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Research Article

The effect of Centrifuged Hot-Dip Galvanisation (CHDG) Process on the Corrosion on Nuts

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ABSTRACT

The bolted fasteners, widely used in various industries, are the fundamental structural components most commonly used in the assembly of steel structures. Bolted fasteners offer advantages such as versatility, reliability, minimal maintenance and inspection costs, easy and fast assembly, and good strength under variable loads. However, fastener failures occur due to complex loading conditions, hydrogen embrittlement during fabrication or service, fatigue failures due to alternative stress, and combined effects of corrosion and stress. Therefore, the study of fastener failure is critical for safety in both every day and industrial applications. Zinc plating has long been a preferred method of protecting fasteners from corrosive environments. One of the most commonly used methods for coating fasteners today is the centrifugal hot dip galvanising (CHDG) process. CHDG is suitable for outdoor applications on small metal parts (bolts, nuts, washers) that cannot be hot dip galvanised. Centrifugation removes all excess zinc from the threads of bolts. Oversized nuts fit perfectly on very small parts. In this study, nut samples coated with CHDG were exposed to corrosion in a corrosive environment according to ASTM B117 standards. At the end of thirteen (13) days, the outer surface of the nut attached to the screw was cut and the screw steps were examined using scanning electron microscopy (SEM) and energy dispersive X-ray spectrometry (EDS). The results show that the zinc coating on the surface produced by the CHDG process is effective in protecting the metal nuts against corrosion. The zinc patina begins its development with exposure to oxygen in the atmosphere, forming a layer of zinc oxide on the surface. Moisture from rain or humid air reacts with the zinc oxide to form zinc hydroxide which then reacts with carbon dioxide present in the air to form the tightly adherent, insoluble zinc patina.

Keywords: *Corrosion, Nut, Centrifugal Hot Dip Galvanising*

Santrifüjlü Sıcak Daldırma Galvaniz (SHDG) İşleminin Somunlar Üzerindeki Korozyona Etkisi

ÖZ

Çeşitli endüstrilerde yaygın olarak kullanılan cıvatalı bağlantı elemanları, çelik yapıların montajında en yaygın olarak kullanılan temel yapısal bileşenlerdir. Cıvatalı bağlantı elemanları çok yönlülük, güvenilirlik, minimum bakım ve denetim maliyeti, kolay ve hızlı montaj ve değişken yükler altında iyi mukavemet gibi avantajlar sunmaktadır. Bununla birlikte, bağlantı elemanı arızaları karmaşık yükleme koşulları, imalat veya servis sırasında hidrojen gevrekleşmesi, alternatif stres nedeniyle yorulma arızaları ve korozyon ve stresin birleşik etkileri

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nedeniyle meydana gelmektedir. Bu nedenle, bağlantı elemanı arızalarının incelenmesi hem günlük hem de endüstriyel uygulamalarda güvenlik açısından kritik öneme sahiptir. Çinko kaplama, bağlantı elemanlarını korozif ortamlardan korumak için uzun zamandır tercih edilen bir yöntemdir. Günümüzde bağlantı elemanlarının kaplanmasında en yaygın kullanılan yöntemlerden biri santrifüj sıcak daldırma galvanizleme (SHDG) işlemidir. SHDG, sıcak daldırma ile galvanizlenemeyen küçük metal parçalar (cıvatalar, somunlar, pullar) üzerindeki dış mekan uygulamaları için uygundur. Santrifüjleme, cıvataların dişlerindeki tüm fazla çinkoyu giderir. Büyük boyutlu somunlar çok küçük parçalara mükemmel uyum sağlar. Bu çalışmada, SHDG ile kaplanmış somun numuneleri ASTM B117 standartlarına göre korozif bir ortamda korozyona maruz bırakılmıştır. On üç (13) günün sonunda vidaya bağlı somunun dış yüzeyi kesilmiş ve vida basamakları taramalı elektron mikroskobu (SEM) ve enerji dağılımlı X-ışını spektrometresi (EDS) kullanılarak incelenmiştir. Sonuçlar, SHDG işlemiyle üretilen yüzeydeki çinko kaplamanın metal somunları korozyona karşı korumada etkili olduğunu göstermektedir. Çinko patina, atmosferdeki oksijene maruz kaldığında gelişmeye başlar ve yüzeyde bir çinko oksit tabakası oluşturur. Yağmurdan veya nemli havadan gelen nem çinko oksit ile reaksiyona girerek çinko hidroksit oluşturur ve bu da havada bulunan karbondioksit ile reaksiyona girerek sıkıca yapışan, çözünmeyen çinko patinayı oluşturur.

Anahtar Kelimeler: *Korozyon, Somun, Santrifüj Sıcak Daldırma Galvaniz*

I. INTRODUCTION

Corrosion is defined as the deterioration of a material, usually a metal, due to its reaction with the environment [1]. The destructive effects of corrosion have a direct impact on the durability and safety. Corrosion is an extremely important economic problem. Economic losses are directly related to the necessity of replacing damaged structures, machinery, equipment, or their components. These losses result from the use of costly corrosion-resistant materials, expenses associated with corrosion protection, and are also indirectly influenced by production stoppages due to the need to replace parts or repair damage [2], [3].

