Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 13 (2), December 2024, pp 2553-2559
ISSN 2147-3471 © 2024

Structural and Morphological Analysis of Electrogalvanized Coating on Sheet Metal

Anıl Şeker*, Merve Hatipoğlu, İrem Arı, Yaren Çetin

Demircioğlu Group, R&D Center, Bursa, Turkey

Accepted 25 June 2024

Abstract
Steel plays a key role in many areas around the world, including the automotive, machinery and equipment, energy, construction and infrastructure industries. In developing countries, the steel industry has led and continues to lead other sectors. As a result of the rapid developments in steel production, the industrial revolution has taken place and great advances have been made in the field of technology. Steel used in industry has high strength, corrosion resistance and advanced production technology. Chemical or electrochemical reactions occur over time on the surfaces of steel obtained as a result of various alloys of iron, depending on their usage areas and locations. In this case, surface coating process is carried out in order to protect the surface of metals against external factors. Metals such as zinc, copper, tin, chromium, nickel, nickel and gold are used in the surface coating process of steels. Zinc coating, which has the most widespread use among metallic coating methods, is called galvanizing. The most widely used method in the coating process in the automotive industry is the electrogalvanized coating method. The method is carried out by electrolysis. The steel part is immersed in an electrolyte solution and an electric current is applied to precipitate zinc ions on the metal surface. In this study, electrogalvanized (EG) coating applied on DD13 sheet material was investigated by Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) in terms of coating thickness, homogeneity, morphology and elemental properties. As a result, the zinc alloy content of the electrogalvanized coating, the distribution and density of the elements in the coating layer, and the corrosion resistance of the coating were examined.

Keywords: *Electro galvanized coating, zinc coating, SEM*

1. Introduction

Steel is a type of alloy composed primarily of iron and carbon, with carbon content typically ranging from 0.2% to 2.1% by weight. Steel is one of the most widely used materials in the world due to its durability and versatility. It is used in a wide variety of applications, including construction, transportation, machinery and consumer goods. The properties of steel can be modified by the addition of alloying elements or by heat treatment [1].

Depending on the area of use and location, various problems may be encountered on the surfaces of steel sheets over time. In order to prevent these problems and to increase the performance of steel materials, different solutions are applied to the steel surfaces and the sheets are coated [5].

Today, the protection of metal surfaces is as important as the use of alternative energy. One of the most common methods to protect the surface of metals against external factors is to coat the surface with another metal. For this purpose, metals such as zinc, copper, tin, chromium, nickel, gold, silver and aluminum are used. The most widely used surface coating metal is zinc. Since zinc is very active, it is a preferred element to protect metals. The process of coating the metal surface with zinc is called galvanizing [9].

Galvanized coating is a type of coating generally made to protect the material from corrosion. Galvanized coating has 6 types. These are hot dip galvanized coating, electrogalvanized coating, zinc spraying, steam galvanizing (dry galvanizing), mechanical coating, zinc rich paint coating. When choosing the galvanized coating method, the desired properties as a result of the coating, the service life of the coating, the environment (indoor or outdoor environment) where the material to be coated will be used, etc. situations are taken into consideration [3]. Galvanizing is usually done by hot-dip, electrolysis or metal spraying methods [4].

*Corresponding author: anilseker@hotmail.com

Electrogalvanizing is a special field of zinc electroplating. The term "galvanizing" refers to the coating of iron or steel with zinc. Originally, galvanizing was done by passing the strip through a bath of molten zinc, specifically known as "hot-dip galvanizing". With the advent of electrolytic deposition, the term "electrogalvanizing" evolved. Originally meaning zinc plating on a variety of substrates, the term is now focused on strip and wire substrates, particularly in the context of sacrificial protection for steel, and has found significant application in the automotive industry, especially since the mid-1980s [2, 13].

