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REVIEW ON EROSION-CORROSION BEHAVIOUR OF ALUMINIUM ALLOY 6061

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Abstract: Aluminium Alloy 6061 (AA6061) is widely recognized for its diverse range of properties and extensive array of applications. The present investigation delves deeply into the erosion-corrosion behaviour of AA6061 in marine environments, emphasizing its resistance to corrosion, mechanical attributes, benefits, and potential uses. AA6061 is well-known for its exceptional strength, excellent weldability, and impressive resistance to corrosion, characteristics that render it a crucial material in various industries such as aerospace, automotive, marine, and structural engineering. Nevertheless, its vulnerability to erosion-corrosion in marine settings presents significant challenges, necessitating a profound understanding of the mechanisms that lead to its degradation to facilitate effective material selection and performance assessment. Through an in-depth and systematic analysis, this study presents valuable insights into the corrosion mechanisms, factors influencing erosion-corrosion rates, and strategies for mitigating such degradation in the case of AA6061. By synthesizing existing knowledge and empirical data, this research makes a meaningful contribution to the ongoing efforts aimed at enhancing the durability and reliability of AA6061 in marine applications.

Keywords: Aluminium alloys, Corrosion, Microstructure, Marine environments, Heat treatment

I. INTRODUCTION

Aluminium alloy 6061 is extensively utilized across marine, aerospace, and automotive industries due to its commendable resistance to corrosion. Researchers have extensively examined its erosion-corrosion behaviour, making it a preferred choice for marine applications such as boat hulls. In aerospace, its lightweight yet robust nature finds utility in structural components like aircraft wings and fuselages. Similarly, in the automotive sector, its corrosion resistance, strength, and malleability make it a preferred material for manufacturing various components including frames, wheels, and body panels. However, despite its numerous advantages, prolonged exposure to atmospheric conditions, especially in coastal areas, poses a significant challenge to its durability and reliability over time.

Due to their remarkable qualities, aluminium alloys are highly valued and used in many different sectors. Their notable lightweight quality is especially important for applications that aim to reduce weight, such those in the automobile and aerospace industries. Aluminium alloys exhibit remarkable strength-to-weight ratios in spite of their low density, which makes them essential for structural applications. In addition, their inherent resistance to corrosion, achieved through the development of a protective oxide layer, ensures durability even under serious environmental conditions, a desirable trait in marine applications. Moreover, their recyclable nature emphasizes environmental awareness while also supporting continuous cost-effectiveness—important aspects in marine engineering where longevity, efficiency, and economic viability are critical criteria.

The corrosion resistance of aluminium 6061 refers to its ability to withstand degradation due to chemical or electrochemical interactions with its environment. This resistance involves multiple degradation mechanisms that may affect metals, alloys, polymers, ceramics, and other materials. Chemically, corrosion resistance involves preventing materials from dissolving into elemental ions, typically caused by exposure to environmental factors such as moisture, oxygen, acids, or salts. In electrochemistry, it usually involves inhibiting redox reactions in which aluminium atoms retain electrons and resist chemical transformations.

Due to its complex behaviour, corrosion has been identified as one of the most challenging issues in materials computation. However, it is clear that the reactions and their impact depend greatly on the structure and composition of the matrix metals or alloys, service loads, environmental factors, interface condition, and overall system, which exhibits "living" changes over time.[1] The ISO defines corrosion as a chemical reaction, usually electrochemical, between a metal and its environment that changes the metal's characteristics and may make it less able to perform as intended in a system. Thermodynamically, aluminium usually forms an oxide layer on its surface between pH values of 4 and 9, which acts as a stopper against more dissolution and maintains the metal's integrity. However, aggressive ions like chloride, which are frequently present in saltwater, have the potential to undermine the integrity of this oxide layer. The protective processes are further complicated by the nature of aluminium alloys, which comprise alloying components scattered throughout both solid solution and intermetallic particles. This complexity in microstructure sets aluminium alloys apart, making them more heterogeneous compared to other types of alloys.[2] Corrosion occurs in many forms, each presenting unique challenges to material integrity in different environments. Galvanic corrosion occurs when dissimilar metals in the electrolyte come into contact, accelerating the decomposition of the reactive metals. Pitting causes localized surface damage that creates small holes and allows aggressive chemical attack to penetrate the material. Crevice corrosion occurs in enclosed spaces where stagnant conditions prevent the removal of corrosive substances and cause localized damage. Microbial corrosion promoted by micro-organisms poses challenges to industrial environments through corrosive by-products. Intergranular corrosion targets grain boundaries due to sensitization caused by contaminants, while high-temperature corrosion accelerates material degradation in oxidizing environments. Each type of corrosion requires specific damage control strategies to maintain the integrity and longevity of the material.

