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CORROSION RESISTANCE OF MILD STEEL WELDED JOINTS: ELECTROCHEMICAL ANALYSIS IN FIVE DIFFERENT ENVIRONMENTAL MEDIA

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Abstract

This study investigates the corrosion behavior of mild steel welded joints exposed to various environmental media to evaluate their performance and durability in diverse real-world settings. The chosen environments—1M H_2SO_4, 1M NaCl, 1M NaOH, soil, and freshwater—represent a range of corrosive conditions from highly acidic and saline to basic and neutral, simulating scenarios that mild steel structures may encounter in industrial, marine, and natural environments. Welded joints were fabricated using optimized welding parameters and subjected to corrosion evaluation through electrochemical impedance spectroscopy (EIS), and potentiodynamic polarization tests. The results revealed that 1M H_2SO_4 caused the highest corrosion rate at 11.31 mm/yr and a corrosion current (Icorr) of 972.42 μA/cm², while freshwater exhibited the lowest corrosion rate of 1.55 mm/yr and an Icorr of 132.87 μA/cm². These findings underscore the significant influence of environmental conditions on the corrosion behavior of welded steel joints. The study recommends the use of advanced protective coatings or alternative materials for structures in highly corrosive environments.

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1.0 INTRODUCTION

Corrosion is a major global issue, particularly in industries such as oil and gas, where it leads to the deterioration of metals through electrochemical and chemical reactions [1]. This process involves the degradation of materials, primarily metals, often exacerbated by mechanical stress [2]. Corrosion not only impacts the structural integrity of engineering systems but also results in substantial economic losses.

Inorganic corrosive agents, including NaCl, HCl, H_2SO_4, and sulfur, are particularly aggressive in industrial settings, accelerating corrosion and leading to extensive material waste [3-4]. For example, corrosion in the United States is estimated to cost $276 billion annually, with indirect costs often exceeding direct costs by a factor of 2 to 10 [5]. Similarly, India allocates about 3.5% of its GDP annually to address corrosion-related losses [6], while in China, the cost is around $310 billion per year, impacting sectors such as infrastructure, transportation, and energy [7]. The oil and gas industry, in particular, faces significant financial impacts due to corrosion, with material degradation leading to considerable losses and necessitating engineering interventions [8-9]. Long-term corrosion also imposes a significant economic burden, highlighting the need for effective asset management strategies [10].

Welding, a common method for joining metals, introduces specific challenges related to corrosion, especially in metal joints. These joints are prone to localized microstructural changes during welding, which can increase their susceptibility to corrosion and reduce their mechanical properties, such as strength, ductility, and fatigue resistance [11]. This vulnerability can lead to premature failures in critical infrastructure like bridges, pipelines, and offshore platforms [12-13].

To mitigate corrosion in welded joints, optimization of welding practices is essential. This includes selecting suitable welding techniques, filler materials, and post-weld treatments to minimize microstructural changes and enhance corrosion resistance [14]. Advances in materials science and surface engineering provide promising methods for improving corrosion resistance while maintaining or enhancing mechanical properties [15]. The impact of welding practices on corrosion rates and mechanical properties is well documented. For example, stress corrosion cracking has been linked to poor welding practices in grade 204 stainless steel pipes and the Point Pleasant bridge disaster [16-17], underscoring the need for proper welding techniques to mitigate corrosion-related issues.

Environmental factors such as temperature, humidity, and exposure to corrosive agents exacerbate the degradation of welded joints, leading to structural failures and reduced longevity. Previous research has investigated corrosion in specific environments but has not comprehensively evaluated a broad range of conditions.

For instance, a study investigated mild steel corrosion in ethanol-water blends and reported that water increased corrosion rates, while ethanol solutions exhibited passive behavior with observable oxides, cracks, and pits [18]. In another work to examine hot-worked mild carbon steel in various acidic environments, it was observed that higher acid concentrations, particularly nitric acid, significantly increased weight loss and corrosion rates [19]. The impact of corrosion under different environmental conditions has been investigated by some researchers, and it was reported that higher Cl^- concentrations under road salt conditions led to increased corrosion rates [20]. In a study to investigate the effects of 9 years of industrial corrosion on steel [21], it was reported that different corrosion types and severities affected fracture modes and reduced ductility. It has also been reported that corrosion type and severity influenced failure modes, with general corrosion causing step-like fractures and local corrosion leading to flat fractures with larger pits [22].