Galvanized coatings made by electrogalvanizing are the process of coating steel with a layer of zinc to protect it from corrosion. The zinc coating acts as a sacrificial anode, preferably corroding with respect to the steel substrate. This process is known as cathodic protection and is effective in preventing corrosion of the steel substrate [8, 10].

Generally, a longer or shorter galvanized coating life is directly proportional to the coating thickness [7]. In the electrolysis method, metal is connected to the cathode and zinc to the anode in the bath solution, and current is applied with a rectifier that provides a high current, low voltage generator, and electrons are removed from the anode and adhered to the cathode, that is, to the surface of the material. In the electrolysis method, decopage, in which the metal surface is cleaned, plating to protect the metal and passivation processes that increase corrosion resistance are carried out respectively. If the part whose surface is to be coated with metal is made a cathode in a suitable solution, the ion in the solution is collected at the cathode as an element [6]. Electro galvanized coating is the method mostly used for coating small sized metals because it forms a thinner surface layer compared to the hot dip process. Pure zinc is used in the electro galvanizing method. Electro galvanized coating process is completed by suspending, degreasing, washing, acid immersion, washing, zinc coating, washing, passivation, washing, drying, drying, unsuspension and packaging processes [11]. Since zinc is a very active metal, it can be combined with other elements and compounds. In the industrial field, zinc plating is done with different baths. These can be classified as acidic, alkaline cyanide-free, alkaline cyanide baths. These baths are used in different areas considering factors such as processing time, economy, adhesion to the surface and decorative appearance [12].

This study investigated the electrogalvanized (EG) coating applied on DD13 sheet material in terms of coating thickness, homogeneity, morphology and elemental properties. Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) were used to analyze the zinc alloy content of the electrogalvanized coating, the distribution and density of elements in the coating layer, and the corrosion resistance of the coating.

2. Method of the Study

2.1. Material

DD13 material sheet was used in this study. The chemical composition and mechanical properties of DD13 material are given in Table 1.

Table 1: DD13 chemical composition and mechanical properties

	Chemical Composition (%)					**Mechanical Properties**		
DD13	C	Mn	P	S	Al	Yield Stress (N/mm^2)	Tensile Stress at Rupture (N/mm^2)	Elongation Amount (%)
	0,08	0,40	0,03	0,03	0,002	170-310	400	33

2.1.2 Coating Parameters

DD13 sheet material electrogalvanized coating process was first subjected to surface preparation. For surface preparation, a process called hot degreasing was performed at 40-70°C. It was then kept in a controlled acid pool at ambient temperature. After 8-10 minutes of controlled waiting in the pool where zinc plating was carried out, it was taken back to the acid pool. It was then transferred to the electric degreasing pool. After the surface was prepared, the DD13 sheet material was rinsed. The material was immersed in a zinc bath at 25-32°C. After neutralization with nitric acid, which is the post-coating process, yellow color passivation was carried out respectively. The product was taken to the lacquer pool for the protection and aesthetic improvement of the coating applied on metal surfaces. Finally, the electrogalvanized coating process was completed by drying for 8-12 minutes. After the completion of the processes, DD13 sheet material was examined.

2.1.3 Sample Preparation
DD13 sheet material was cut with a rough cutting device in 15-15 mm dimensions. The cut sample was cold bakelite to prevent damage to the coating. After the bakelite section sample was sanded with SiC paper sanding and polishing device, the sample preparation process was completed. The bakelite section of the sample is given in Figure 1.