There are five primary methods of corrosion control that play a vital role in mitigating the detrimental effects of corrosion: material selection, coatings, inhibitors, cathodic protection and design. Material selection involves selecting materials that are inherently resistant to corrosion or that can be treated to increase their resistance. Coatings, such as paints and metallic coatings, create barriers between the metal surface and the corrosive environment, preventing direct contact and corrosion initiation. Inhibitors are chemicals that can be added to the environment or applied directly to the metal surface to inhibit corrosion reactions. Cathodic protection involves the application of an external electrical current or sacrificial anode to shift the corrosion potential of the metal to a more passive state. Finally, design considerations such as proper drainage, ventilation and avoidance of crevices can minimize corrosion by reducing the accumulation of moisture and corrosive agents. Each of these methods is critical to effective corrosion management and will be further explored in subsequent chapters to provide a comprehensive understanding of corrosion control strategies (Figure 1).

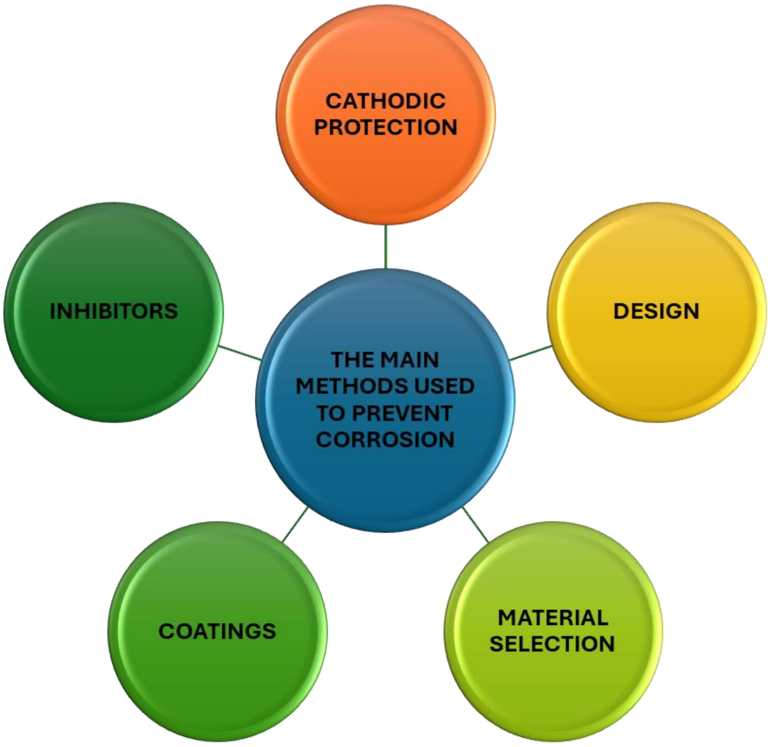


Figure 1. *The main methods used to prevent corrosion*

The world population has been growing at a significant rate in recent decades. Naturally, the consumption of all type of metals increases accordingly. Steel is the most widely used material in the world due to its versatility, low cost and good strength properties [4]. Carbon steel products are widely used in the automotive, infrastructure and construction industries. It is a material that determines the development of industry and society as a whole, and its production is constantly growing [5]. It is therefore important to be able to preserve this metal cheaply and effectively for a long period of time.

Zinc has been widely used in the surface treatment of various steel structures to improve the service life of the structure, due to its good corrosion resistance. Zinc forms galvanized steel after solidification on the surface of the steel [6].

The hot-dip galvanizing process offers a unique combination of superior properties such as high strength, formability, light weight, corrosion resistance, low cost and recyclability. In the hot dip galvanizing process, a steel sample is cleaned, fluxed and then immersed in a molten zinc bath at a temperature of approximately 450 °C [7]. Hot dip galvanized steels have been extensively used in industrial sectors such as automobiles, household appliances or construction due to their excellent corrosion resistance properties [8], [9]. While the hot-dip galvanizing process is successfully applied to large metal parts, the centrifugal hot-dip galvanizing process (CHDG) is applied to small metal parts. Centrifugation is employed to achieve a homogeneous coating by removing excess zinc from the surface. In this process, the steel product is rotated in a crucible to facilitate the removal of excess zinc through centrifugal force. Consequently, a more uniform and thinner zinc coating is achieved, enhancing the quality of the coating and providing more durable protection (Figure 2).

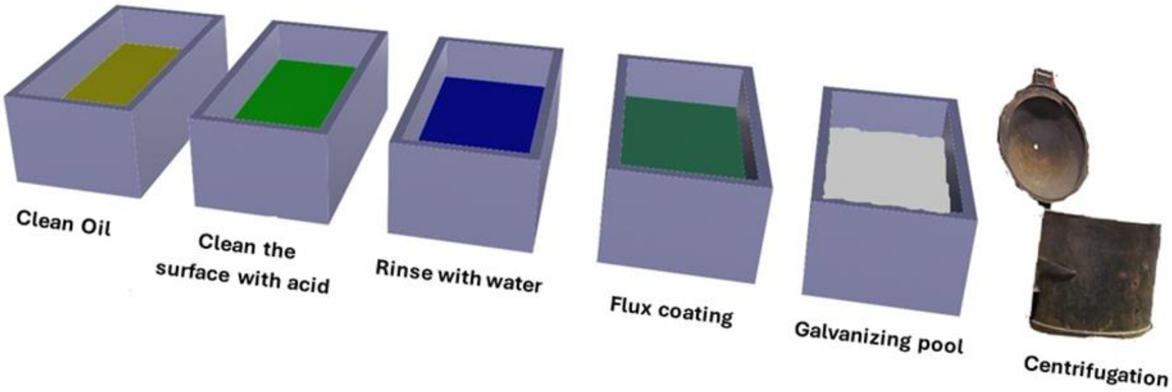


Figure 2. *The CHDG process*

In this study, the morphological changes of the nuts tested according to ASTM B117 standards for 13 days before and after the experiment were compared by SEM and EDS analysis and the results were discussed.

