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Original Research Article

Effects of Welding Techniques on the Corrosion Resistance of Mild Steel

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Abstract: The performance and longevity of welded structures depend heavily on corrosion resistance, particularly when mild steel is used as the primary material. The paper provides an overview of the investigation of the influence of various welding techniques on the corrosion resistance of mild steel. The study combines mild steel specimens using spot-welding, gas metal arc, and electric arc welding techniques. Electrochemical and immersion testing techniques are used to assess the welded samples' resistance to corrosion. The impact of metal microstructure, welded zone surface characteristics, corrosion rates, and filler material selection on corrosion resistance is examined. The results demonstrate that the choice of welding process has a significant effect on mild steel corrosion resistance. Some techniques have a higher level of corrosion resistance owing to the use of heat. As exposure duration rises, both diluted and concentrated hydrochloric acids cause weight loss in the absence of an inhibitor. The temperature increased over time until 190 minutes, which resulted in a decrease in temperature efficiency. In the impact test, adding 3%, 6%, and 9% of the welded components to the metal alloy increased the impact's energy output from 12.32 J to 12.69 J, 12.99 J, and 13.51 J, respectively. The energy effect of the reinforced mild steel was reduced owing to the brittleness of the welded parts relative to the ductile metal matrix. The composite absorbs impact stresses, and the enhanced weight ratio of the welded mild steel thereby increases its toughness.

Keywords: Welding Techniques, Mild Steel, Metal microstructure, Hydrochloric Acids.

1.0 INTRODUCTION

Low-carbon steel is a material that is frequently used in construction owing to its advantageous mechanical qualities, low cost, and simplicity of manufacture for manufacturing enterprises. However, mild steel is susceptible to corrosion, which can significantly impact its performance and structural integrity. In the construction, oil and gas, and automobile industries for instance, corrosion can significantly impact the durability of infrastructure and buildings, leading to costly maintenance and repairs; pipeline leaks, which can cause environmental and safety hazards, as well as financial losses, and structural damage to vehicles, reducing their lifespan and resale value, respectively. Corrosion is a significant issue that degrades mild steel's mechanical qualities and eventually causes it to fail. Understanding the concept of corrosion and its effects on mild steel is crucial in developing effective corrosion mitigation strategies. Corrosion results to the deterioration of the metal surface, leading to the loss of material and degradation of its mechanical properties when reacted with the environment. The main factors that cause mild steel to corrode include moisture, humidity, and electrolytes such as salts and acids that promote electrochemical processes (Roberge, 2019).

Rust is an oxide compound made of iron oxides that are liberated from the metal surface during the oxidation process that mild steel goes through as it corrodes. The formation of rust not only alters the appearance of mild steel but also weakens its structural integrity, reducing its load-bearing capacity. Corrosion resistance refers to the ability of a material, such as mild steel, to withstand the corrosive attack and maintain its functional and structural integrity over time. Enhancing the corrosion resistance of mild steel is essential to prolong its service life, prevent costly repairs, and ensure safety in various applications (Raja and Sethuraman, 2017).

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In order to mitigate corrosion in mild steel, several protective coating measures such as paints, primers, and corrosion inhibitors are utilized. The coatings decrease the progression of corrosion by acting as an inhibitor between the corrosive atmosphere and the metal surface. As a substitute, mild steel can be alloyed with elements like molybdenum, nickel, and chromium to increase its susceptibility to corrosion by generating an ineffective oxide coat that protects the surface (Aung and Ghazali, 2018). The necessity for understanding factors influencing the corrosion resistance of mild steel, including environmental conditions, alloy composition, surface preparation, and welding techniques, is essential for selecting appropriate materials and implementing corrosion prevention strategies in various industries (Ashworth and Lee, 2013).

1.1 Mild Steel and Its Properties

The low carbon content of mild steel is typically lower than 0.25%, which contributes to its good flexibility, cost-effectiveness, broad variety of uses, as well as its favorable mechanical characteristics.