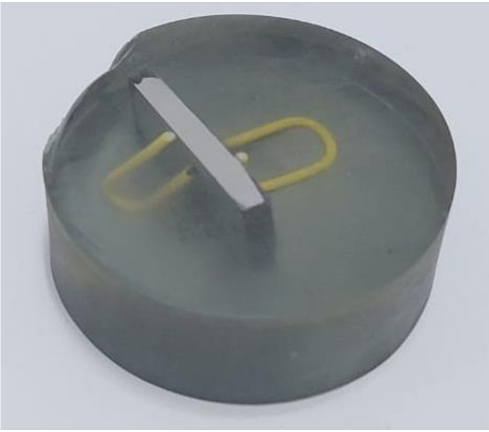


Figure 1: Bakelite section of the sample

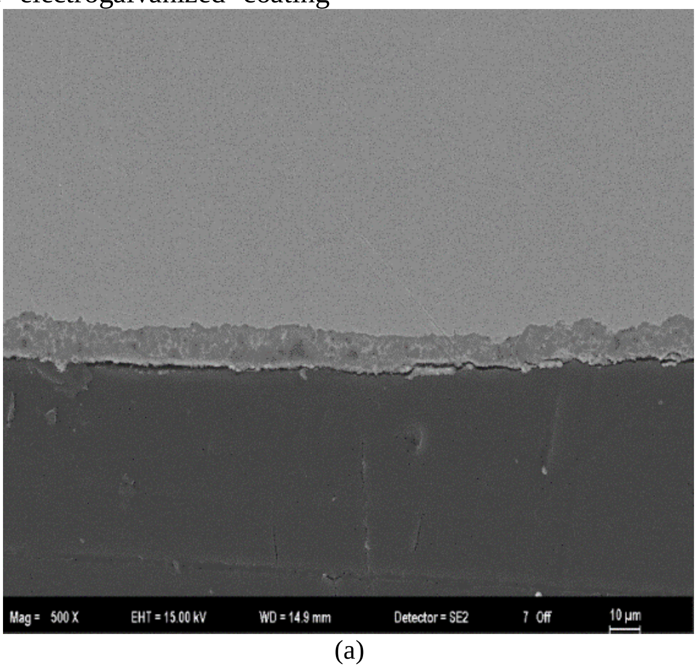
2.2. Structural Investigations
2.2.1. Scanning Electron Microscopy (SEM)
Scanning electron microscopy (SEM) equipped with EDS (energy dispersive spectrometer) was used to examine the coating cross-section. The cross-sectional view of the samples is given in Figure 2.

Figure 2 shows the cross-sectional images of the electrogalvanized sample at 500X, 1000X and 2000X magnification. In the SEM images; it was observed that a distinct coating layer was formed on the surface of the sample after the electrogalvanized coating process. It was determined that the coating layer was homogeneously distributed and the surface had a generally uniform morphology. However, some micro cracks and roughness were also observed in the high resolution images.

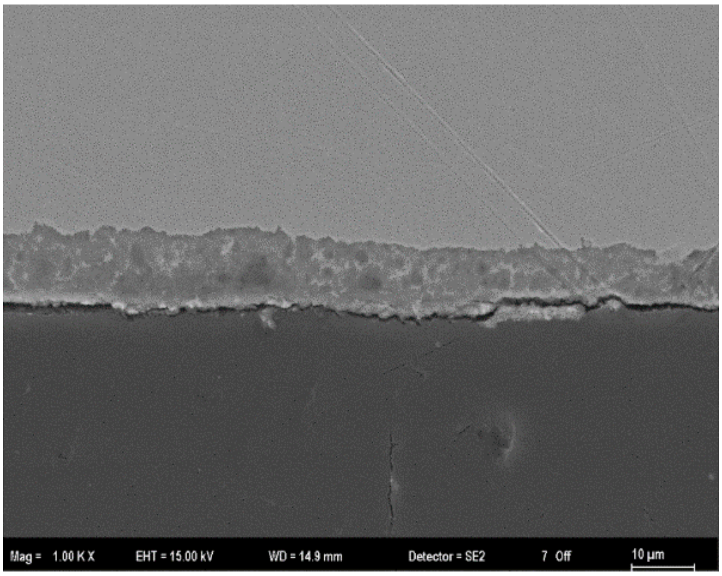
Figure 3 shows the coating thickness of the electrogalvanized sample. The coating thickness was measured at five different points of the coating surface. As a result of these measurements, it was determined that the average coating thickness was 11.42 μ. Considering factors such as environmental conditions and frequency of use, it is predicted that the optimum coating thickness should be between 8 and 30μ for electrogalvanized coating to provide adequate protection. In this case, it was determined that the electrogalvanized coating applied on DD13 sheet material meets these optimum conditions.