Erosion-corrosion happens when moving fluids, sometimes with tiny solid particles, wear away both the protective surface layer and the main metal underneath. This problem impacts various industries, such as mining and moving solids through pipes. While corrosion and oxidation mainly trouble sectors like chemicals, oil, gas, marine, and power generation, erosion effects are less significant. When erosion and corrosion occur together, they can cause severe damage.[3]

II. COMPUTATIONAL MODELLING OF CORROSION MECHANISMS IN ALUMINIUM ALLOYS

C. Dong, Y. Ji, X. Wei et al. [1] Investigated various aspects related to integrated computation of corrosion, focusing on theoretical calculation methods and developing tendencies in corrosion studies. Specifically, three applications were examined, it explored the use of advanced computational techniques, including first-principle methods alongside molecular dynamics, peridynamic theory, and finite element analysis. These methods were used to build detailed models capable of understanding the micro-mechanisms behind phenomena like stress corrosion cracking and hydrogen-induced cracking. Moreover, the study looked into the intricate calculations needed to understand passivity and the breakdown of passive films. This engaged examining phenomena such as point defects diffusion and its relationship with energy level degeneracy. Additionally, the author explored how artificial intelligence (AI) technology could impact corrosion prediction and the development of corrosion-resistant materials. By reviewing existing literature, they highlighted AI's potential not just in forecasting corrosion degrees, but also in aiding the design of new materials with improved corrosion resistance.

III. INVESTIGATING THE CORROSION BEHAVIOUR OF ALUMINIUM ALLOY IN THE RED SEA

A. H. Al-Moubaraki et al. [2] Investigated how aluminium alloys (Al 7075, Al 2024, and Al 6061) react to the corrosive conditions of the Red Sea. It uses weight loss measurements and potentiodynamic polarization techniques to analyze corrosion rates and patterns, along with optical photography, scanning electron microscopy, and energy-dispersive spectroscopy to examine corrosion products. The study finds that corrosion rates decrease consistently over time, following a bimodal model more closely than a power law function. It also ranks the alloys in terms of susceptibility to Red Sea water corrosion, with Al 6061 being the least affected, followed by Al 2024, and Al 7075 showing the highest vulnerability. Furthermore, the study looks into how temperature affects corrosion, noting that higher temperatures lead to increased anodic and cathodic current density and a decrease in corrosion potential. Interestingly, Al 7075 is less affected by temperature changes compared to the other alloys. Pitting corrosion emerges as the primary corrosion pattern after prolonged immersion in all alloy surfaces. The detection of Sulphur peaks in the energy-dispersive spectroscopy spectra of Al 7075 after corrosion suggests bacterial involvement in the corrosion process.

IV. STRATEGIES FOR ENHANCING THE CORROSION RESISTANCE OF ALUMINIUM ALLOY IN MARINE ENVIRONMENTS

M. Lavanya et al. [3] Investigated how aluminium reacts to erosion and corrosion when exposed to seawater-like conditions. They used a special setup to shoot a jet of water mixed with sand at aluminium samples. By varying the flow rate of the water, they observed how quickly the aluminium wore away. They also used different techniques to study the surface of the aluminium and identify any changes happening at the microscopic level. The results suggest that higher flow rates and temperatures make the erosion and corrosion worse. This information could help in choosing the right materials for equipment and pipes used in circulating seawater to prevent excessive damage.