Iron (Fe) and carbon (C) make up the majority of mild steel, along with tiny quantities of other elements, including manganese (Mn), sulfur (S), and phosphorus (P). Mild steel has distinct qualities that set it apart from higher-carbon steels due to its low carbon content (Verma and Sharma 2019). Mild steel is appropriate for a variety of structural applications due to its mild toughness. Usually, it has a tensile strength between 400 and 550 MPa. As a result of its high ductility, which makes it easy to mold, bend, and shape with no breaking, it is perfect for use in the production of components for the equipment, building, and automobile sectors. Due to its high durability, it can withstand impacts and abrupt loading situations without breaking. Mild steel is relatively soft and has low hardness, which makes it susceptible to wear and abrasion and can be hardened through various heat treatment processes if required.

Unprotected mild steel can undergo rusting, leading to degradation of its surface and structural integrity when exposed to moisture, oxygen, and corrosive environments (ASTM International, 2018).

Mild steel finds extensive use in numerous industries and applications, such as, (i) structural components in buildings, bridges, and infrastructure, (ii) automotive bodies, frames, and chassis, (iii) pipelines, tanks, and storage containers, (iv) machinery and equipment manufacturing and (v) general fabrication and construction projects.

1.2 Effects of Corrosion on Mild Steel

In engineering, corrosion is a big problem that may have a big impact on mild steel. There are different kinds of corrosion that can happen, including galvanic, uniform, pitting, and corrosion in crevices. A number of variables, including the metal's composition, temperature, exposure duration, and environment, can affect the kind of corrosion. Mild steel is particularly susceptible to corrosion due to its composition, which contains a high proportion of iron as shown in Figure 1.

Figure 1: Effects of Corrosion on Mild Steel (Marder, 2018)

The effects of corrosion on mild steel include a reduction in mechanical strength, changes in the material's appearance, and reduced durability. In situations where the material is subjected to extreme environmental conditions, this might result in structural collapse. Corrosion can result in large financial losses because of the great expense of replacing or repairing damaged equipment (Kumar *et al*., 2019). Numerous techniques have been devised to improve materials' resistance to corrosion in order to counter these obstacles. These include choosing the right materials for particular applications and applying coatings, alloys, and surface treatments that resist corrosion. Corrosion testing and monitoring are also essential to assess the effectiveness of these methods and ensure the long-term reliability and safety of materials (Bhargava and Gadekar, 2012).

1.3 Mild Steel Welding Techniques

Welding is a fabrication process used in both private and public institutions workshops or industries where metal joining is required. It is a fundamental process in the manufacturing and construction industries, providing the means of joining two or more metal components to create a strong and durable bond. Gas Metal Arc Welding (GMAW), Electric Arc Welding (EAW), and Spot Welding are various welding techniques with unique applications, advantages, and limitations. These techniques play a pivotal role in diverse industries, including automotive, aerospace, shipbuilding, infrastructure development, and more (Ogunlade, 2020; Ibrahim 2019; and Adeyemi, 2018). Since mild steel is inexpensive, strong, and easy to weld, it is frequently utilized in industrial and structural applications. Nonetheless, the welding procedure may have an impact on mild steel's resistance to corrosion. Using the wrong welding method or procedures can result in a variety of flaws, including imperfections, fractures, and permeability, all of which can serve as potential places for corrosion to start. The microstructure and chemical composition of the heat-affected zone (HAZ) of the joint being welded may vary, thereby influencing the material's corrosion behavior (Patel and others, 2013).

1.4 Factors that Influence Corrosion in Welded Joints

Corrosion in welded joints is influenced by various factors that can impact the integrity and durability of the weldment such as welding technique, base metal composition, welding consumables, post-weld heat treatment (PWHT), surface preparation and coating, and environmental factors. The choice of welding technique can significantly impact the corrosion resistance of welded joints. The following factors affect the corrosion resistance of welded joints via welding technique, welding parameters, base metal composition, heat affected zone (HAZ) and welding environment (Dillman, 2012; Liu, *et al.,* 2020).