Figure 4 shows the EDS analysis image of the electrogalvanized sample. Table 2 shows the percent atomic concentration values of the electrogalvanized sample. When the values are examined, it is seen that the oxygen ratio in the electrogalvanized coating area is 57.93%, iron is 3.65% and zinc is 38.43%. In the bakelite region, the oxygen content was 90.32%, iron 1.36% and zinc 8.32%.

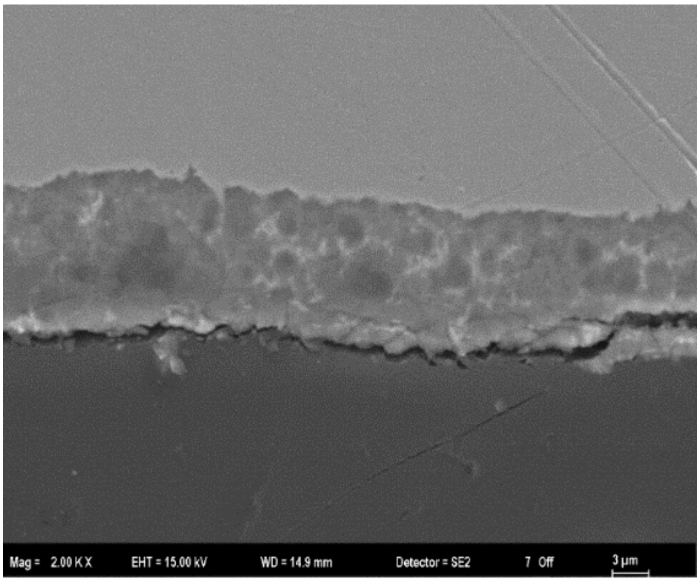
In the base (steel) region, the oxygen content was 0.62% and iron 99.38%. The zinc concentration value in the electogalvanized coating layer provides information about the thickness and homogeneity of the coating. A higher zinc concentration indicates a thicker coating layer or a more homogeneous coating process.



(a)



(b)



(c)

Figure 2. Cross-sectional views of the electrogalvanized specimen at a) 500X b) 1000X c) 2000X magnification

Table 2. EDS analysis values of the electrogalvanized sample

Atomic Concentration (%)			
Layer	**Oxygen**	**Iron**	**Zinc**
Electrogalvanized Coating Zone	57,93	3,65	38,43
Bakelite Region	90,32	1,36	8,32
Underlay (Steel) Zone	0,62	99,38	0

