Mechanical and Corrosive Nature of Galvanized Steel in Sodium Chloride Solution

A. A. Chowdhury[a], Iis Siti Aisyah[b]
[a]School of Mechanical, Materials & Mechatronic Engineering University of Wollongong, Australia
Northfields Ave, Wollongong NSW 2522, Australia
azrin@uow.edu.au
[b]University of Muhammadiyah Malang
Jl. Raya Tlogomas No. 246 Malang 65144, Indonesia

Abstract

Galvanizing also termed as zinc coating is a scientifically approved method applied to protect iron and steel against the effects of corrosion. In the galvanization process, aluminum is added with zinc. Zinc has numerous properties under different environmental conditions. These properties are subject to change when it comes to the coating process. The common properties here may include its appearance, hardness, the thickness along with other mechanical and physical properties. Due to these properties, there may also be inconsistency on the coating structure. Therefore, the addition of aluminum unto zinc will ensure that various unfavorable properties are eliminated for the better improvement of the zinc coating process. Aluminum possesses stronger mechanical properties and therefore valid for the coating process. It ensures that zinc is not arrived by the corrosion agents. In this study, it will be focused on the impact of aluminum addition on corrosion behavior in hot-dip galvanized steel. In this study, the galvanization process was performed using the dry process. The percentage variation of zinc resulted in different results in the rate of corrosion. The hardness of zinc thus increased via additional of aluminum percentage.

Keywords: *galvanization; corrosion; sodium chloride solution; steel*

1. INTRODUCTION

According to [1] over the years, there have been attempts in harmonizing a long time conflicting definition of galvanization. However, the current literature affirms that galvanizing is more of dazzling and economical means of preventing corrosion, and aiming to wide application on industrial and commercial steel equipment [2]. For instance, such materials may include; roofing's, utility poles, fencing materials and not limited to agricultural and industrial components. The earlier usage of zinc coated materials dates back to the 19th century. By this error, there was heavy use of hot-dipped galvanized steel sheets that were used as roofing materials [3]. Before the onset of this error, the sheets of steel were manually dipped into a bath of molten zinc after undergoing a promising cleaning and whipping by the use of ammonium chloride and sulfuric acid. It is conducted to give protection on metal against the effects of corrosion. The knowledge on the importance of galvanized steel materials came into lame light on the earlier 1950s. Devillers, and Niessen (1976) confirms that before this error individuals were not enlightened on the causes and the exact effects of corrosion [4].

2. METHODS

Through this experiment, mild steel strips are galvanized through the batch hot dipping process. The sample is dipped in various proportions of the aluminum-zinc bath. After this, the corrosion propensities of the galvanized sample are examined in the sodium chloride solution.

The appearance before and after corrosion was also noted. Metallographic techniques were also applied to measure the coating thickness of these samples [5].

Preparation of substrate

In this experiment, the substrate that was coated has the size of 6 cm by 2cm. The substrate was purely mild steel that was striped and rolled.

Cleaning before galvanization

The steel to be used in this experiment had to be dip galvanized and after fabrication had to be free from lubricants before immersion in molten zinc. In most galvanization coatings, inadequate surface preparations have been the cause of defects in the coating process.

According to Kautek, (1988) in the batch hot-dip galvanization process, the material to be galvanized had to be degreased and then inserted in hydrochloric acid [6]. The whole idea behind this was to remove some salts that might have remained on the surface of the material. Each of the degreasing steps was followed by a water rinse to avoid clotting of substances unto the surface [7].

The alkaline cleaning

This was necessary since there was urgency in ensuring that the strength of the alkaline solution was effective in the experiment, especially in the degreasing process. The alkaline sample was then rinsed with water before acid marinating. After the rinsing, it was then dried.

Acid pickling

In this section, aqueous solutions of hydrochloric acid were used to remove rust from the steel parts before galvanizing. This experiment 25 percent concentration of hydrochloric acid was used.

2.1 Batch Galvanizing Procedures

Lapshin, (1975) asserts that there are two types of convectional batch galvanization techniques that are currently used in the application [8] of wet and dry process. The dry process involves the use of a crucible-top flux blanket. According to Larouk, and Yakhlef, (2012) the dry process only uses a pre-flux [9]. Hereafter the material is degreased, the intended work-piece are inserted in an aqueous flux solution, it is dried and thereafter immersed in the molten zinc bath. An experiment conducted using the dry technique is as shown in Figure 1.