1.5 Corrosion Resistance Improvement

Mild steel found applications in industries due to its excellent mechanical and physical properties, low cost, and ease of fabrication. However, mild steel is highly susceptible to corrosion, which compromises its structural integrity and reduce its lifespan when exposed to the environment, resulting in the deterioration of the metal over time as shown in Figure 2.

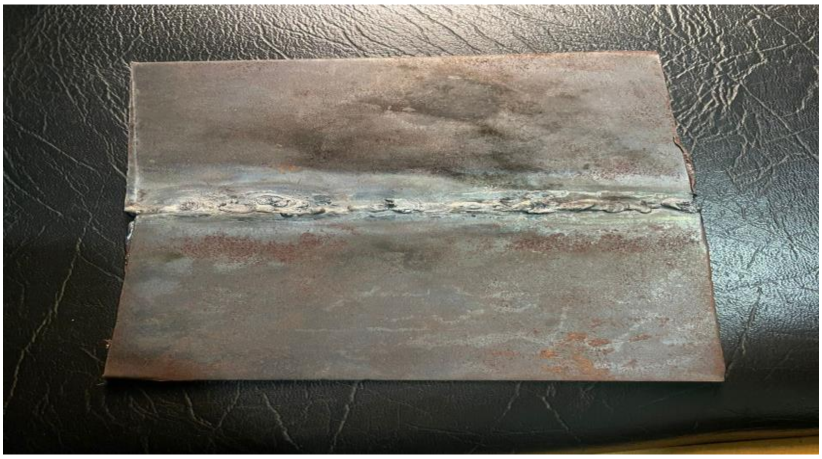

Figure 2: Corrosion Improvement on Welded Mild Stee (Mohammed *et al.*, 2018)

There are several measures that can be taken to improve the corrosion resistance of welded joints in mild steel. One common technique is to apply a protective coating to the welded joint after welding. This can help to prevent the initiation of corrosion and protect the material from environmental factors that may cause corrosion. Another technique is to use corrosion-resistant filler metals during welding, which can help to minimize the formation of defects and improve the overall corrosion resistance of the joint (Patel *et al.,* 2013). There are many ways to stop or lessen mild steel corrosion, such as coating, using inhibitors, and cathodic protection. These techniques function by modifying the environment or erecting an impediment between the metal and the corrosive surroundings (Dey *et al.,* 2015). The use of nanomaterials as coatings to protect against corrosion, as well as the development of new inhibitors that are more effective and environmentally friendly in practice (Phani and Balasubramaniam, 2019).

2.0 MATERIAL AND METHOD

2.1 Materials and Equipment

Fusion-welded Supplies: 2 M of hydrochloric acid solution, distilled water, ethanol, acetone, mild steel joints, and methyl paper. Various tools are used for different kinds of measurements, including a digital thermometer, funnel, filter paper, conical flasks, test tubes, measuring cylinders, hack saws, and rotary evaporators. The investigation of the impact of welding on mild steel's resistance to corrosion involves the use of gas metal arc welding (GMAW), electric arc welding (EAW), and spot welding.

2.2 Metal Specimen Processing Procedure

The mild steel utilized in this work is welded, mechanically cut to dimensions of 2.0 x 0.2 x 2.5 cm (a surface area of 11.8 cm2), and shined using an emery paper range of 400 to 1200 grades. As seen in Figure 3, the sample's surface was smoothed down by grinding it in a grinding machine.