This study independently examines the corrosion behavior of mild steel welded joints across a comprehensive range of environments, including 1 M H_2SO_4 (acidic), 1 M NaCl (saline), 1 M NaOH (alkaline), soil, and freshwater. Unlike previous studies that typically assess corrosion in isolated conditions, this research integrates multiple experimental techniques such as weight loss measurements, electrochemical impedance spectroscopy (EIS), and potentiodynamic polarization tests to provide a detailed understanding of how diverse environments specifically impact welded joints. The novelty of this study lies in its broad evaluation of environments that replicate various industrial conditions, allowing for a nuance understanding of how different conditions affect corrosion resistance. This approach avoids the generalization of welded joints' behavior across all environments, providing valuable insights for making informed decisions on material and welding technique selection based on specific environmental conditions. By doing so, the study aims to prevent failures and enhance the durability of welded structures across different industrial applications.

2.0 MATERIALS AND METHODS

2.1 Materials

The mild steel plate used was procured from a popular building materials market in Onitsha, Nigeria. It is dimensioned 1000mm x 100mm x 10mm with chemical composition of 0.18%C, 0.65%Mn, 0.03%Si, 0.023%P and balance Fe. The plate was cut into smaller pieces of 100mm x 100mm x 10mm and two pieces joined together using the shielded metal arc welding machine after proper edge preparation. The butt joint used in this work was formed based on recommended welding parameters that can produce high tensile strength, hardness, and impact strength. The welding parameters were a current of 103.396 A, a speed of 246.019 mm/min, and a voltage of 221.696 V [23].

2.2 Method

2.2.1 Preparation of test samples

After making the joints, the joints and the entire parent plate were thoroughly cleaned by removing of scales and rust, followed by use of different grits of emery papers to clean and smoothen the surface. Thereafter, different test samples were prepared from the prepared materials. Corrosion test samples: corrosion test samples with dimension 20 mm x 20 mm x 10 mm were made from the welded joint areas with the joint at the middle. Samples for electrochemical corrosion monitoring (potentiodynamic polarization and electrochemical impedance spectroscopy) methods were also prepared.

All the samples were stored in a desiccator after preparation before use in order to prevent oxidation.

2.2.2 Preparation of corrosion media

Five different corrosion media were used for the analysis. They include: 1M H_2SO_4 prepared from analytical grade H_2SO_4; 1M NaCl prepared from 99.99% analytical grade NaCl salt; 1M NaOH also prepared from analytical NaOH; soil collected from Otefe-Oghara in Delta State, Nigeria and fresh water obtained from a stream also from Otefe-Oghara. The laboratory prepared aqueous solution were made to simulate industrial, sea and other media encountered by mild steel in its applications.

2.2.3 Corrosion testing

A. Gravimetric method

The already prepared samples were weighed and completely immersed in the different media prepared. Monitoring was carried out periodically at interval of seven (7) days for sixty days. At each monitoring day, the sample is withdrawn from the medium, clean in water and rinse in acetone, dried and reweighed. The weight before and after immersion were recorded (Eo and Ei respectively) and weight loss (w) evaluated using Equation 1, while corrosion penetration rate is calculated with Equation 2.

$$W = Eo - Ei \tag{1}$$

$$CR = \frac{8760W}{\rho At} \tag{2}$$

Where, CR, ρ, A, and t represent the corrosion rate (mm/yr), density of the sample (7.9g/cm^3), surface area (cm^2), and time (hr) respectively.

B. Electrochemical method

The potentiodynamic polarization (PDP) and the electrochemical impedance spectroscopy (EIS) were also used to examined the corrosion behaviour of the welded joints exposed to the diverse media.

Potentiodynamic Polarization:

For Tafel studies, the test procedures adopted followed the recommendations described in ASTM Standards. Prepared surfaces of mounted and polished 1 cm² carbon steel samples were immersed in the corrosion cell which contained 100 ml of all the prepared media. The temperature of the test environment was maintained at 25°C to ensure consistency. Prior to testing, the samples were allowed to stabilize for 30 minutes at open circuit potential (OCP). The specimens were scanned with the Versastat equipment in potentiostatic mode within the -250 mV to +250 mV range at a scan rate of 1.0 mV/s.