II. MATERIAL AND METHOD

The nuts used in this study are M8 nuts manufactured to ISO 4032 standard. It is used as a fastener in the connection of carcass elements and pad hooks in the construction industry [10]. Fasteners (nuts and bolts) were plated with 114 μm zinc using the CHDG method. The fasteners were well cleaned prior to the corrosion experiments (Figure 3). The galvanised steel bolts and nuts were exposed to the corrosive medium for 1, 5, 9 and 13 days according to ASTM B117 standards [11]. To examine the corrosion occurring in the bolt steps at the end of 13 days, the nut exposed to corrosive environment were mechanically cut. The surface morphologies of the galvanised nuts were observed using a scanning electron microscope (SEM, FEI Quanta FEG 250) and elemental composition analysis was carried out using an energy dispersive X-ray spectrometer (EDS) before and after the experiment. Galvanised nuts were mounted on an aluminium stub using double-sided carbon tape and an accelerating voltage of 20 KeV was applied for the SEM analyses.

III. RESULTS AND DISCUSSION

A. SALT SPRAY TEST RESULTS

A salt spray test (ASTM B117) provided relative corrosion resistance values for CHDG coated nuts in a standardised corrosive environment. The experimental results presented in this study were obtained using 5% NaCl at 35 °C with 50% humidity for 13 days. Figure 3 shows images of bolts and nuts coated by the CHDG process prior to salt spray testing. Before the salt spray test, the surfaces of the bolts and nuts appear to be bright and intact appearance.

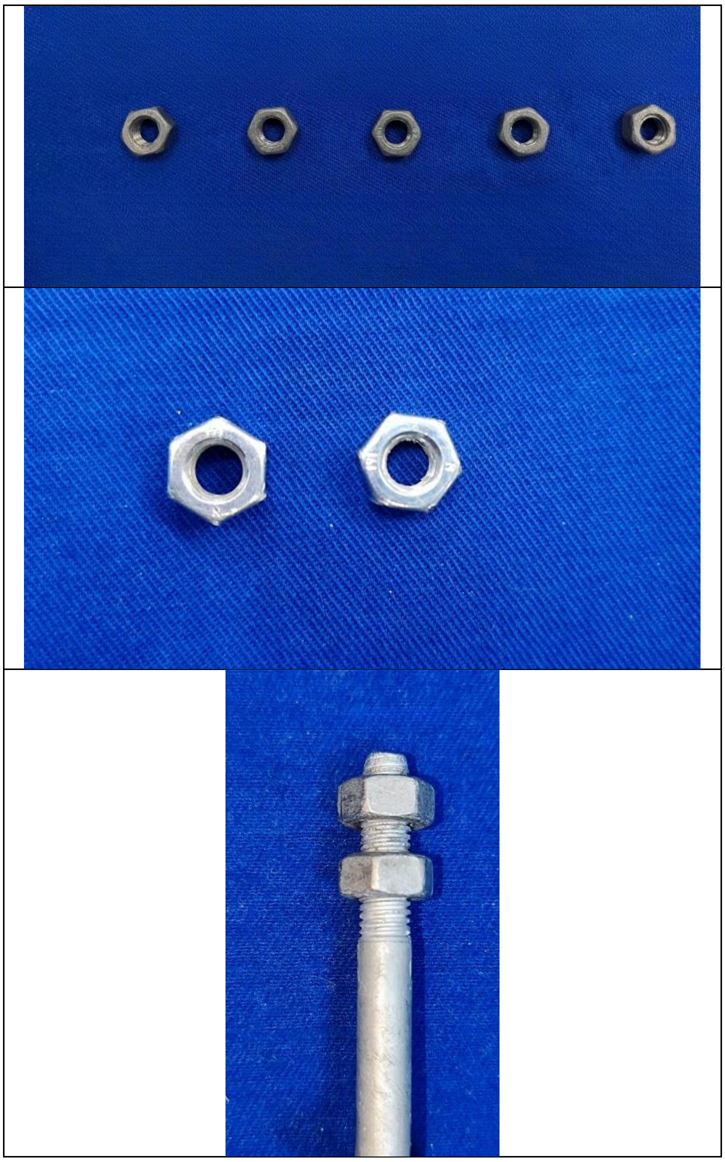


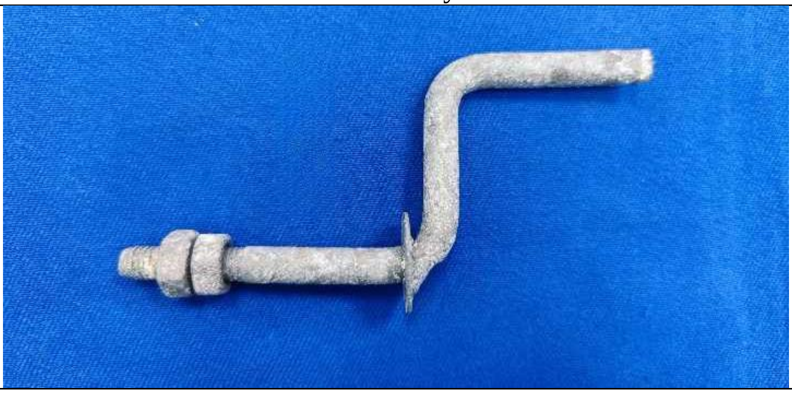
Figure 3. *Visual inspection before the salt spray test*