Figure 1. Batch galvanization of dry technique

According to McMurray, (2001) in as much as degreasing, pickling, water rinsing, together with other cleaning procedures remove most of the surface deterioration and scale from iron and steel, small amounts of impurities in the form of oxides, chlorides, sulfates, and sulfides are retained [10]. Unless removed, these impurities will interfere with the iron-zinc reaction when the iron part or steel is immersed in molten zinc solution [5].

2.2 Flux used after acid picking

After acid pickling is done, whenever the sample is in the free atmosphere, it forms rust on its surface. To avoid the rust formation, fluxing was to be done as soon as possible [5]. The flux composition in this experiment was; 75 wt%$ZnCl_2$, 15 wt% NH_4Cl_2, 6wt%NaCl, 4wt% KCl in distilled water. For better effectiveness, the fluxing bath temperature is maintained at 40º C. The sample was dipped in this solution for about 5 minutes. The article was then to be dried at 200°C.

2.3 Galvanizing bath

In this experiment, the samples were immersed in different bath compositions. The standard temperature was maintained at 600-650°C. The immersion duration for all the samples was restricted at 1 minute. The bath composition used in this experiment was as shown:

1. Pure Zinc
2. % Al , 4% Pb, 95% Zn
3. 3.97% Al -Zn
4. 8.4% Al-Zn
5. 10.94%Al-Zn
6. 15.569%Al-Zn

Analysis of these samples via optical electron spectrometer is conducted, both pure zinc and aluminum collected commercially are also analyzed for their purity. The spectrometer analysis is as shown in Table 1.

Table 1. Result of purity analysis using optical electron spectrometer

	Al	Zn	Pb	Mg	Sn	Cu	Fe
Sample Pure Zn	-	99.984	-	-	.00208	-	.01325
Sample Pure Al	99.708	.00206	.00027	.00748	.00435	.00230	.16180
Sample 3.98% Al-Zn	3.9761	95.747	.00051	.00118	.00202	.26022	.01185
Sample 8.4% Al -Zn	8.4084	91.313	.00280	.00261	.00363	.25674	.01244
Sample10.97% Al-Zn	10.974	88.767	.00081	.00127	.00166	.24249	.01301
Sample15.57 % Al-Zn	15.569	84.169	.00081	.00126	00219	.24216	.01557

After the substrate is dipped, cooling is conducted in still air.

2.4 Corrosion test

After the galvanization process, corrosion test was carried out through various concentrations of sodium chloride solutions. These concentrations were 5% NaCl, 10% NaCl, 20% NaCl. The rate of corrosion at different solutions were also measured. The same procedure was also maintained for 8.4% Al-Zn, 10.96% Al-Zn, 15.56%Al-Zn,8.4% Al-Zn samples. This was as shown in Figure 2.

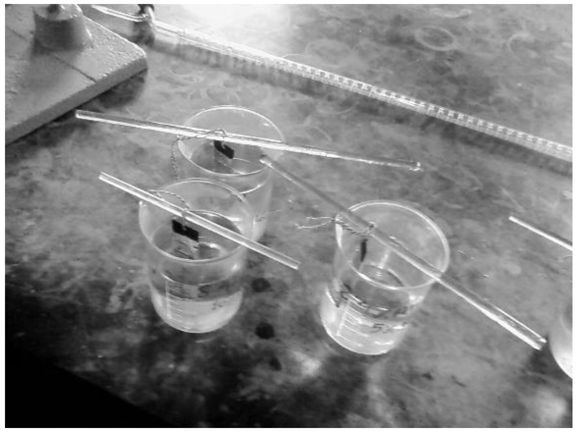
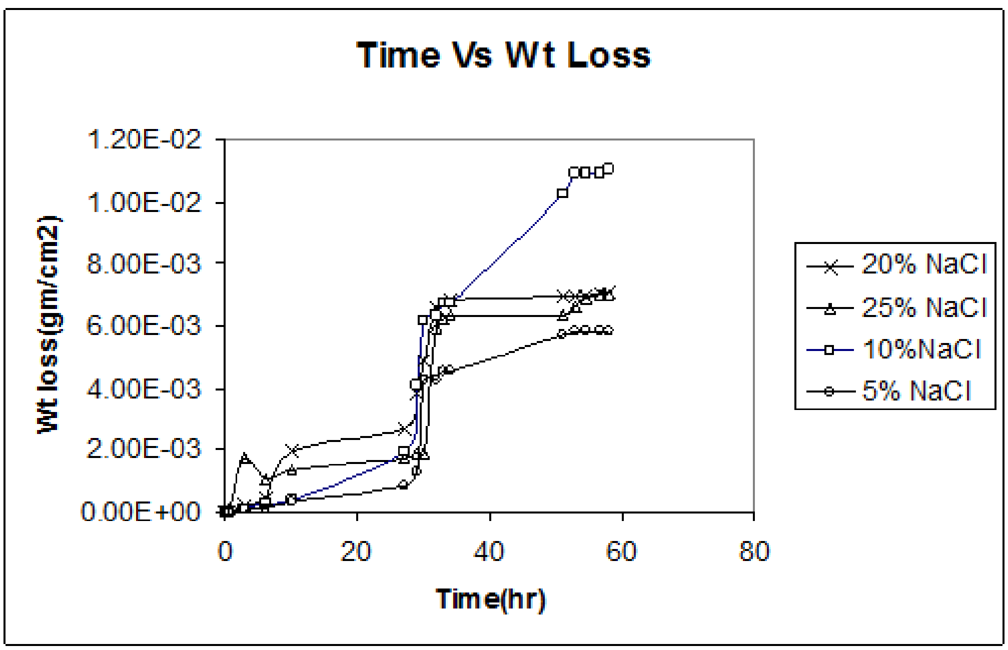