Figure 3: Surface Smoothening

2.3 Preparation of 2 M HCl Acid

A molar mass of 35.5g was used to make standard concentrated HCl acid with a density of 1.18 g/cm^3 and a percentage purity of 35%. Equations 1 and 2 were used to get the concentrated HCl acid's molarity.
concentration = standard volume x density x percentage purity ………………. (1)

Concentration = 1000 x 1.18 x 35%

$$\text{Molarity} = \frac{\text{Concentration}}{\text{Molar Mass}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ldots\ldots\ldots (2)$$

$$= \frac{1000 \times 1.18 \times 35\%}{35.5} \qquad = 11.63\text{m}$$

$C_1V_1 = C_2V_2$ ……………………….. (3)

Where: C is concentration and V is volume
500cm3 of 2M HCl acid will be required,
$11.63 \times V_1 = 2 \times 500$

$$V_1 = \frac{1000}{11.63}$$

$$= 85.99\text{cm}^3$$

Thus, in order to get the required concentration, 85.99 cm3 of HCl from a standard Winchester bottle was dissolved in 500 cm3 of distilled water. With the goal of doing the corrosion experiment, the test solutions were produced in many vessels.

2.4 Experimental Procedure

The seed extracts were made by combining them with an aggressive 2 M HCl solution, both in the presence and absence of the inhibitors under study, at varying concentrations at room temperature.

The mild steel coupons were weighed, recorded, and then, with the help of an acid-resistant plastic clip, put into the corrosive. Over the course of 18 hours, the coupons were gradually retrieved at 3-hour intervals. At each exposure period, the mild steel coupons were taken out, properly cleaned to get rid of the corrosion product, rinsed with distilled water and acetone, and allowed to air dry. The corrosion rate, weight loss rate, and inhibitory efficiency were measured and recorded for the corroded coupons.

The characteristics of mild steel's corrosion attack were compared and confirmed using thermometric measurement, which involved utilizing a digital thermometer with a probe to determine the reaction system's temperature. As instructed, the temperature probe was placed inside the test tube. The prepared corrosive solution was placed inside the test tube, along with mild steel coupons that were carefully dropped into the solution and swiftly sealed. The thermometer probe was pierced through the test tube's lid. Up until it reached its maximum temperature, the temperature change was tracked and recorded at regular intervals. The experiment was conducted again, with and without varying inhibitor concentrations. The corrosion rate was used to compute the reaction number, which was derived from previous research (Ajayi *et al*., 2013; Solomon *et al*., 2010) with equation 4

$$R\ (^{\circ}\mathrm{C\,min}^{-1}) = \frac{T_m - T_i}{t} \text{ ………………….. (4)}$$

Where T_m is the maximum temperature, T_i is the initial temperature of the system and t is time (min) taken to reach the maximum temperature.

Equation 5 illustrates the computation of the inhibition efficiency, I (%), based on the reaction number percentage decrease.

$$I = \frac{R_{aq} - R_{wi}}{R_{aq}} \times 100 \text{ ……………… (5)}$$

Where $R_{aq}$the reaction is number of the aqueous solution and R_{wi} is the reaction number in each inhibitor.

The thermometric measurement is obtained from the experimental set-up shown in Figure 4.

Figure 4: Experimental Setup of Thermometric Measurement

The pendulum hammer is raised to the required height and then released to allow free swing. As the pendulum swung freely, the initial energy available in the hammer was noted. The procedure was repeated to desired height and was securely fixed. The spot-welded specimen was prepared for testing and fixed on the anvil.

The clamped pendulum hammer is released while swung towards the specimen, causing it to fracture. As the pendulum swung to the other side, the energy reading on the scale and post-impact energy reading were noted. The shock absorbing capacity was calculated using the initial and final energy values obtained during the test. The energy absorbed during fracture and shock absorbing capacity were estimated for mechanical properties analysis of the welds after corrosion exposure.

3. RESULTS AND DISCUSSION

The examination of mechanical and microstructural characteristics emphasizes how crucial it is to use different welding processes to influence mild steel's ability to withstand corrosion in the atmosphere.