The specimens placed in the salt cabinet were removed at the end of the 1st, 5th, 9th and 13th days respectively and examined visually (Figure 4). After 1 day of salt spray testing, it was observed that the lustre of the coating had diminished and the zinc coating had begun to corrode, resulting in the appearance of white patches. It can be seen that the degree of corrosion increases with the duration of exposure. At the end of the 13th day, white corrosion products were observed prominently covering the surfaces of both the bolt and nut samples. This observation indicates that the zinc coating applied to these components has undergone uniform corrosion. No brown colour formation was observed on the surface of the bolt and nut at the end of the specified periods. The continued presence of the protective zinc coating, indicated by the absence of brown rust, demonstrates that the underlying matrix material remains protected from corrosive elements and potential degradation. The coating thickness of the nut removed from the test chamber on the 13th day of the salt spray test was 224 µm. The increase in coating thickness may be due to the formation of possible oxide layers such as ZnO, $Zn_5(OH)_8Cl_2 \cdot H_2O$ or $Zn_5(CO_3)_2(OH)_6$ formed on the surface of the nut [12].

After 1 day

After 5 days

After 9 days



After 13 days

Figure 4. *Visual inspection after the salt spray test*

B. SURFACE MORPHOLOGY ANALYSİS

SEM-EDS analysis was performed to investigate the surface morphologies of galvanized nuts cut in half before corrosion and exposed to a corrosive environment for 13 days. Figure 5 shows SEM images taken from the thread area of galvanized nuts before exposure to corrosion.