J. Erkmen et al. [6] Investigated how well different types of paint coatings protect a high-strength aluminium alloy (6061-T6) from corrosion in seawater. They used a solvent-based paint with metallic pigments and applied it to the alloy. Then, they used a method called electrochemical impedance spectroscopy to study how the corrosion progressed. By analyzing various factors like potential change, current change, and images, they found that certain paint coatings provided better corrosion resistance than others. Specifically, they observed that paint with a gold colour containing copper pigment was less effective at preventing corrosion compared to silver-coloured paint containing aluminium pigment. J. Erkmen et al. [6] Investigated the corrosion behaviour of uncoated and painted forms of a high-strength aluminium alloy (6061-T6) in seawater. They examined how silver-coloured and gold-coloured paints, as well as their damaged states, affected corrosion. Tests were conducted under various surface conditions for a duration of 1400 seconds at room temperature in seawater. The study used electrochemical impedance spectroscopy (EIS) to assess corrosion, a method known for its reliability and non-invasiveness. The results indicated that painted surfaces generally had higher corrosion resistance compared to uncoated surfaces, while damaged surfaces had lower resistance. The complexity of the coating content influenced the number of resistors on the surface. When analyzing Nyquist curves and Rp values, it was observed that higher resistance led to more irregular curves and smaller diameters. Furthermore, the gold-coloured coating with copper and aluminium pigments showed lower durability compared to the silver-coloured coating with only aluminium pigments.

Zaifol Samsu et al. [12] Investigated the corrosion behaviour of aluminium alloy 6061 T6 when immersed in Reactor TRIGA Mark II pool water containing about 0.1% NaCl content. They used direct current electrochemical methods to study the corrosion behaviour. The results indicated that the corrosion rate of the aluminium alloy increased in the presence of 0.1% chloride ion content in the demineralized water reactor pool compared to normal demineralized water. This increase in corrosion rate was attributed to the aggressive attack of chloride ions on the metal surface. The study also involved additional tests such as corrosion behaviours diagram and cyclic polarization, which further supported the findings. In conclusion, aluminium alloy 6061 T6 exhibited high corrosion resistance in demineralized water, but the presence of chloride ions reduced this resistance, emphasizing the importance of controlling chloride ion content in the water to prevent corrosion.

L. Fan et al. [17] Investigated into various surface treatment methods for 6061 aluminium alloy profiles used in the construction industry. These methods included sand powder film coating, flat powder coating, hard anodized film, and ordinary heat-sealing oxidized coating. The study aimed to assess the corrosion resistance of these coated aluminium alloys in a 3.5 wt.% NaCl solution (pH 6.5–7.5) and to analyze how different surface treatments affected their corrosion resistance over time. Through scanning electron microscope (SEM) analysis and electrochemical workstation testing, it was observed that the corrosion inhibition performance of the coatings decreased with increasing corrosion time. The order of decline in performance was found to be sand powder film coating > hard anodized film > flat powder coating > ordinary heat-sealing oxidized coating. Specifically, after 2 hours of corrosion, sand powder film coating and hard anodized film exhibited better inhibition performances compared to flat powder coating and ordinary heat-sealing oxidized coating. However, after 200 hours of corrosion, the performance ranking shifted, with hard anodized film and ordinary heat-sealing oxidized coating showing superior inhibition performances. These findings provide insights into the effectiveness of different surface treatments in enhancing the corrosion resistance of aluminium alloy profiles in construction applications.

R. Rosliza et al. [21] The author conducted a study to assess the efficacy of tapioca starch in enhancing the corrosion resistance of AA6061 alloy in seawater. Various electrochemical techniques, including gravimetric analysis, potentiodynamic polarization, linear polarization resistance, and electrochemical impedance measurements, were employed to evaluate the corrosion behaviour. Results indicated that tapioca starch notably reduced corrosion rates, corrosion current densities, and double layer capacitance while increasing polarization resistance. Inhibition efficiency was found to increase with higher concentrations of tapioca starch. The Langmuir adsorption isotherm model fitted well with experimental data, confirming the adsorption of tapioca starch on the metal surface. SEM and EDS analysis confirmed the formation of tapioca starch precipitates on the metal surface, which mitigated the corrosion reaction. Tapioca starch demonstrated significant potential in improving the corrosion resistance of AA6061 alloy in marine environments.

V. INFLUENCE OF ALLOYING ELEMENTS AND REINFORCEMENTS ON THE CORROSION BEHAVIOUR OF ALUMINIUM ALLOYS

C. Peng et al. [4] Investigated the corrosion tendencies of 6061 aluminium alloy when exposed to a simulated Nansha marine atmosphere for 40 days. They utilized electrochemical measurements, microscopic observations, and X-ray photoelectron spectroscopy (XPS) tests to analyze the corrosion behaviour. The findings revealed significant occurrences of both intergranular corrosion (IGC) and intragranular corrosion on the surface of the alloy sample. The presence of Mg2Si phase and AlFeSi particles, as the primary intermetallic compounds in the alloy, was closely associated with the initiation and spread of IGC. Additionally, the study observed preferential dissolution of Mg from the Mg2Si phase, and the reasons behind this phenomenon were elucidated based on thermodynamic principles. This investigation contributes valuable insights into comprehending the corrosion mechanisms of 6061 aluminium alloy in simulated Nansha marine conditions.