The linear (Tafel) portions of the curves were extrapolated to obtain the corrosion potential (E_{corr}) and corrosion current density (i_{corr}). The corrosion rates (mm/yr) were then determined using Equation 3 [24];

$$CR = K_1 \frac{I_{corr}}{\rho} EW \tag{3}$$

Where, CR represents the corrosion rate (mm/yr), icorr is the corrosion current density (μA), EW is the equivalent weight of steel, and ρ is the density. The inhibition efficiency was determined using Equation 4.

$$\eta\ (\%) = \frac{i_{cu} - i_{ci}}{i_{cu}} \times 100 \tag{4}$$

Where, i_{cu} and i_{ci} are the corrosion current density values without and with corrosion inhibitor respectively.

Electrochemical Impedance Spectroscopy:

Electrochemical Impedance spectroscopy was conducted with the aid of a computer controlled potentiostat instrument, VERSASTAT 4. The analysis was performed using Versastat electrochemical software and a three-electrode set up containing a counter electrode (CE), reference electrode (RE) and sample of the investigated steel as the working electrode (WE). The WE (i.e. the steel sample) was mounted on epoxy resin to give an exposed surface of 1cm^2. The samples were degreased before the test. The samples were immersed in the environments containing 0 to 4g/l of the inhibitor and long enough for corrosion to reach steady/equilibrium state (OCP).

Electrochemical impedance spectroscopy measurements were conducted at the corrosion potential. The amplitude of the voltage signal varied in the range ± 10 mV, and studies were conducted from high to low frequencies. The machine was set to apply AC signals of 10 mV peak-to-peak amplitude at the equilibrium potential in 0.1Hz to 100 kHz frequency range. Data obtained were analyzed using EIS Spectrum Analyzer or Echem Analyst software (Gamry). The equivalent circuit model was selected to fit the impedance data, including elements such as solution resistance (R_s), charge transfer resistance (R_{ct}), and double layer capacitance (C_{dl}). The Rs element is the electrolyte resistance which is reflected in corrosive environment. The resistance of charge transfer (R_{ct}) and the double layer capacitance (C_{dl}) are the primary factors that can be obtained from the analysis of the Nyquist spectra [25]. R_{ct} element is characterized by the charge transfer resistance of the interface metal/electrolyte, associated with the process of oxidation of metal, while the capacitance C_{dl} double layer capacitance, occurring on the border of phases under consideration. The exponent n allows for the determination of the homogeneity of corrosion process.

C. Scanning Electron Microscopy (SEM)

Surfaces of the corroded samples were examined under the SEM. A Field Emission Scanning Electron Microscope (FE-SEM) (FEI Quanta 450 FEG model) was deployed for this analysis. This is with a view to ascertaining the effect of each environment of the surface of the welded joint at the end of exposure period in the various corrosion media.

3.0 RESULTS AND DISCUSSION

3.1 Corrosion Rates from Gravimetric Measurement

Figure 1 illustrates the corrosion rate variations of the welded mild steel over time in the diverse environments, providing a visual summary of the observed corrosion behaviors.