Figure 2. Sodium chloride solution

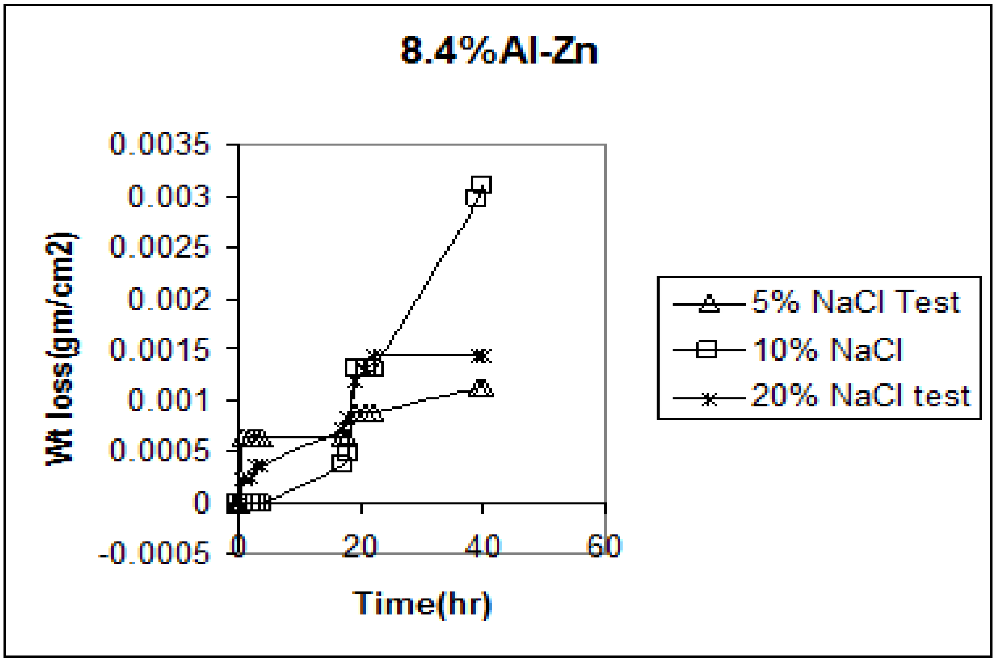
3. Results and Discussion

The rate of corrosion against time of 3.33% of AlZn in a NaCl media can be graphically represented as follow;