M. K. Abbass et al. [10] Investigated the resistance of a metal matrix composite made of aluminium alloy (Al 6061) reinforced with silicon carbide (SiC) particles, with concentrations of 10wt% and 20wt%. The composites were prepared using a stir casting technique with a vortex method. The corrosion behaviour of these composites in seawater (3.5% NaCl solution) was analyzed using potentiostatic polarization measurements. The corrosion rate was determined using the Tafel equation and polarization results. The study found that the addition of SiC particles to the aluminium alloy matrix increased the corrosion rate, indicating reduced corrosion resistance compared to the base alloy. Examination of microstructures revealed that SiC particles were uniformly distributed in the Al 6061 matrix, showing good wettability and bonding between the matrix and reinforcement. This uniform distribution led to a high retention percentage of SiC particles in the matrix, contributing to increased alloy hardness. Both composites containing 10 wt% and 20 wt% SiC exhibited lower corrosion resistance than the base alloy (Al 6061) when exposed to a 3.5% NaCl solution. Anodic polarization curves were similar for the base alloy and both composite samples, indicating similar electrochemical behaviour. However, the base alloy displayed less susceptibility to pitting corrosion in the 3.5% NaCl solution compared to the composite samples. The study demonstrates that the incorporation of SiC particles into the aluminium alloy matrix adversely affects its corrosion resistance in a seawater environment. Despite improvements in alloy hardness due to SiC reinforcement, the composite materials exhibit higher corrosion rates compared to the base alloy. These findings underscore the importance of considering corrosion resistance when designing metal matrix composites for marine applications.

H. C. Ananda Murthy et al. [18] Investigated into the corrosion behaviour of Aluminium Matrix Composites (AMCs) reinforced with ceramic particulates, particularly focusing on Al-TiC particulate composites. The study involved preparing Al 6061-TiC particulate composites via stir casting and examining their corrosion resistance in chloride medium using electroanalytical techniques such as Tafel, cyclic polarization, and Electrochemical Impedance Spectroscopy (EIS). Additionally, SEM and EDX analyses were performed to assess the microstructures of both the matrix alloy and the reinforced composites, aiming to understand the impact of titanium carbide on corrosion resistance. The findings indicated an enhancement in corrosion resistance in the composites compared to the matrix alloy, attributed to the strong bond between TiC particulates and aluminium, potentially leading to electrochemical decoupling. EIS results revealed an increase in polarization resistance with higher TiC content, suggesting charge transfer control of the corrosion process. Overall, the study suggests that titanium carbide holds promise as a reinforcement for improving corrosion resistance in Aluminium Metal Matrix Composites (AMMCs).

VI. STRATEGIES FOR ENHANCING THE CORROSION RESISTANCE OF ALUMINIUM ALLOYS IN MARINE ENVIRONMENTS

S. M. Mohammed et al. [5] Investigated how the corrosion behaviour of aircraft aluminium alloys 2024 and 6061 changes when subjected to cyclic polarization testing in Rainwater, both before and after heat treatment at room temperature (25°C). The results showed that the corrosion resistance of both alloys decreases after undergoing specific heat treatments. For AA2024 alloy, the decrease was observed after solution treatment at 495°C for 2 hours, followed by artificial aging at temperatures ranging from 150°C to 300°C for 1 and 2 hours. Similarly, for AA6061 alloy, the corrosion resistance decreased after solution treatment at 530°C for 2 hours, followed by artificial aging at temperatures ranging from 150°C to 300°C for 1 and 2 hours. S. M. Mohammed et al. [5] Examined the impact of solution treatment on the Brinell hardness and corrosion resistance of aircraft aluminium alloys 2024 and 6061. Results showed that the Brinell hardness initially increased to a peak value and then decreased for both alloys after specific heat treatments. This pattern suggests that initially, the deposition of particles was coherent, maintaining microscopic composition similar to the pre-treatment state. However, as deposition increased, it became semi-coherent or incoherent, resulting in decreased hardness due to larger grain size and regarding corrosion resistance, the study found that AA6061 alloy exhibited higher resistance compared to AA2024 alloy after solution treatment and artificial aging at various temperatures. This difference in resistance is attributed to the characteristics of precipitate particles, particularly those containing copper, which render alloys more susceptible to pitting corrosion. The study shows that the hardness of both alloys increased initially after treatment but then decreased. Despite improvements in hardness, heat treatment led to a decrease in corrosion resistance. AA6061 alloy demonstrated superior resistance to corrosion in rainwater compared to AA2024. Additionally, AA6061 alloy showed re-passivation potential in certain conditions, indicating greater resilience to corrosive environments and reduced susceptibility to pitting corrosion.