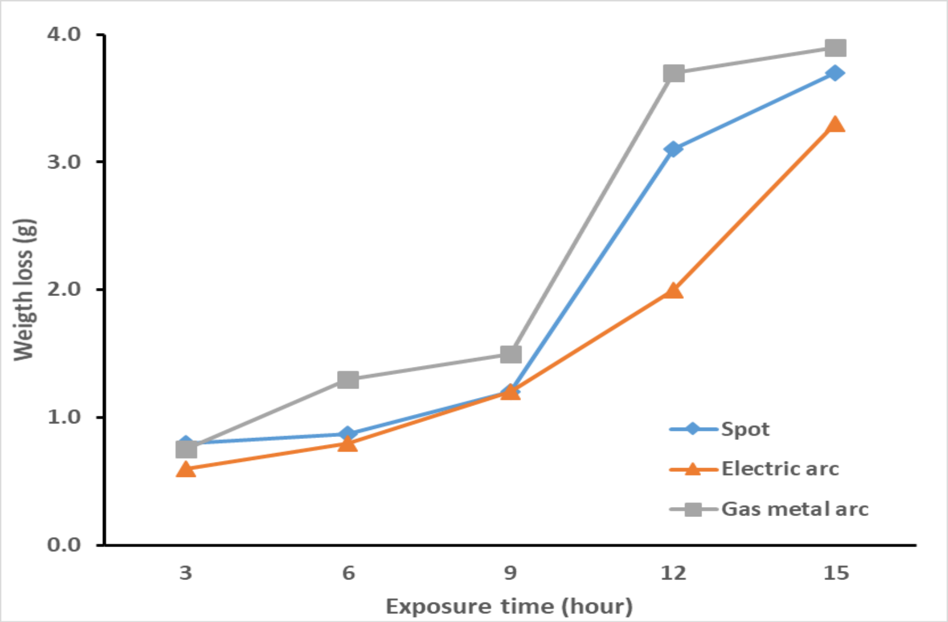

Figure 5: Weight loss on Exposure Time

As mild steel is exposed to the environment, Figure 5 shows its microstructural characteristics. It has been noted that when exposure duration rises without an inhibitor, the weight loss of welded mild steel increases. These suggest that although mild steel corrosion cannot be completely avoided, it may be managed and reduced. Human error may be the cause of some curves showing weight loss in mild steel not showing straight lines when exposed to different times of time. As the temperature rises, observations show that mild steel loses weight more quickly when there is no inhibitor present.

3.1 Thermometric Measurement (°C)

The quantitative data on temperature measurements associated with different welding techniques under various conditions or test sets is illustrated in Figure 6. It shows the set of data representing thermometric measurements in degrees Celsius (°C) for different welding techniques.