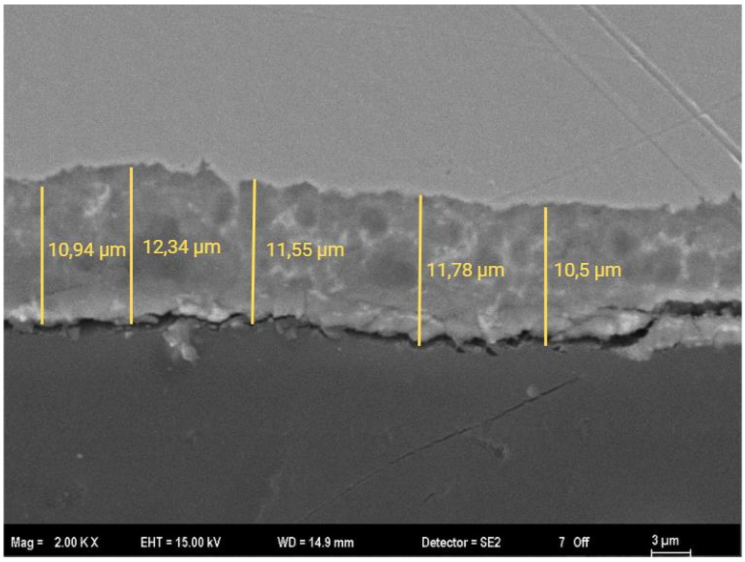


Figure 3. Image of the coating thickness of the electrogalvanized sample

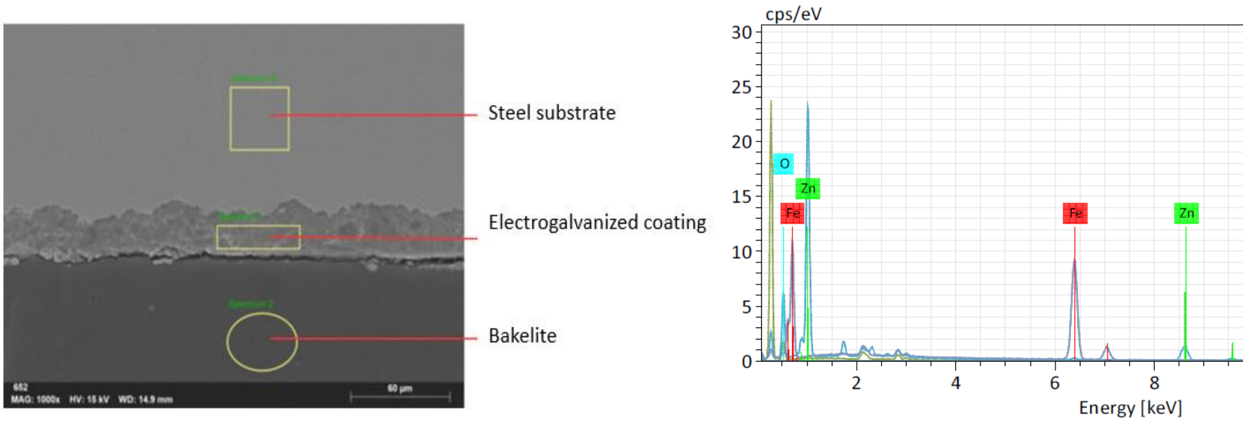


Figure 4. EDS analysis image of the electrogalvanized sample

Figure 5 shows the SEM-EDS elemental mapping image of the electrogalvanized sample. In the images, it is observed that the surface of the zinc coating layer is homogeneous. The EDS maps showed that the coating layer was enriched with zinc and the elements of the base material were not present in the coating layer. The EDS mapping results show that the steel substrate material contains Fe and is mainly composed of carbon in the region where bakelite is present.

3. Findings and Discussions

Electrogalvanized specimens were subjected to salt fog test for 480 hours. Firstly, white layer and color change were observed at 192 hours. It is seen in Figure 6 c that the white layer and color change spread at 480 hours, which is the end of the test. This test is performed to measure the corrosion resistance time of the specimen.

Upon completion of the full 480-hour test period, further examination revealed that the white layer and color changes had become more widespread. The progress observed during this test indicates that although the electrogalvanized coating initially provides a protective barrier, its effectiveness decreases over time. The white layer and color changes indicate that the coating is not fully protecting the substrate against the effects of corrosion. The data obtained from the 480-hour salt fog test provide valuable information to evaluate the corrosion resistance of electrogalvanized coatings and the durability of this coating method under corrosive conditions.

Future studies may focus on investigating alternative coating methods or treatment methods to increase the durability and corrosion resistance of galvanized coatings.