A. Almansour et al. [8] Investigated how AA6061 corrodes naturally at different temperatures and in different environments. They wanted to see how the microstructure and corrosion behaviour of AA6061 are affected by temperature and the type of liquid used to cool it down. They tested samples that were either untreated or naturally aged at temperatures of 490°C, 530°C, and 570°C, and quenched in either water or oil. They looked at the structure using a microscope, tested hardness, and immersed the samples in solutions with different pH levels (acidic, neutral, and alkaline) to see how fast they corroded. The results showed that the corrosion rate varied depending on the temperature and the quenching liquid used. A. Almansour et al. [8] Investigated how the temperature of solution heat treatment and the type of quenching liquid affect the corrosion behaviour of aluminium alloy AA6061, along with the impact of natural aging. By artificially aging the initial specimens, six different structures were obtained. The hardness of all structures was lower than that of the initial specimen due to its high dislocation density, with hardness increasing as the heat treatment temperature rose. Quenching in oil resulted in lower hardness compared to water quenching. In acidic salt solutions, the initial sample showed a higher corrosion rate than the naturally aged specimens, with the heat-treated specimen at 530°C (quenched in oil) exhibiting the highest corrosion rate among the heat-treated samples. In neutral salt solutions, the specimen treated at 570°C (quenched in oil) showed the highest corrosion rate. This trend was also observed in alkaline solutions.

S. M. Mohammed et al. [9] Investigated how the corrosion behaviour of two types of aluminium alloys, AA 2024 and AA 6061, was affected by a process called solution treatment. Solution treatment involves heating the alloys to specific temperatures for a certain duration. The aim was to understand how this treatment influenced the alloys' susceptibility to corrosion in a solution of 0.5M hydrochloric acid (HCl) at room temperature (25°C). The researchers conducted cyclic polarization tests to assess the corrosion resistance of the alloys before and after solution treatment. They found that the corrosion resistance of AA 2024 decreased significantly after solution treatment at 495°C for 2 hours, while that of AA 6061 decreased after treatment at 530°C for the same duration. Pitting corrosion was observed as the primary form of corrosion for both alloys. The study highlighted several key findings. Firstly, the microstructure analysis revealed that both alloys exhibited a higher amount of a specific phase after solution treatment and aging at various temperatures. For AA 2024, the precipitate phase was identified as $Al2Cu$, while for AA 6061, it was $Mg2Si$. Secondly, the research confirmed that AA 6061 generally had better corrosion resistance compared to AA 2024 in the tested environment. This was attributed to the formation of a protective layer on the surface of AA 6061, which enhanced its resistance to pitting corrosion. Furthermore, the study demonstrated that the corrosion resistance of both alloys decreased after solution treatment. This decrease was particularly notable for AA 2024 treated at 495°C for 2 hours and then aged at temperatures ranging from 150°C to 300°C. Lastly, the research identified that AA 6061 exhibited re-passivation potential in various conditions, indicating its ability to resist corrosion. This re-passivation potential was observed in both the as-received condition and after solution treatment followed by aging at different temperatures. The study explained the effects of solution treatment on the corrosion behaviour of AA 2024 and AA 6061 aluminium alloys in an acidic environment. It provided valuable insights into the microstructural changes induced by the treatment and how these changes influenced the alloys' corrosion resistance. These findings contribute to a better understanding of the factors affecting the durability and performance of aluminium alloys in practical applications.

Mohammed EL-Sayed et al. [11] Investigated the corrosion resistance of 6061 aluminium alloy, specifically focusing on the effect of various aging treatments and solution pH on corrosion characteristics. The study included aging time at different temperatures (225°C, 185°C, and 140°C), constant aging time (24 hours) across temperatures ranging from 100°C to 450°C, and the influence of solution pH on corrosion. Standard immersion corrosion tests and potentiodynamic polarization techniques were employed to evaluate corrosion behaviour. The investigation aimed to understand how aging parameters and solution conditions affect corrosion susceptibility, dominant corrosion modes, and corrosion kinetics, with a focus on the microstructural changes induced by aging treatments, such as the type, volume fraction, size, and distribution of precipitate particles.