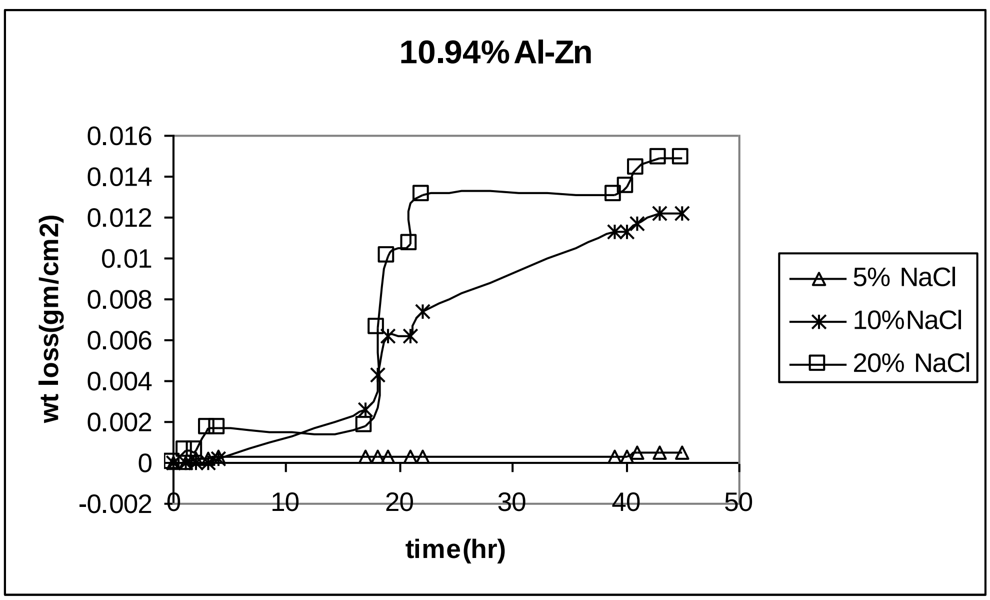
Graphic 1. Corrosion rate

According to the graph, the reaction can be categorized into three parts that include the active, passive and the transmissive regions. The active region normally appears like any other metal. The passive region is reached where the time weight increases fast to a level where the weight drops marginally. The corrosion rate increases with time after ushering in the transpassive phase. According to the graph, the state of corrosion is higher in a NaCl solution that is 10%. In a case where the concentration of Zinc and Aluminum is raised to 8.4%, a completely different graph is produced.



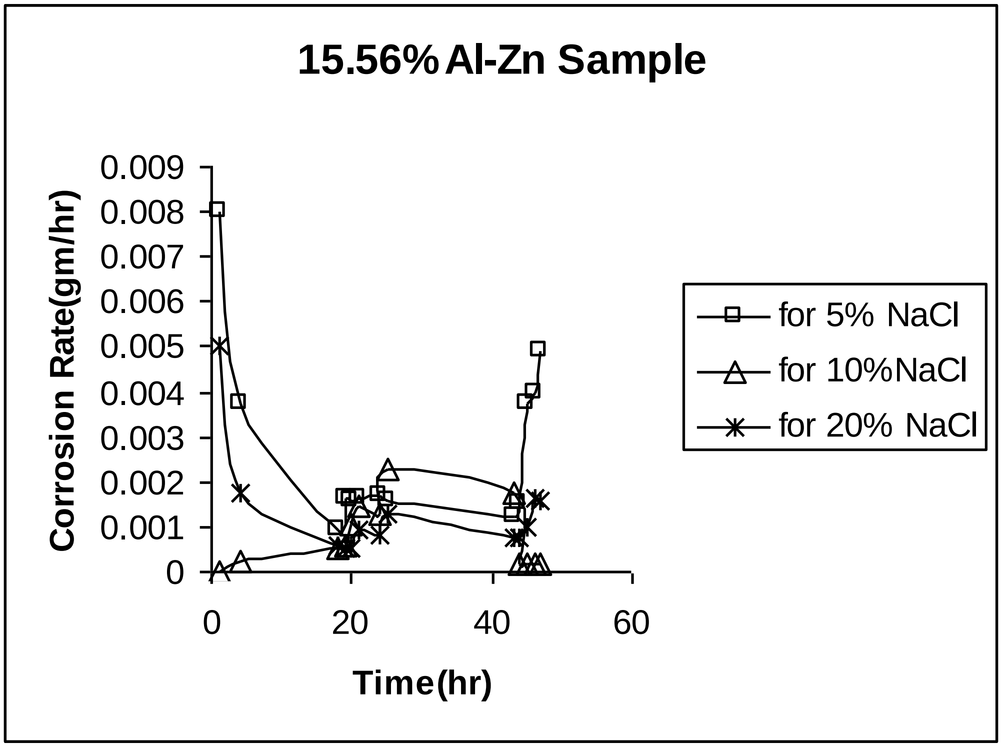
Graphic 2. Corrosion rate in 8.4% Al-Zn

In the above presentation, the rate of corrosion rate is higher in 10% and 20% than the 5% solution of NaCl. The rate of corrosion is higher in transpassive phase in the 10% solution while the 5% solution, the passive region is shorter.