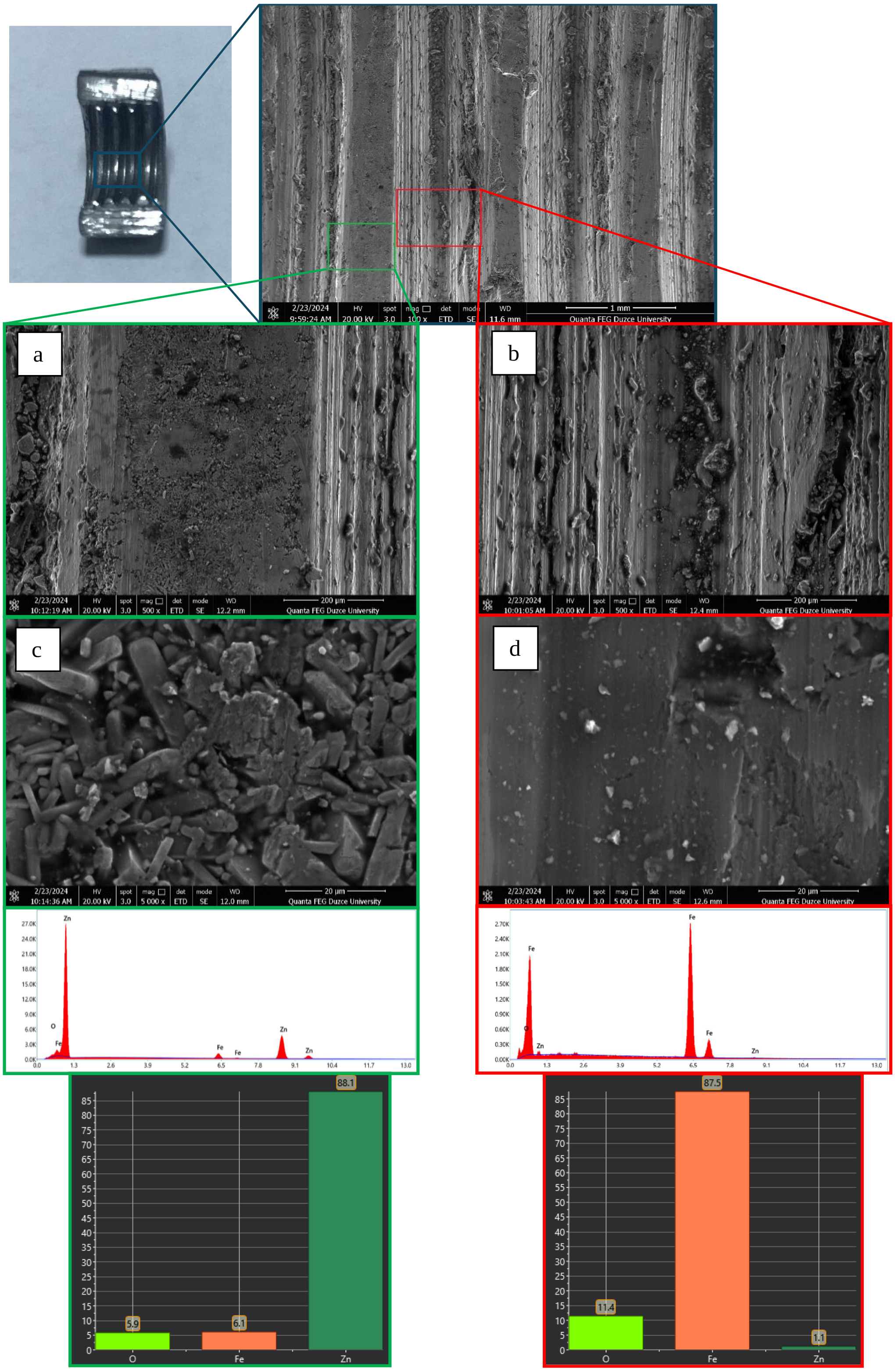


Figure 5. *SEM images of galvanized nuts before corrosion (a and c: 500x and 5000x of top regions; b and d: 500x and 5000x of hollow regions)*

In Figure 5, the red area shows the hollow area and the green area shows the top area in the galvanized nut sample. It can be seen that the surface is rough as a result of coating the nut with Zn. As a result of EDS analysis, Zn, Fe and O were detected on the surface of the nut. Zn, used as the main coating element, functions in two capacities, both as a barrier against corrosion and as a matrix element protector [13]. As a result of EDS taken from the tops in the thread area, 88% Zn was detected, while 1% Zn (87.5% Fe) was detected in the hollow areas. This indicates that the top areas are better covered with Zn, while the hollow areas are less covered. Similarly, in the EDS element mapping results, it can be seen in Figure 6 that the Zn element is concentrated in the top regions and Fe is dominant in the hollow regions.

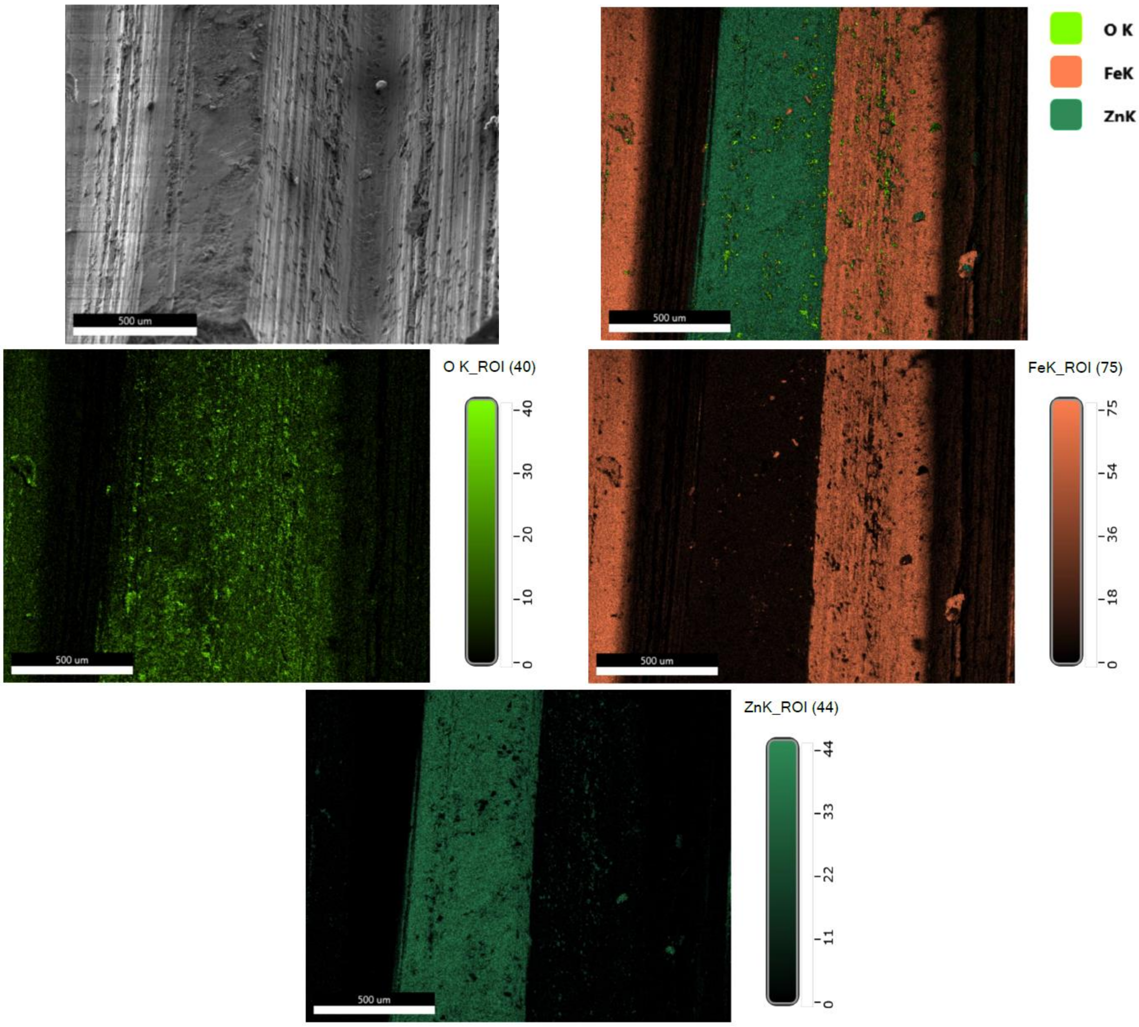


Figure 6. *EDS element mapping images of galvanized nuts before corrosion*

Figure 7 shows SEM images and EDS results of galvanized nuts exposed to a corrosive environment for 13 days.