Olandir V. Correa. [13] Investigated the effect of aging time on the corrosion behaviour of 6061 aluminium alloy in NaOH (sodium hydroxide) and NaCl (sodium chloride) solutions. Aluminium alloys of the 6XXX series, such as Al-Mg-Si, are commonly used in various industrial applications due to their high mechanical strength and corrosion resistance. The final mechanical properties of these alloys are achieved through specific precipitation hardening heat treatments, and the aging time during these treatments can affect both mechanical properties and corrosion resistance. The study involved aging the 6061-aluminium alloy at 200°C for different durations ranging from 1 to 36 hours. The corrosion behaviour of the aged alloy was evaluated using potentiodynamic polarization and electrochemical impedance spectroscopy techniques. The results indicated that the corrosion resistance of the alloy decreased with increasing aging time up to certain points in both NaOH and NaCl solutions. In NaCl, the corrosion resistance decreased up to 8 hours of aging, while in NaOH, it decreased up to 24 hours of aging. However, longer aging times led to an increase in corrosion resistance again in both solutions. Additionally, the study found that the alloy was active in NaOH and exhibited a well-developed passive region in NaCl.

S. L. Joseph Leon et al. [15] Investigated the examination of the effects of various process parameters on the mechanical properties of joints produced by Friction Stir Welding (FSW) in Aluminium 6061 alloy, a material commonly utilized in aircraft construction. FSW, known for its ability to create defect-free welds with favourable mechanical properties in aluminium alloys, operates through frictional heating and plastic deformation without reaching the melting point of the metal. The investigation specifically focused on parameters such as tool rotational speed and welding speed, aiming to optimize them for enhanced joint characteristics. Through tensile testing, microstructural analysis, and hardness measurements in both the weldment and heat affected zone, the study revealed significant findings. These included the influence of rotational speed on weld soundness, the formation of fine grains and strengthening precipitates contributing to superior tensile properties, and the relationship between welding speed and the size of the weld nugget. Ultimately, the study underscores the importance of optimizing FSW parameters to achieve superior mechanical properties in aluminium 6061 alloy joints, particularly in aircraft structural applications.

K. Muna et al. [19] Investigated the impact of the friction stir welding process on both the microstructure and corrosion behaviour of 6061 aluminium alloy. The welding process was conducted using a milling machine with variations in tool rotation speeds and welding travel speeds. Microscopic analysis was employed to examine the microstructure of different regions within the weld, including the stir nugget, thermo-mechanically affected zone, heated affected zone, and base metal. Corrosion tests were performed on both the base alloy and welded joints in a 3.5% NaCl solution, with corrosion current determined through potentiostatic polarization measurements at 30°C. Analysis of polarization diagrams suggested that pitting corrosion was predominantly influenced by aluminium passivation in the NaCl solution. The study revealed that the corrosion rates of the welded joints exceeded those of the unwelded base metal. The conclusions drawn from the study included observations on the role of microstructure in influencing corrosion type and morphology, the superior corrosion resistance of the base alloy compared to the friction stir welds, the more noble corrosion potential of the base alloy compared to the welds, the heightened susceptibility of friction stir weld zones to pitting corrosion compared to the base alloy, and the comparatively lower susceptibility to corrosion of one specific friction stir weld sample relative to another in the NaCl solution.

I. Guzmán et al. [20] Investigated into the electrochemical corrosion behaviour and mechanical strength of weld joints made from aluminium 6061 under two different heat treatment conditions. Gas metal arc welding in pulsed mode was employed to create the joints. The study found that the heat input significantly affects both the mechanical strength and corrosion resistance of the weld joints. Higher heat input resulted in stronger joints but poorer corrosion performance, particularly in the heat-affected zone. The formation of galvanic couples due to variations in precipitate distribution, as well as the presence of zones with different hardness, were identified as key factors influencing these properties. Solubilization heat treatment improved mechanical strength but had mixed effects on corrosion resistance. The study suggests further investigation into optimizing heat input parameters for better quality weld joints, as well as exploring different filler metals and heat treatments.