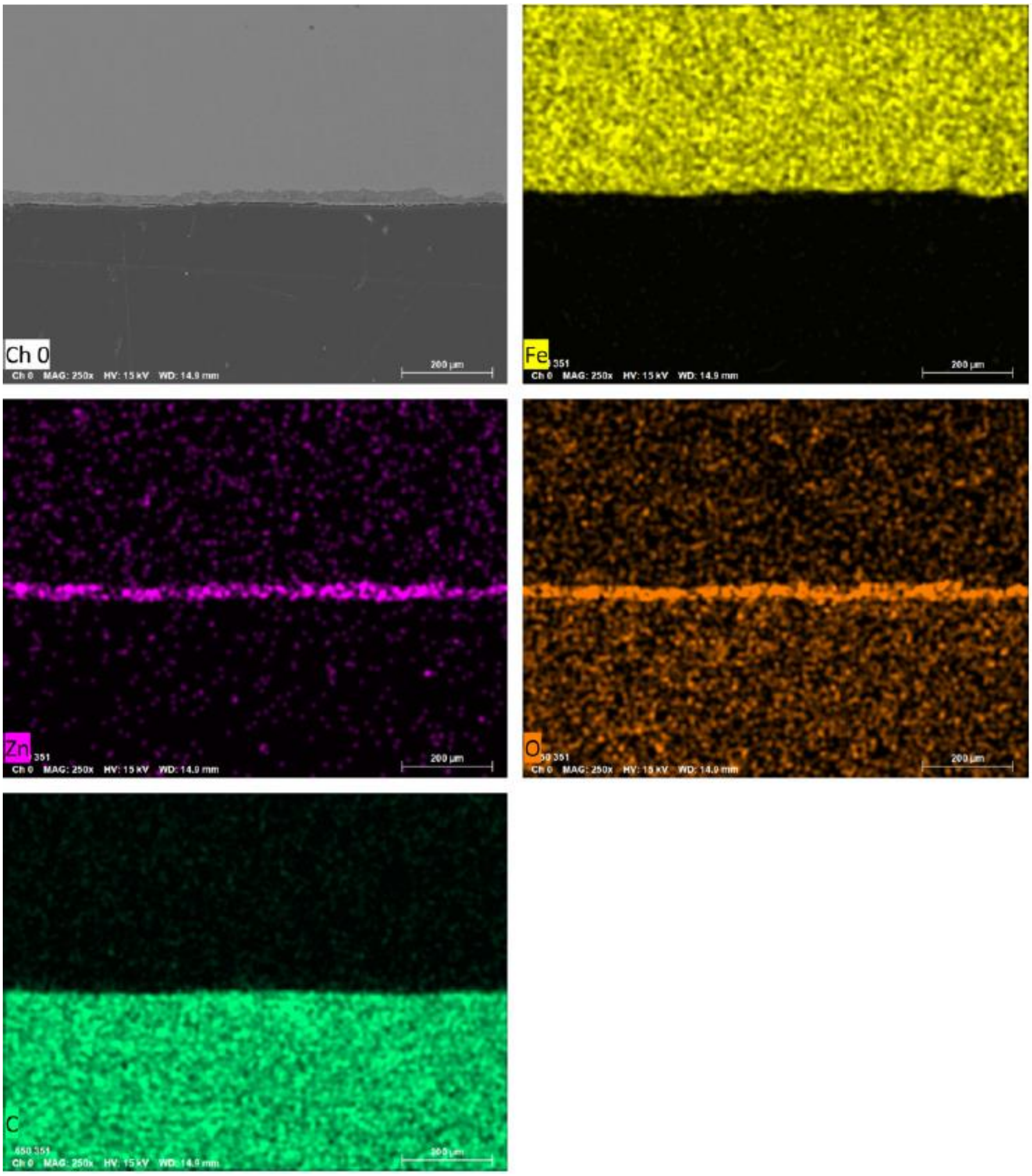


Figure 5. SEM-EDS elemental mapping image of the electrogalvanized sample

(a) (b) (c)

Figure 6. Appearance of electrogalvanized specimen a) before salt fog test b) at 192 hours c) at 480 hours

4. Conclusion

In this study, electrogalvanized (EG) coating applied on DD13 sheet material was imaged by Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) for coating thickness, homogeneity, morphology and elemental properties. During imaging, high-resolution EDS maps were taken to determine the elemental distribution in different regions. Field EDS analysis was performed on the electrogalvanized coating sample to determine the chemical composition of different regions. A salt fog test was performed for the corrosion resistance of the sample.