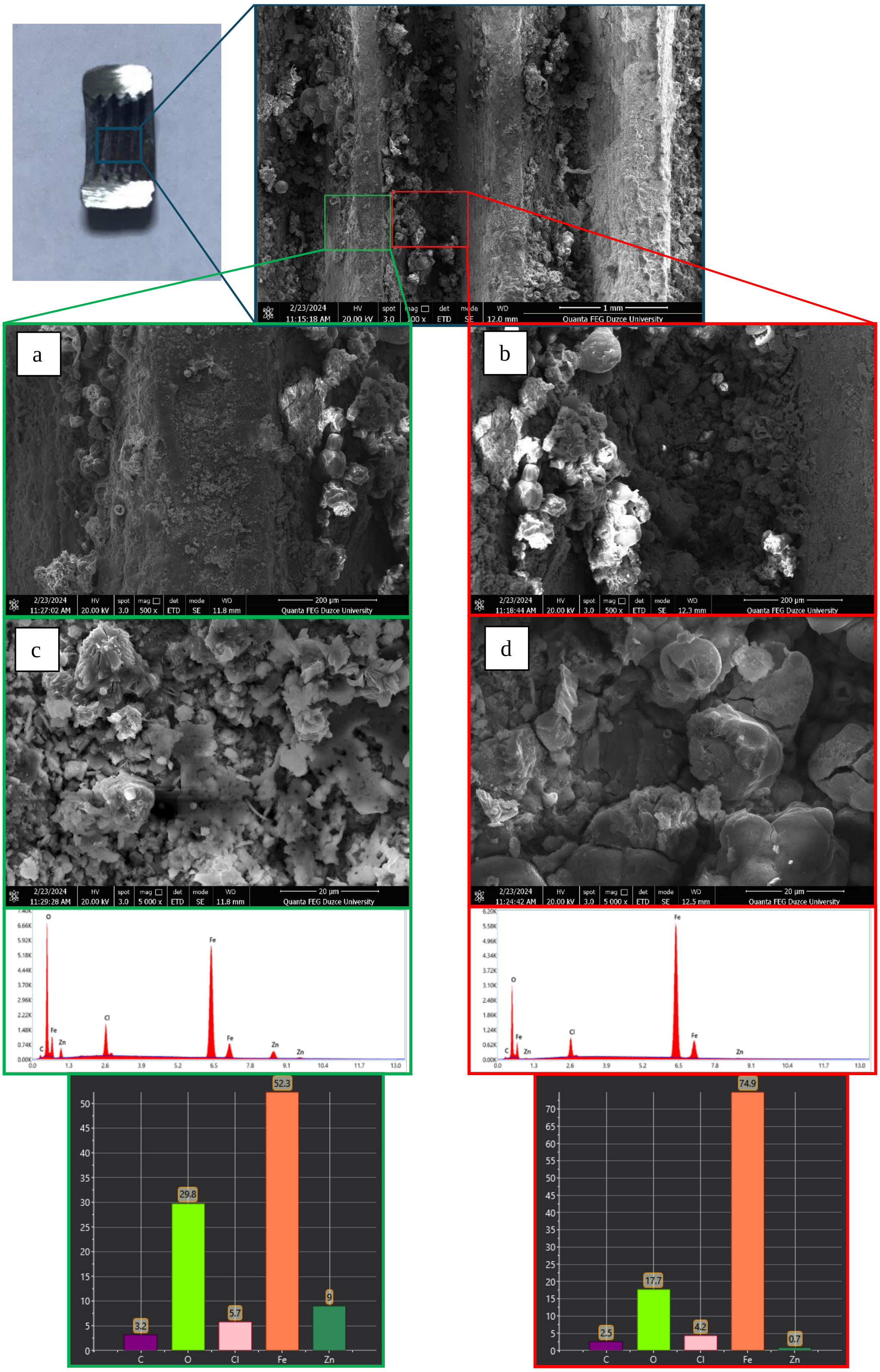


Figure 7. *SEM images of galvanized nuts exposed to corrosive environment after 13 days (a and c: 500x and 5000x of top regions; b and d: 500x and 5000x of hollow regions)*

In the SEM images of the galvanized nut after corrosion, it is seen that corrosion products occur in both hollow and top regions (Figure 7). After 13 days, it is seen that different corrosion products are formed in different parts of the surface. EDS data show that Zn, Fe and O are the main components of corrosion products. The presence of Cl ions on the surface was observed upon exposure to the salt test. Zn, the main component in the coating layer, decreased with the intensification of corrosion after 13 days of exposure. It was determined that the Zn rate was lower in the hollow regions compared to the top regions. While the Fe content was 52.3% in the top region, it was found to be 75% in the hollow region. Since it is difficult for the electrolyte to reach the thread area during the first exposure period in bolt-nut samples, the area is dry and corrosion is less. However, when it enters the electrolyte over time, it keeps the thread area wet and the deterioration of zinc accelerates the formation of Fe-based corrosion products on the surface [13]. Figure 8 shows the EDS element mapping images of galvanized nut samples after corrosion. According to the EDS mapping result, the presence of corrosion products in the thread area of the galvanized nut was detected. It has been determined that corrosion products are associated with regions richer in Fe.

