ude, O. O., Kuye, S. I., Dare, E. O., Alamu, K. O., & Afolalu, S. A. (2016). Potentiodynamic Polarization of Brass, Stainless and Coated Mild Steel in 1M Sodium Chloride Solution. In *International Journal of Engineering Research in Africa* (Vol. 23, pp. 1-6). Trans Tech Publications.