Graphic 3. Corrosion rate in 10.94% Al-Zn

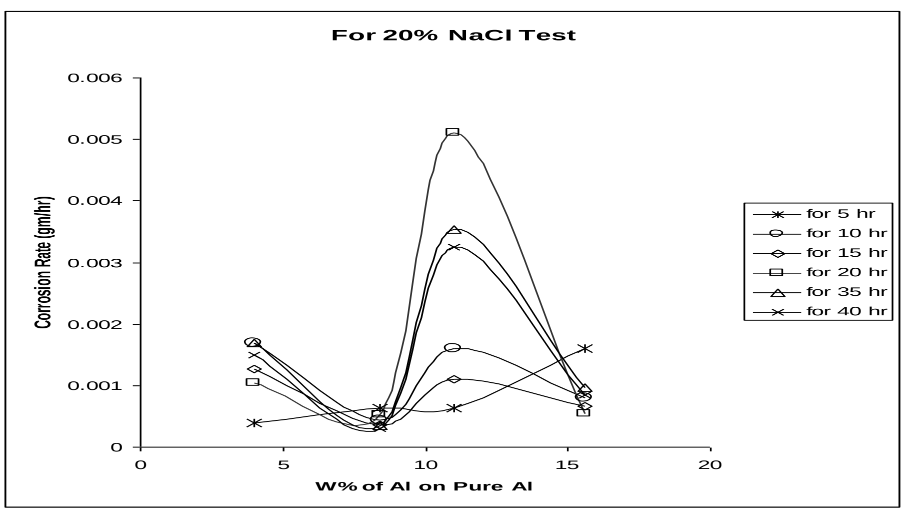
In the figure above, 20% NaCl rate of corrosion is higher than any other solution in active and trans passive state, the corrosion rate of 5% NaCl is almost constant than any other region.



Graphic 4. Corrosion rate in 15.56 Al-Zn

In the above diagram, 5% NaCl rate of corrosion is higher in active region than the others. The corrosion rate of 5% NaCl also goes passive state more quickly than the others. Immediately after passive state 10% NaCl rate of corrosion decrease. Corrosion rate of 5% NaCl increase more than 20% NaCl.

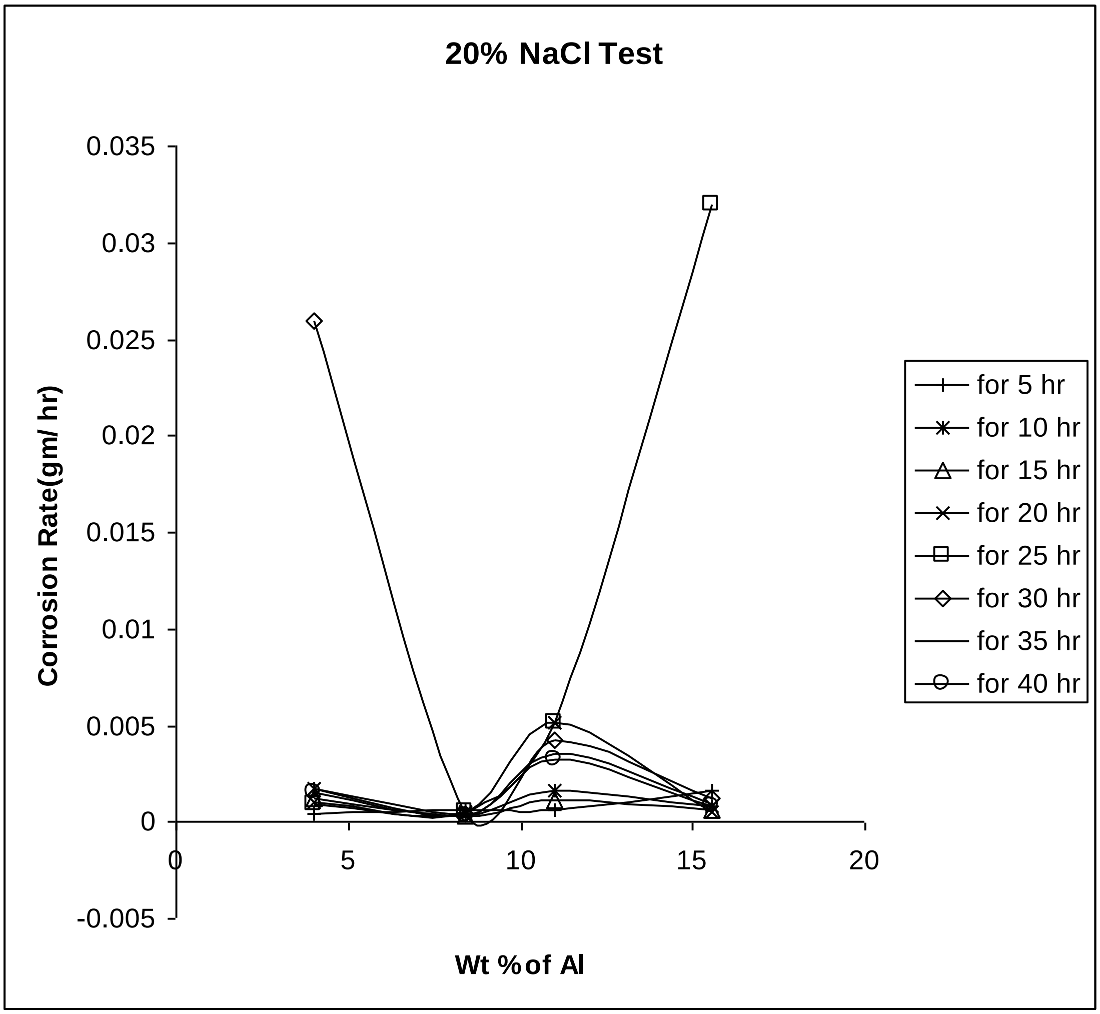
3.1 Corrosion Rate Vs. Wt% of Al with 20% NaCl Solution