According to the Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) imaging results of the electrogalvanized coating, it was determined that the surface had a homogeneous distribution and a generally uniform morphology.

The zinc coating thickness of 11.42 µm, which is the amount of zinc coating thickness applied on DD13 sheet material, is within the standard value range of 5-25 µm zinc coating thickness determined according to ASTM B633-13 standards and the coating applied is in accordance with the specified standards.

According to ASTM B117/ISO 9227 Standard for Corrosion Tests in Artificial Atmospheres, "After the test applied for 720 hours, there should be no surface defects such as staining, deterioration, cracking, fracture, flaking, delamination and red rust on at most 5% of the part surface", it was observed that the red rust rate on the coating was below &5% and no surface defects occurred as a result of the salt fog test performed for 20 hours under conditions in accordance with the standards.

It was seen that the temperature, pH, salt mixture combinations affecting the coating quality in the electrogalvanized coating process provided optimum conditions according to ASTM B117/ISO 9227 and ASTM B633-13 standards.

Electrogalvanized coating has been found to be preferable in various applications considering its features such as low coating thickness, high performance and post-assembly applicability.

References

[1]. Krauss, G. (2015). Steel: Processing, structure, and performance. ASM International.
[2]. Smith, W. F. (1990). Principles of materials science and engineering (2nd ed.). McGraw-Hill International Editions.
[3]. Hirn, A. (2019). NG galvanizing handbook. Nordic Galvanizers.
[4]. Güven, V. (1999). Continuous zinc coating using the hot-dip method [Master's thesis, Istanbul Technical University, Institute of Science and Technology].
[5]. Şenyüz, G. (2008). Comparison of the forming capabilities of 304 quality stainless steel and galvanized sheets [Master's thesis, Institute of Science and Technology].
[6]. Kaya, B. (2007). Nano composite coating [Master's thesis, Institute of Science and Technology].
[7]. Uyanık, M. (2012). Investigation of the effects of SIC nanoparticle-added acidic zinc plating baths on the corrosion resistance and mechanical properties of the material [Master's thesis, Institute of Science and Technology].
[8]. Jia, J. X., Song, G., & Atrens, A. (2007). Experimental measurement and computer simulation of galvanic corrosion of magnesium coupled to steel. Advanced Engineering Materials, 9(1–2), 65–74. https://doi.org/10.1002/adem.200600150
[9]. Özer, N. (2021). Corrosion in construction materials and methods of corrosion protection. Uludağ University Journal of Engineering Faculty, 26(3), 1159–1178. https://doi.org/10.17482/uumfd.887249
[10]. Karakas, Ö. (2013). Consideration of mean-stress effects on fatigue life of welded magnesium joints by the application of the Smith–Watson–Topper and reference radius concepts. International Journal of Fatigue, 49, 1–17. https://doi.org/10.1016/j.ijfatigue.2012.12.007
[11]. Ç. V. S. G. Ministry & İ. Directorate. (2016). Assessment of occupational health and safety risks and chemical exposure in galvanizing workplaces.
[12]. Hasçalık, A., & Özek, C. (2002). Examination of parameters for zinc plating by electrolysis method. Technology, 5.
[13]. Gerengi, H, Sen, N, Uygur, I, Kaya, E, (2020). Corrosion behavior of dual phase 600 and 800 steel in 3.5 wt.% NaCl environment, Journal of Adhesion Science and Technology, Vol.34, No.8, pp. 903-915.