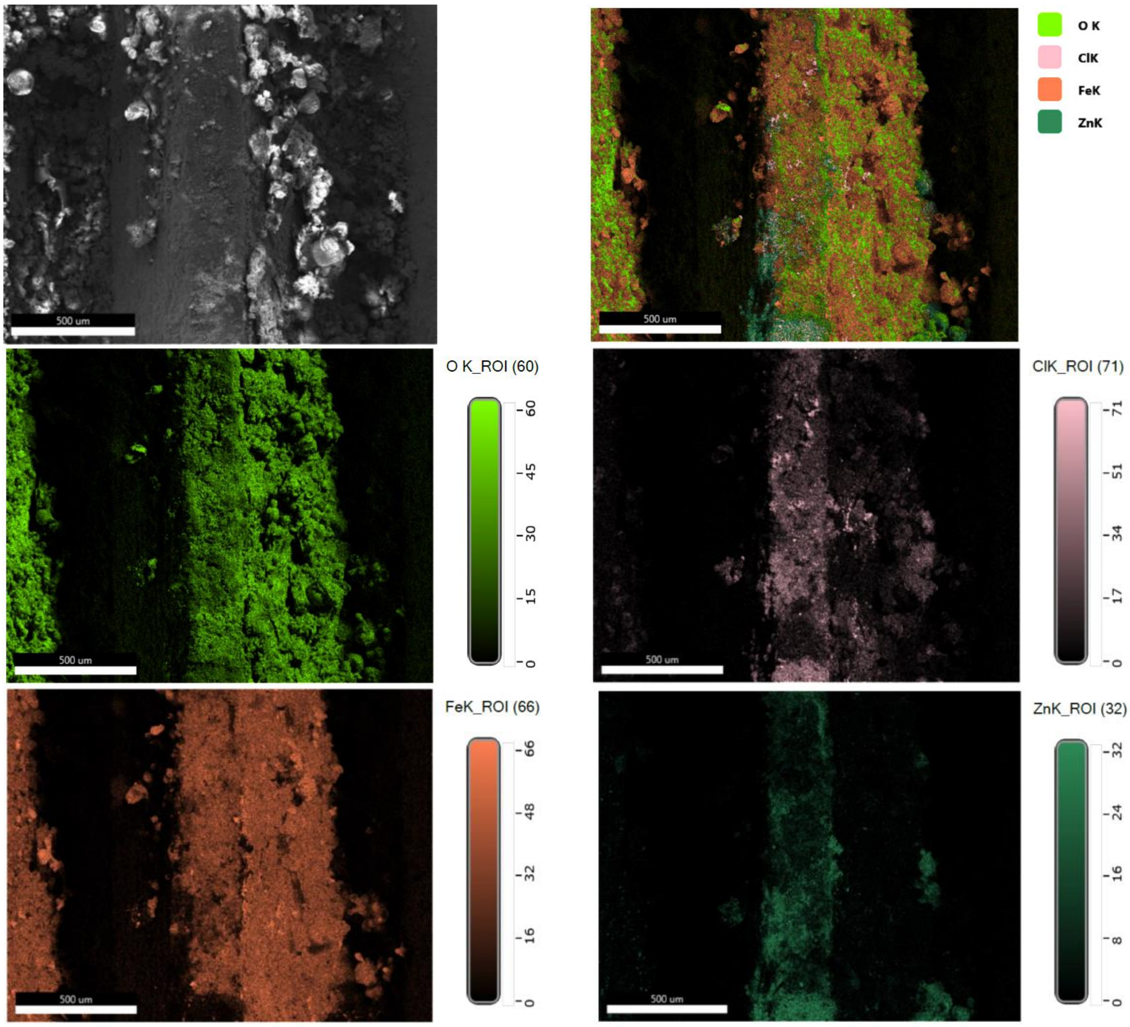


Figure 8. *EDS element mapping images of galvanized nut samples after 13 days*

The cross-sectional images of galvanized nut specimens before and after 13 days of exposure to the salt spray test were observed using SEM-EDS, as shown in Figure 9.