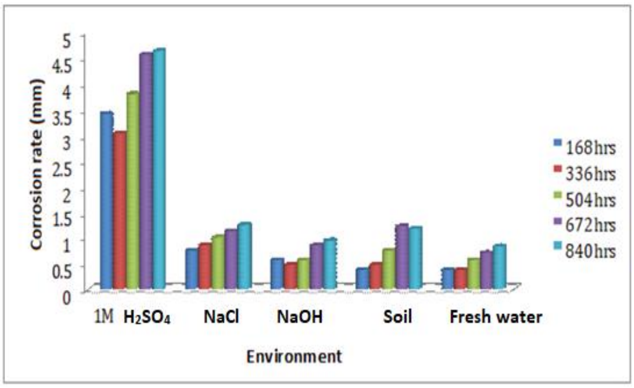

Figure 1: Variation of corrosion rate of welded mild steel in different media

As revealed in Figure 1, initially, the welded mild steel samples exposed to a 1M NaCl solution was observed to demonstrate a diverse array of physical characteristics over time. The surface exhibited grey and black patches in the first week, which progressively developed into rough, brownish corrosion products covering 40-70% of the surface by the third and fourth weeks. By the fifth week, the formation of circular pits and black patches highlighted a progression from general corrosion to localized pitting. The NaCl solution's transition from a clear state to a dark yellowish-brown hue and the accumulation of brown particles at the bottom revealed the dissolution of metal ions and the aggressive nature of chloride ions in accelerating corrosion processes [26-27]. This observation underscores the critical role of chloride ions in enhancing localized pitting, a phenomenon that is often underexplored in standard corrosion studies.

In contrast, the corrosion behavior of the welded mild steel in a 1M NaOH solution exhibited an initially high corrosion rate, which decreased by 16% in the second week before rising again until the fifth week. The formation of oxide films during the first week acted as a temporary barrier against corrosion, which was disrupted over time. The presence of dark brown patches on the steel's surface at the end of the fifth week indicated that while NaOH-induced oxide film formation initially slowed corrosion, the subsequent breakdown of this film led to renewed corrosion activity [28]. This observation highlights the dynamic nature of corrosion in alkaline environments, where protective oxide films can form and fail, offering a nuanced perspective on corrosion resistance mechanisms in alkaline conditions. Similar results were reported by some other researchers [29-30].

When exposed to fresh water, the welded mild steel displayed relatively mild corrosion compared to other environments. The initial grey corrosion products and light brownish water colour evolved into a dark yellow hue by the third week, accompanied by black edges and smooth grey surfaces. The gradual development of brown corrosion patches at the bottom of the water demonstrated a slower corrosion rate, attributed to the relatively benign nature of the freshwater environment as reported by Fiskal et al. [31]. This slower corrosion progression provides a contrast to more aggressive environments and highlights the importance of water chemistry in determining corrosion rates.

In stark contrast, the exposure of mild steel to 1M H_2SO_4 solution resulted in severe, uniform corrosion. The initial smooth, shiny grey surfaces transformed to a light green acid solution, which then changed to a brown-yellow and ultimately a light black appearance with extensive corrosion patches by the fourth and fifth weeks. This severe corrosion is attributed to the high acidity of the sulfuric acid, which aggressively disrupts passive films on the steel surface, facilitating continuous corrosion [30, 32]. This finding reflects the potent corrosive effects of sulfuric acid and the limitations of passive film protection in highly acidic environments.

The behavior of the welded mild steel in underground soil revealed rapid corrosion from the third week onwards, with a noticeable dark yellowish-brown color and brown particles by the end of the fourth week. The development of circular pits on the surface indicated the presence of localized corrosion, likely driven by anaerobic bacteria and a soil pH of 5, which creates a conducive environment for corrosion acceleration [33]. This observation underscores the complex interactions between soil conditions, microbial activity, and corrosion processes, providing insights into the role of environmental factors in corrosion as reported Liu et al.[34].

Overall, the welded mild steel specimens exposed to different environments exhibited varied corrosion rates and characteristics, driven by the specific chemical and physical properties of each medium. In 1M H_2SO_4, the aggressive sulfuric acid environment led to rapid corrosion due to the destruction of passive films, while the soil environment's combination of microbial activity and moderate acidity accelerated corrosion processes. The interaction between low hydrogen ion concentrations in the water and available oxygen facilitated corrosion cell formation, highlighting the importance of environmental conditions in influencing corrosion rates [35].