Graphic 5. Corrosion rate vs. Wt% of Al on Pure Al

The graph above shows 20% NaCl test of different samples. It is however observed that with no corrosion rate in 5hrs, the rest for all are in the similar pattern. In the beginning, corrosion rate reduces with increasing the percentage of aluminum up to 8.4% Al. Then corrosion rate increases with increasing of aluminum. This is observed for increasing % Al up to 10.94% Al. The corrosion rate again decreases, though, after 5hrs, the rate of corrosion increases with increasing percentage of aluminum.

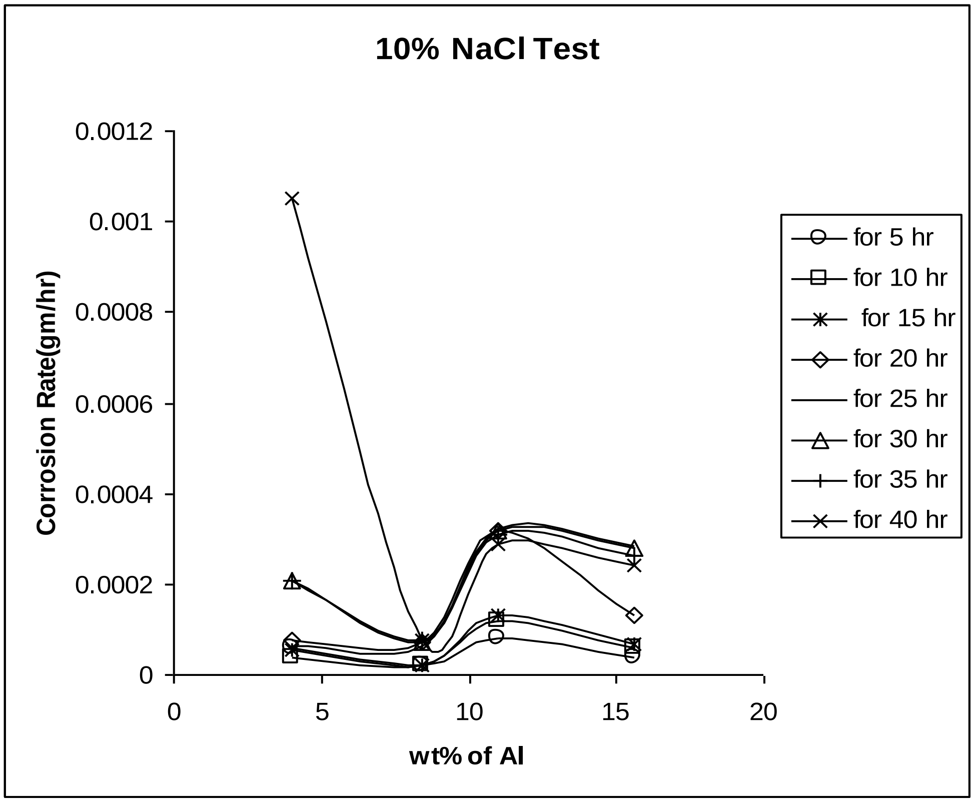
Corrosion rate for 25hr and 30hr again shows different behavior. As illustrated in the figure below. In 25hr, the corrosion rate is at first constant for increasing the percentage of aluminum up to 8.4% Al. Corrosion rate then increases abruptly. Corrosion rate decreases with increasing %Al. A decrease in corrosion rate is then detected as shown in the figure below.



Graphic 6. Corrosion rate vs. Wt% of Al

3.2 Corrosion Rate Vs. Wt% of Al with 10% NaCl Solution:

It is observed in the figure below that from 5 to 35hr are in the similar pattern. The rate of corrosion at first decreases up to about 8.4% Al then again increases up to about 10.94% Al. Corrosion rate again decreases sharply for 40hrs in first portion.