VII. THE INFLUENCE OF METAL CATIONS ON THE CORROSION BEHAVIOUR OF ALUMINIUM ALLOYS

Md. S. Islam et al. [7] Investigated into the corrosion behaviour of A6061 aluminium alloy when exposed to simulated aqueous solutions containing various metal cations. Through surface analysis techniques and electrochemical tests, they examined how the presence of cations, particularly Zn2+, influenced the corrosion process. The study found that immersion in solutions with Zn2+ resulted in a smaller mass change compared to other cation-containing solutions. Electron microscopic images revealed the deposition of Al-hydroxide products on the alloy surface, confirmed by X-ray photoelectron spectroscopy (XPS). In addition, a Zn-layer was observed on specimens immersed in Zn2+-containing solutions, leading to inhibited corrosion of the aluminium alloy. Electrochemical analysis showed higher impedance in Zn2+-containing solutions due to the formation of Zn-related layers and oxide films on the surface. The study demonstrated the significant influence of metal cations, particularly Zn2+, on the corrosion behaviour of A6061 aluminium alloy in aqueous environments.

VIII. TRADITIONAL AND GREEN CORROSION PROTECTION TECHNIQUES FOR ALUMINIUM ALLOYS

P. Rao et al. [14] Investigated the use of biopolymer starch as an eco-friendly green inhibitor to control the corrosion of 6061 aluminium alloy in a 0.25M hydrochloric acid solution. They studied the effectiveness of starch as an inhibitor using potentiodynamic polarization and electrochemical impedance spectroscopy techniques. The investigation focused on understanding how the inhibition efficiency of starch varied with changes in temperature and inhibitor concentration. The study found that the percentage inhibition efficiency increased with higher temperatures (ranging from 30 to 50 degrees Celsius) and with higher concentrations of the inhibitor (ranging from 100 to 800 ppm). Kinetic and thermodynamic studies indicated that starch underwent chemisorption and followed the Langmuir adsorption isotherm when interacting with the metal surface. Surface morphology studies supported the adsorption of the inhibitor molecule on the metal surface. Also, the research demonstrated that starch acted as a mixed inhibitor, exhibiting chemisorption behaviour and adhering to the Langmuir adsorption isotherm. Starch was identified as a promising eco-friendly and biodegradable biopolymer for controlling the corrosion of 6061 aluminium alloy in hydrochloric acid solutions.

W. Zhan et al. [16] Investigated the development of synchronous chemical conversion coatings on multi-metal substrates to enhance corrosion resistance for new energy light vehicle bodies. Titanium/zirconium-based coatings were applied on aluminium alloys and galvanized steel. The formation process was characterized into three steps using open circuit potential measurements. Potentiodynamic polarization and electrochemical impedance spectroscopy showed reduced self-corrosion current density and increased resistance. Surface morphology and composition were analyzed via scanning electron microscopy, X-ray photoelectron spectroscopy, and electron probe microanalysis. The coatings exhibited uniformity with minor cracks, pores, and intermetallic compounds, providing active sites for chemical conversion nucleation. The coatings primarily consisted of metallic oxides ($Al_2O_3/TiO_2/ZrO_2$) and metal fluorides (ZrF_4) for aluminium alloys, while galvanized steel coatings comprised metallic oxides ($TiO_2/Fe_2O_3/ZrO_2$). Overall, this study proposes a significant approach to enhance the corrosion resistance of multi-metal substrates, facilitating their application in various industries, particularly in the automotive sector.

IX. SUMMARY

The synthesis of research on corrosion behaviour and reduction strategies for aluminium alloys yields a comprehensive comprehension of corrosion processes and their implications. Investigations encompass theoretical methodologies utilizing advanced computational techniques, including first-principle methods and molecular dynamics, to interpret micro-mechanisms governing corrosion phenomena like stress corrosion cracking and hydrogen-induced cracking. Furthermore, studies delve into practical aspects, such as assessing aluminium alloy corrosion in diverse environments like seawater and acidic solutions. Empirical methodologies, such as electrochemical measurements and surface analysis techniques, offer insights into the complex factors influencing corrosion resistance. Additionally, researchers explore innovative approaches for corrosion inhibition, encompassing the application of eco-friendly inhibitors like starch and the development of protective coatings and surface treatments. Overall, these studies contribute to a comprehensive understanding of corrosion mechanisms and provide valuable insights for designing corrosion-resistant materials and reduce the adverse effects of corrosion in real-world scenarios.

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