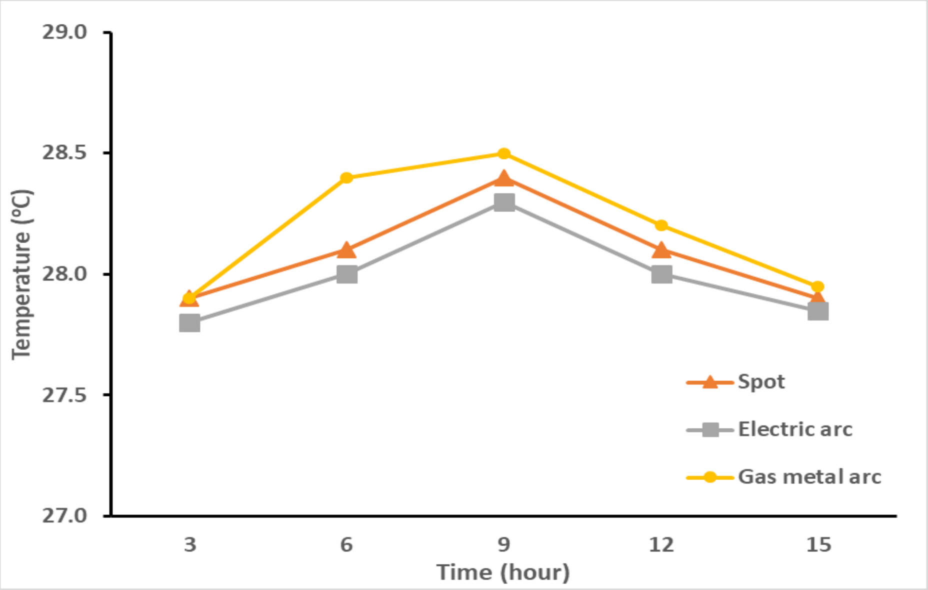

Figure 6: Effect of Temperature on Exposure Time

With time, the temperature rose to a maximum at 190 minutes, after which it dropped. The cause is thought to be a rise in the free movement of the corrosion product Fe2+ (ion) being blocked, which decreases the production of additional ions and precipitates with time. As a result, less heat is produced, and the corrosion reaction slows down, as contained in Kareem *et al*., (2019).

3.2 Impact Measurement (J)

The average impact energy of each sample was determined by conducting experiments on three identical specimens of the sample. To determine the composite's resilience to an abrupt load, an impact test was conducted. The labor necessary to shatter a test specimen, or the reported impact energy absorbed, is displayed in Table 1.

Table 1: Impact measurement (J)

Spot welding	Electric arc welding	Gas metal arc welding	Average
13.93	13.52	9.52	12.32
14.12	13.96	9.99	12.69
14.62	14.25	10.12	12.99
15.43	14.96	10.15	13.51

The findings indicate that when the weight percentage of the three distinct welding processes falls, the impact energy rises. The absorbed impact energy rose from 12.32 J to 12.69 J with the addition of 3% welded materials to the metal alloy. The impact value climbed to 12.99 J when the number of welded materials was raised to 6%. The impact value rose to 13.51 J when the ingredients were added at a rate of 9%. Because the welded components were more brittle than the ductile metal matrix, the impact energy of the reinforced mild steel was seen to have decreased.

3.3 Visual Inspection

Corroded welded mild steel specimen at room temperature with and without addition of inhibitor in two HCl solutions was investigated by visual inspection to compare their corrosion rates. After being exposed for eighteen hours, as indicated from Figure 7 to Figure 14, the examined corroded sample is displayed on plates 4.1, 4.2, 4.3, 4.4, 4.5, 4.6, 4.7, 4.8, 4.9, and 4.10. It is submerged in a concentrated HCL and diluted HCL (2M) solution with 0.5 g/l, 0.3 g/l, and 0.1 g/l concentrations of the AASE inhibitor as contained in Awe *et al.,* (2015).

Figure 7: Welded Mild steel sample1 immersed in concentrated HCl after 18 hours exposure time

Figure 8: Welded Mild steel sample2 immersed in concentrated HCl after 18 hrs exposure time

Figure 9: Welded Mild steel Immersion in concentrated HCL with 0.1g/l concentration (AASE inhibitor after 18 hours exposure)

Figure 10: Welded Mild steel Immersion in concentrated HCL with 0.3g/l concentration

Figure 11: Welded Mild steel sample immersed in concentrated HCL with 0.5g/l concentration

Figure 12: Welded Mild steel A Immersion in 2M HCl after 18 hours exposure time

Figure 13: Welded Mild steel B Immersion in 2M HCl after 18 hours exposure time

Figure 14: Welded Mild steel Immersion in 2M HCl solution with 0.1g/1 concentration

4. CONCLUSION

Weight loss, thermometric readings, and impact measurements were used to investigate the corrosion on welded mild steel in 2M HCl. The following deductions were made:

i. When the exposure duration rises, the weight loss with concentrated HCL without inhibitor and the weight loss with diluted HCL (2M) without inhibitor both increases.
ii. As time passed, the temperature rose until it reached its peak at around 190 minutes, after which it fell. However, when the temperature rises, the temperature efficiency drops. Consequently, when the system's sample temperature rises over time to attain its steady state, it does so at an increasing rate.

iii. The brittle properties of the welded components cause the observed decline in impact energy of the reinforced mild steel. The toughness of the composite improves and its capacity to absorb impact loads increases when the weight ratio of welded mild steel grows relative to the composite's decreasing weight percentage.

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