Corrosion rates of welded mild steel are influenced by exposure time and environmental factors, revealing a complex interplay between the rate of degradation and the formation of protective layers over time. Initially, as exposure time increases, the corrosion rate often accelerates due to the breakdown of protective oxide films and the onset of aggressive corrosion reactions. However, over time, this rate may stabilize or decrease as new protective layers or corrosion products form. For instance, in a 1M H_2SO_4 environment, the weight loss increased from 3.5mm/yr in the first week to 4.76mm/yr in the fifth week, reflecting the strong corrosive effect of sulfuric acid which disrupts passive films and promotes continuous metal dissolution [36]. Conversely, in 1M NaCl solution, initial corrosion rate is due to chloride ions disrupting passive films, leading to pitting corrosion [37], while the relatively moderate increase in corrosion rate over time shows that chloride-induced damage evolves into localized corrosion [38]. The 1M NaOH environment initially presents high corrosion rates due to the alkaline solution's reactivity, which is mitigated over time by the formation of a protective oxide film, demonstrating how pH variations influence both initial corrosion aggression and long-term protective processes [38]. In fresh water, the corrosion rate was the lowest among the tested environments, with a gradual increase in weight loss reflecting a less aggressive environment where corrosion is slowed by the formation of protective layers [39]. In soil, rapid corrosion was observed starting from the third week, with dark yellowish-brown corrosion products and pits indicating how soil conditions such as pH and microbial activity accelerate corrosion [20], offering insights into the role of environmental aggressiveness in metal degradation.

The findings from these environments reveal that corrosion rates are not simply a function of time but are also influenced by complex environmental interactions, including pH, chloride concentration, and microbial presence. This comprehensive analysis provides a nuanced understanding of how different conditions affect corrosion behaviour, demonstrating that corrosion processes are dynamic and multifaceted phenomena.

3.2 Results of Electrochemical Impedance Spectroscopy

Figure 2 shows the Nyquist plot for welded mild steel in different corrosive media, while Table 1 summarizes the corresponding EIS parameters obtained from these measurements. These results provide a basis for discussing the corrosion behavior of the welded steel under various conditions.

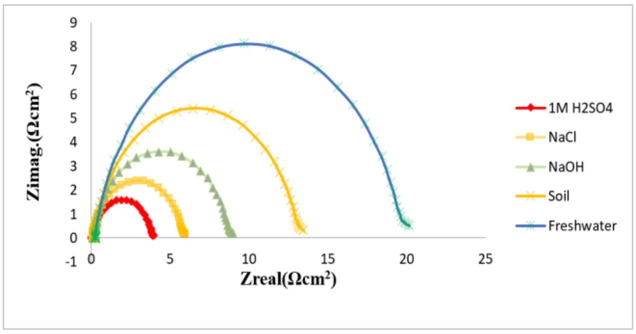

Figure 2: Nyquist plot of welded mild steel in different media

Table 1: Electrochemical Impedance Spectroscopy (EIS) parameters of welded mild steel in different media

Environment	R_s(Ωcm²)	R_{ct}(Ωcm²)	C_{dl}(μFcm⁻²)	Corrosion rate (mm/yr)
1 M H_2SO_4	0.1672	72.606	3527583.68	16.02
NaCl	0.1986	103.759	574220.86	11.21
NaOH	0.2681	148.171	234152.80	7.85
Soil	0.3085	246.951	113434.31	4.71
Freshwater	0.3978	434.008	58776.44	2.68

The welded mild steel exhibits the highest corrosion rate in 1M H_2SO_4, with a charge transfer resistance (R_{ct}) of 72.606 Ωcm² and a corrosion rate of 16.02 mm/yr. This severe corrosion highlights the highly aggressive nature of sulfuric acid, which disrupts passive films on the steel surface and accelerates corrosion. For welded steel structures exposed to acidic environments, it is essential to use advanced protective measures such as specialized coatings or alternative materials to enhance durability and prevent rapid degradation [39]. In contrast, the lowest corrosion rate is observed in freshwater, with the largest R_{ct} of 434.008 Ωcm². The relatively benign nature of freshwater indicates that welded steel structures in such environments face minimal corrosion risk, making freshwater environments suitable for deploying steel structures with minimal additional protection.