Graphic 7. Corrosion rate vs. Wt% of Al with 10% NaCl

3.3 Corrosion Rate Vs. Wt% of Al for 20% NaCl Solution

The figure below shows 5 to 35hr corrosion rate behavior with increasing in % of aluminum is the same. In such a case, corrosion rate slightly increases then decreases. Corrosion rate again increase. Corrosion rate in this stage is higher than the first case. In 40hr, corrosion rate decreases then later it increases [11] confirms this.

According to Panzenböck, and Schütz, (2014) in the industrial situation, materials made from galvanized steel last longer especially industrial once which when painted may last for 25-40 years without having another coating in that period[12].

Again, the galvanization as a method of coating is considered better than the conventional use of paints in which some are organic and previous [13]. This compared to galvanization coating that is more resistant to external factors both physical and chemical.

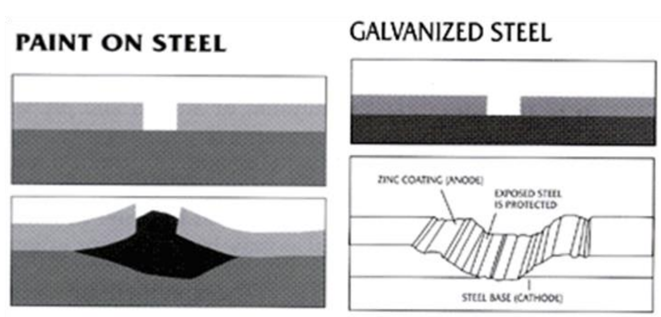


Figure 3. Steel Coatings

However, the ability of the galvanized materials to resist erosion and the resistance period is highly affected when they are exposed to extreme temperatures above 200C [14].
This can be diagrammatically represented as follows:

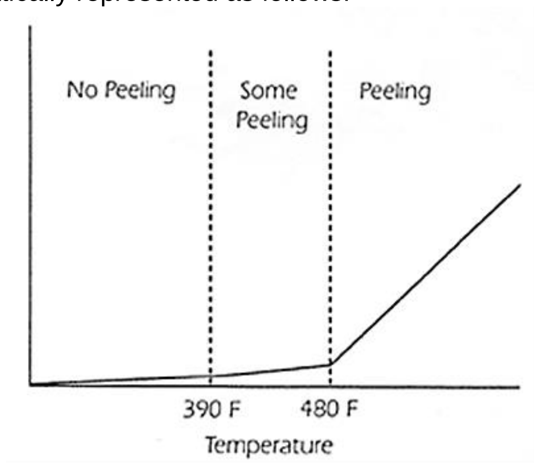


Figure 4. Material performance

Iron and steel are prone to corrosion hence need to undergo the galvanizing process for protection from such corrosions [15]. Simpson, (1993) affirms that aluminum is a very important element used in the galvanizing process because of its thick, hardness and other mechanical and physical properties [16]. The galvanizing process consists of various layers where the first metals are having iron zinc compounds then later covered entirely with aluminum. The importance of zinc coating varies on various things [17]. First is the slow rate of corrosion compared to that of iron, the less appearance of the zinc products and the protection of iron by zinc through the electrolysis process. The concentration of aluminum up to a percentage of 0.01% in an alloy of Cadmium and iron help in improving drainage and increment of the brightness of the coating. An aluminum concentration of a percentage lower than 0.01% is maintained in the zinc bath upon using bath flux. The coating in both zinc and steel are applied to protect the metal against corrosion [18].

4. Conclusion

The aluminum coating has various positive impacts cutting across economic, physical and mechanical impacts which are very evident when applied. According to Toi, Kobashi, and Iezawa, (1994) galvanizing process is renowned for its attractive and economic nature, protecting the corroded the industrial and commercial steel articles [19]. Examples include siding roofing nails, roofing, and other fasteners. The commercial use of the zinc-coated iron and the galvanized steel that is painted is dated back to the 19th century. The original hot-dipped process is the corrugated sheet, hence used as a roofing material. Individual sheets of steel were dipped by hand into a molten zinc bath after cleaning of sulfuric acid together with ammonium chloride in the original hot –dip process. It's also very important to note that freshly galvanized steel always progresses through the natural processes of weather. An article experiences a natural protective patina, during the first few weeks of galvanization [20]. Upon proper development, patina provides corrosion for the active zinc.