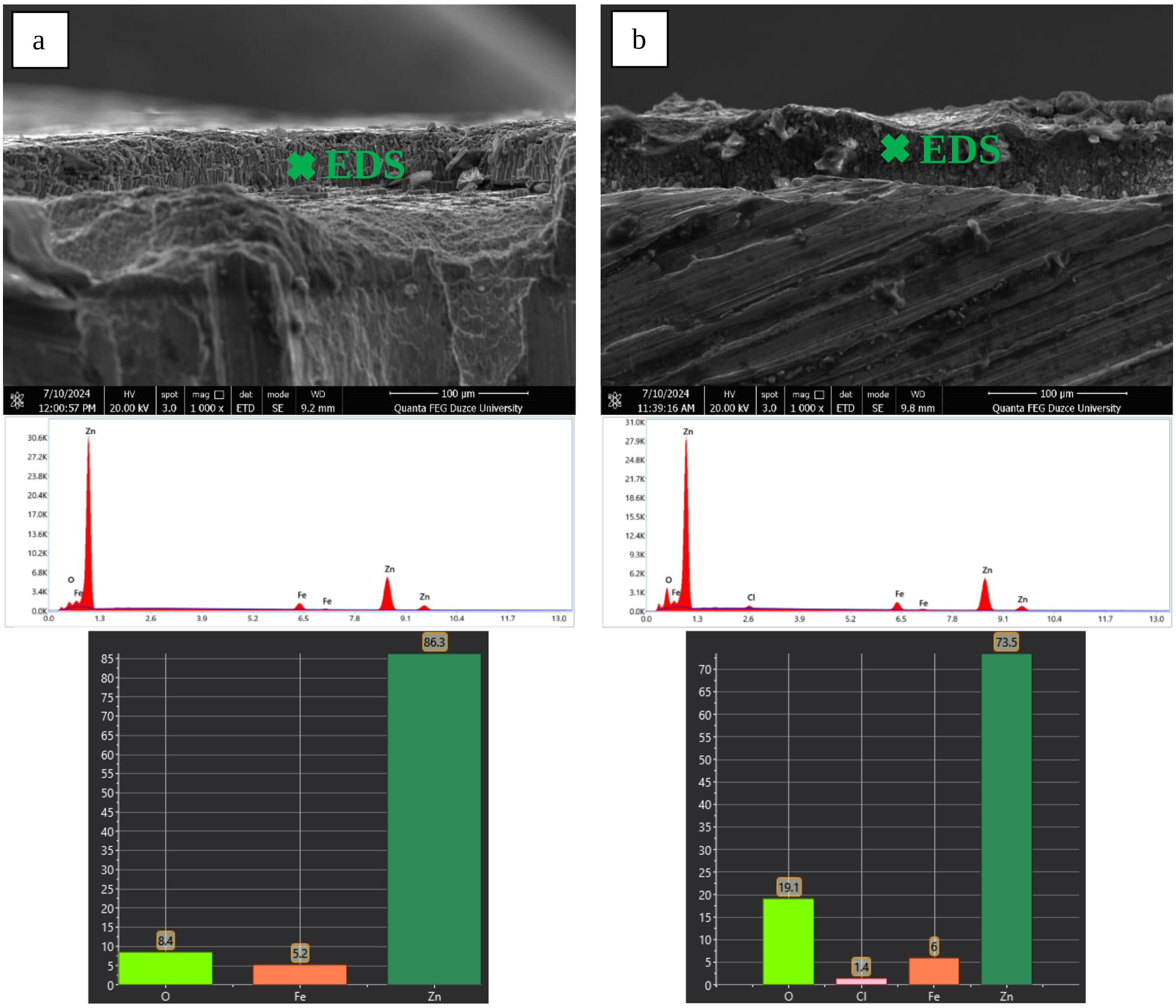


Figure 9. The cross-sectional images and EDS spectrum of the nut: (a) Before corrosion and (b) After the salt spray test.

It can be seen from the cross-sectional morphologies shown in Figure 9 that the layer thickness on the surface increases when galvanised nuts are exposed to corrosion. As mentioned in the salt spray test results section, the increase in thickness of the Zn layer after 13 days is due to the formation of oxide layers on the surface. The EDS results for the elements O, Fe and Zn in the coating layer before the corrosion tests were 8.4%, 5.2% and 86.3% respectively. After being subjected to the salt spray test for 13 days, the EDS results showed that the O and Fe ratio increased to 19.1% and 6%, respectively, while the Zn ratio exhibited a decrease to 73.5%. Additionally, the presence of 1.4% Cl from the environment was also observed.

IV. CONCLUSION

The corrosion evolution of CHDG coated steel nuts exposed to a corrosive environment for 13 days according to ASTM B117 standards was investigated and the results were as follows.

1. Steel nuts coated with Zn by the CHDG method were found to be corrosion resistant. At the end of the 13th day, the coating thickness was found to have increased to 224 µm. It is believed that this increase is due to the formation of oxide layers on the surface.
2. As a result of the data obtained by SEM-EDS analysis, it was observed that corrosion products start to form in the nut thread area after 13 days. However, after 13 days of aggressive testing, this result shows that the CHDG coating continues to protect the threads of the nut. This is

evidenced by the fact that the Zn element is still present on the surface of the threads in the EDS mapping analysis.

3. According to the EDS results, it was determined that the Zn ratio was lower in the hollow regions compared to the top regions, and therefore corrosion was observed to be more intense in the hollow regions.
4. The cross-sectional SEM images showed that the thickness of the coating layer deposited on the nuts by the CHDG process increased after the salt spray test for 13 days. The EDS results of the coating layer showed an increase in the O and Fe ratios, a decrease in the Zn ratio and the presence of the Cl element on the surface.
5. Electrochemical corrosion detection methods such as Dynamic Electrochemical Impedance Spectroscopy (DEIS) can be used to further investigate the corrosion mechanisms of CHDG coated steel nuts over the time. In addition, the structures of Zn and Fe based corrosion products formed on the surface should be investigated by using characterisation techniques in further research.

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