The NaCl (saltwater) environment shows a moderate corrosion rate with an R_{ct} of 103.759 Ωcm². Chloride ions in saltwater facilitate electrochemical corrosion processes, leading to localized pitting and general corrosion [37]. This finding emphasizes the need for effective anti-corrosive measures, such as the application of protective coatings and regular maintenance, for steel structures in marine or saline environments. In the NaOH (basic) environment, the Rct increases to 148.171 Ωcm², indicating a lower corrosion rate compared to acidic and saline conditions. The alkaline environment supports the formation of a passive oxide layer, which provides some corrosion resistance [40]. However, this protection is not permanent, and ongoing inspection and maintenance are necessary to ensure the long-term integrity of welded steel joints in alkaline conditions. The soil environment reveals a relatively low corrosion rate with an R_{ct} of 246.951 Ωcm². Soil conditions are less aggressive due to the reduced availability of corrosive agents and the potential for the formation of protective layers [34]. Nevertheless, for buried welded steel structures, it is still important to consider factors such as soil pH and microbial activity and implement protective strategies like cathodic protection and corrosion-resistant materials for enhanced durability.

3.3 Potentiodynamic Polarization Analysis

Figure 3 shows the Tafel plots for welded mild steel in various corrosive media, while Table 2 provides the potentiodynamic polarization parameters for each environment.

Table 2: Potentiodynamic polarization parameters of welded mild steel in different media

Environment	$-E_{corr}$ (mV)	I_{corr} (μAcm^{-2})	β_a (mV/dec)	$-\beta_c$ (mV/dec)	Polarization resistance R_p (Ω)	CR (mm/y)
1 M H_2SO_4	521.72	972.42	65.957	90.423	17.065	11.31
NaCl	526.94	482.67	46.170	56.169	22.185	5.61
NaOH	527.46	308.56	32.979	42.552	25.598	3.59
Soil	526.42	254.44	26.383	30.744	30.717	2.96
Freshwater	525.90	132.87	18.421	127.127	35.837	1.55

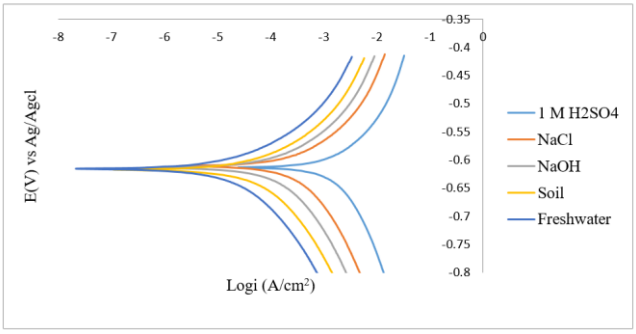

Figure 3: Tafel plots of welded mild steel in different media

Potentiodynamic polarization analysis presented in Figure 3 and Table 2 confirms that 1M H_2SO_4 exhibits the highest corrosion rate with an Icorr of 972.42 µA/cm² and a corrosion rate of 11.31 mm/yr, consistent with the EIS findings. This further confirms that sulfuric acid environments pose a severe threat to welded steel structures, hence, the need for robust protective measures. In freshwater, the lowest Icorr of 132.87 µA/cm² and a corrosion rate of 1.55 mm/yr further indicate that welded steel structures experience minimal corrosion in such environments. This demonstrates that freshwater environments are relatively safe for steel structures, requiring minimal protective interventions.

The NaCl environment shows a moderate Icorr of 482.67 µA/cm² and a corrosion rate of 5.61 mm/yr, illustrating the significant role of chloride ions in accelerating corrosion. This finding emphasizes the need for regular maintenance and protective coatings to combat chloride-induced corrosion in marine environments. In the NaOH environment, an Icorr of 308.56 µA/cm² corresponds to a corrosion rate of 3.59 mm/yr. The presence of a passive oxide layer in alkaline conditions provides partial protection, but continued monitoring is necessary to maintain this protective film and prevent corrosion over time. Finally, the soil environment exhibits an Icorr of 254.44 µA/cm² with a corrosion rate of 2.96 mm/yr. This suggests that while soil conditions generally offer some protection, effective corrosion management techniques like cathodic protection and appropriate coatings are still recommended for buried steel structures.

3.4 Comparison of Electrochemical Results across Media

The electrochemical results confirm that 1M H_2SO_4 caused the most severe corrosion, with the lowest charge transfer resistance (R_{ct}) and highest corrosion current density (Icorr), accelerating steel degradation.

NaCl also showed significant corrosion due to chloride-induced pitting.

In contrast, NaOH and soil environments provided some protection, as NaOH promoted passive oxide formation, while soil limited exposure to corrosive agents. Freshwater exhibited the lowest corrosion rate, requiring minimal protective measures.