References

[1] Cross, S., Gollapudi, S. and Schuh, C. (2014). Validated numerical modeling of galvanic corrosion of zinc and aluminum coatings. *Corrosion Science*, 88, pp.226-233.

[2] Daloz, D., Steinmetz, P. and Michot, G. (1997). Corrosion Behavior of Rapidly Solidified Magnesium-Aluminum-Zinc Alloys. *CORROSION*, 53(12), pp.944-954.
[3] DAVIES, D., DENNISON, J. and MEHTA, M. (1971). Stress Corrosion Crack Propagation and Cathodic Protection in Medium Strength Aluminum-Zinc-Magnesium Alloys. *CORROSION*, 27(9), pp.371-375.
[4] DEVILLERS, L. and NIESSEN, P. (1976). Accelerated Grain Boundary Corrosion of Dilute Zinc-Aluminum Alloys Under High Applied Cathodic Currents. *CORROSION*, 32(4), pp.152-154.
[5] Garbracht, K. (2001). Surface coating of Fe3Si-sheet won steel research Best Paper Award 2000. *Steel Research*, 72(9), pp.376-377.
[6] HAEUSELER, H. and CANSIZ, A. (1983). ChemInform Abstract: THE ZINC ALUMINUM SULFIDE (ZNAL2S4)-ZINC GALLIUM SULFIDE (ZNGA2S2), ZINC ALUMINUM SULFIDE-CADMIUM ALUMINUM SULFIDE (CDAL2S4), AND ZINC ALUMINUM SULFIDE-ZINC ALUMINUM SELENIDE (ZNAL2SE4) QUATERNARY SYSTEMS. X-RAY AND VIBRATIONAL SPECTR. *Chemischer Informationsdienst*, 14(25).
[7] Hazan, J. and Yahalom, J. (1993). Corrosion of protected aluminum and zinc. *Corrosion Science*, 35(1-4), pp.223-229.
[8] Kautek, W. (1988). The galvanic corrosion of steel coatings: aluminum in comparison to cadmium and zinc. *Corrosion Science*, 28(2), pp.173-199.
[9] Lapshin, V. (1975). GK-2 four-tub galvanization device. *Biomedical Engineering*, 9(6), pp.361-362.
[10] Larouk, Z. and Yakhlef, F. (2012). Microstructure Characterization of Low Carbon Steel Used for Galvanization. *Advanced Materials Research*, 445, pp.703-708.
[11] McMurray, H. (2001). Localized Corrosion Behavior in Aluminum-Zinc Alloy Coatings Investigated Using the Scanning Reference Electrode Technique. *CORROSION*, 57(4), pp.313-322.
[12] Panzenböck, M. and Schütz, P. (2014). Embrittlement of Mild Steels during Hot Dip Galvanization. *Microscopy and Microanalysis*, 20(S3), pp.1868-1869.
[13] Schonbein, N. (1842). New theory of the galvanization of metals. *Journal of the Franklin Institute*, 33(2), p.111.
[14] SHETH, K. and CHAR, T. (1962). Corrosion Inhibition of Aluminum-Zinc Alloy in Hydrochloric Acid Solutions. *CORROSION*, 18(6), pp.218t-223t.
[15] Shi, L., Chen, J., Zhang, F. and Shang, G. (2011). The Research and Preparation of one Kind of Sylvite Galvanization and Sulfate Galvanization General Brightener. *Advanced Materials Research*, 230-232, pp.226-229.
[16] Simpson, T. (1993). Accelerated Corrosion Test for Aluminum-Zinc Alloy Coatings. *CORROSION*, 49(7), pp.550-560.
[17] Sotoudeh, K., Nguyen, T., Foley, R. and Brown, B. (1981). The Chemical Nature of Aluminum Corrosion: I Corrosion of Aluminum Surfaces by Aluminum Salts. *CORROSION*, 37(6), pp.358-362.
[18] Tang, N. and Liu, Y. (2010). Corrosion Performance of Aluminum-containing Zinc Coatings. *ISIJ International*, 50(3), pp.455-462.
[19] Toi, Y., Kobashi, K. and Iezawa, T. (1994). Finite element analysis of thermal elasto-plastic behaviours of bridge girders in hot-dip galvanization. *Computers & Structures*, 53(6), pp.1307-1316.
[20] Wang, R., Zhang, P., Wang, Y., Wu, H., Wei, D., Wei, X., Wang, Q. and Chen, X. (2013). Galvanic corrosion behaviour of hot-dipped zinc-aluminum alloy coated titanium-aluminum couples. *Materials and Corrosion*, 65(9), pp.913-918.