These findings reveal that the type of corrosion prevention strategies to be adopted in welded steel joints should be dependent on the nature of the environment the material will be exposed to.

3.5 Corrosion Effects on the Surface Morphology of Welded Steel Joints

The SEM images presented in Figures 4a–4f reveal the effects of various corrosive environments on the microstructure of the welded steel samples.

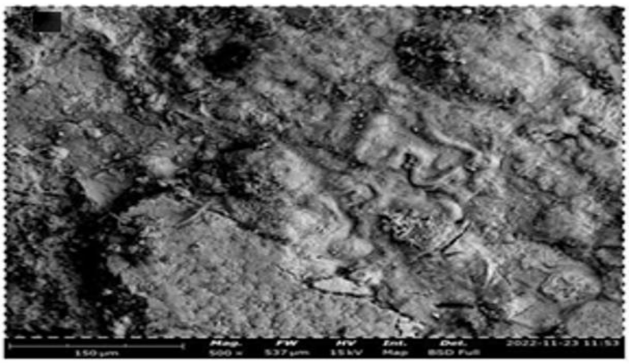

Figure 4a: SEM image of welded steel joint before corrosion

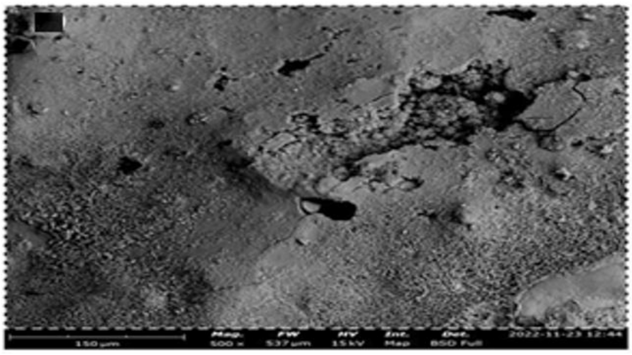

Figure 4b: SEM image of corroded welded steel (after 60 days in 1M H_2SO_4)

The SEM images in Figures 4a–4f demonstrate the corrosion effects on the microstructure of welded steel joints under different environmental conditions. Figure 4a shows the microstructure of the welded steel joint before any corrosion exposure. Figure 4b depicts the microstructure of the welded steel after 60 days of exposure to a 1M H_2SO_4 solution, revealing significant corrosion damage with widespread pitting and intergranular attack. Similar result was obtained by Loto [41]. The SEM image in Figure 4c shows the welded steel after 60 days in a NaCl (sodium chloride) solution, characterized by localized pitting and crevice corrosion, particularly at the weld interface. Figure 4f presents the microstructure of the welded steel after 60 days of exposure to freshwater, indicating moderate general corrosion with some pitting and surface roughening. The SEM image in Figure 4e depicts the welded steel after 60 days buried in soil, showing extensive corrosion damage, including widespread pitting, crevice corrosion, and intergranular attack. Figure 4d shows the welded steel after 60 days in a NaOH (sodium hydroxide) solution, revealing severe corrosion with significant material loss, pitting, and intergranular attack on the metal surface.

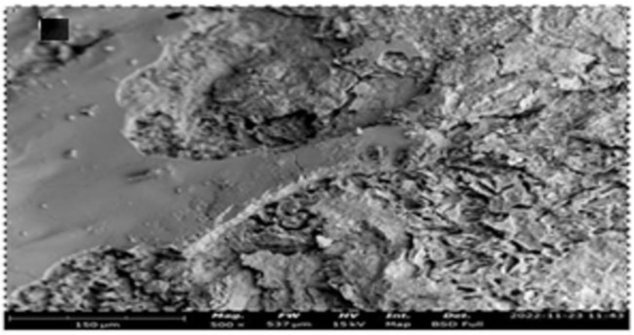

Figure 4c: SEM image of corroded welded steel (after 60 days in NaCl solution)

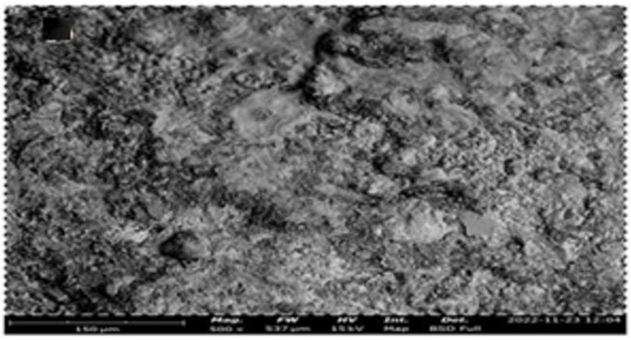

Figure 4d: SEM image of corroded welded steel (after 60 days in NaOH solution)

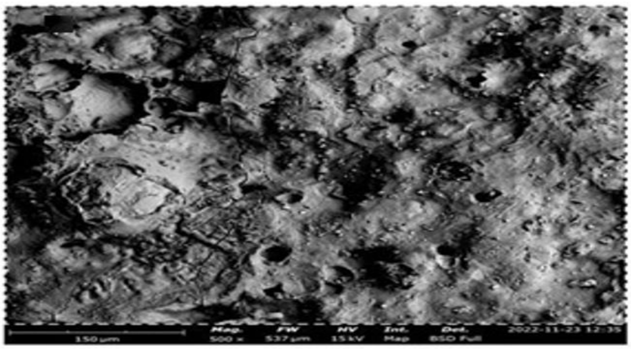

Figure 4e: SEM image of corroded welded steel (after 60 days buried in soil)

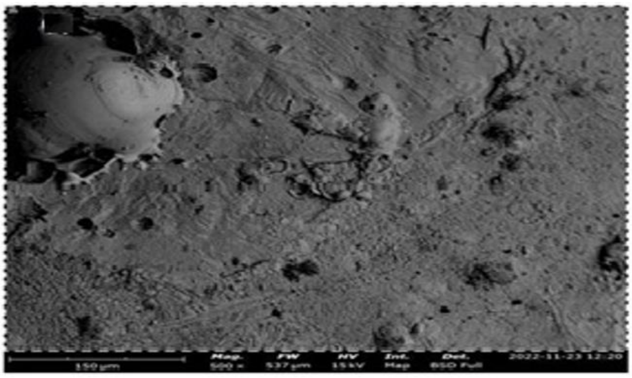

Figure 4f: SEM image of corroded welded steel (after 60 days in freshwater)

4.0 CONCLUSION

This study investigated the effects of different environmental conditions on the corrosion behavior of mild steel welded joints produced with optimized welding parameters. The findings revealed that the corrosiveness of the environment significantly impacts both the corrosion rate and the material integrity of the welded joints. Specifically, the 1M H_2SO_4 environment exhibited the highest corrosion rate, with severe degradation of material properties due to its highly acidic nature. In contrast, freshwater provided the most favorable conditions, with the lowest corrosion rate. Moderate corrosion effects were observed in the NaCl and NaOH environments, where NaCl induced pitting corrosion and NaOH facilitated the formation of a passive oxide layer that offers some protection. Soil conditions, while showing relatively low corrosion rates, still necessitate protective measures for long-term durability. Electrochemical impedance spectroscopy (EIS) and potentiodynamic polarization results confirmed that 1M H_2SO_4 had the highest corrosion rate with an Icorr of 972.42 $\mu A/cm^2$ and a corrosion rate of 11.31 mm/yr, while freshwater had the lowest corrosion rate with an Icorr of 132.87 $\mu A/cm^2$ and a corrosion rate of 1.55 mm/yr. These observations emphasize the importance of selecting appropriate materials and protective measures based on environmental conditions to ensure the longevity and performance of welded steel structures. Based on these findings, it is recommended that for applications in highly corrosive environments, such as those exposed to sulfuric acid, advanced protective coatings or alternative materials be used to enhance the durability of welded steel structures. Additionally, for environments like NaCl and NaOH, regular maintenance and the use of effective anti- corrosive measures are essential. Future research should focus on long-term studies to further understand corrosion mechanisms and to develop predictive models for optimizing welding parameters in diverse environments. Implementing these recommendations will help to improve the design, maintenance, and resilience of welded steel structures in various operational conditions.

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