



Susceptibility of Welded 0.025% Carbon Steel Joints to Corrosion in Seawater Environment

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Abstract: The 0.025% carbon steel is a low-carbon steel with numerous uses in engineering design, because of its many beneficial engineering qualities. They are cheap steels that are weak and soft yet have exceptional toughness and ductility, as well as good machinability and weldability. The degradation of a metal is called corrosion. It is the metal's return, either fully or partially, to a more stable mineral state. Seawater is a complex chemical system that can corrode low carbon steels. This study examined the susceptibility of as-received, welded, and annealed low-carbon steel samples at different temperatures to corrosion in a marine environment. A power saw was used to cut the low carbon steel in half. An electric arc welding equipment is used to fuse the two sides together after one of their edges has been chamfered. The low carbon steel rods were placed in a furnace and fully annealed at two distinct temperatures: 920°C and 960°C, with an hour-long soaking period. The steel samples the un-welded (as-received), welded but not annealed, and welded and annealed samples were subjected to a corrosion test at room temperature in the lab by submerging them in seawater for 100 days. The samples were then removed every 20 days, and their weights were noted. The data collected and the corrosion rate computed were used to calculate the weight loss caused by corrosion activities on the steel. According to the data, the samples' weight loss and corrosion rate initially increased up to a certain degree before beginning to decline. The welded and annealed samples were found to exhibit greater corrosion activity than the as-received and welded but unannealed samples.

Keywords: Corrosion rate, Low carbon steel, Annealing, Seawater, Weight loss

INTRODUCTION

A significant amount of the overall steel production is made up of low carbon steels (0.002-0.25%). Since they make up more than 98% of building materials, they are the most important alloys utilized in the petroleum and petrochemical sectors [1-4]. Because of its moderate strength, good weldability, and formability, low-carbon steel finds extensive use in everything from transportation pipelines to chemical and oil and gas storage tanks [5-7]. However, in chemical and sour crude oil conditions, such as seawater, this material is prone to corrosion [8]. Corrosion-induced deterioration of materials made of low carbon steel is now widely acknowledged as an inevitable aspect of existence. For example, over the past ten years, there have been 2241 large pipeline accidents documented in the United Kingdom (UK), and corrosion losses in the United States alone are close to \$350 million annually [9-11].

Petroleum pipeline explosions frequently result in fatalities and environmental contamination in Nigeria. A pipeline explosion in Idjerhe (Jesse) was reported to have claimed hundreds of lives [12]. More than 250 Nigerians perished in a similar occurrence in Adeje village, close to Warri, Delta State [13]. Many industries, including the onshore and offshore oil and gas, pulp and paper, marine, automotive, and food processing sectors, as well as the building of storage tanks and processing vessels, employ low carbon steels extensively. In order to improve the performance of these low-carbon steel materials, it should be possible to influence and control their properties when they are being used in corrosive media. Therefore, the purpose of this research is to assist solve the corrosion issues that are typically encountered when utilizing materials made of low carbon steel in seawater and to suggest parameters under which low carbon steels may be used. Low carbon steel corrodes in natural saltwater by forming and growing thick, compact layers made of organic materials, oxides, and insoluble salts [14–18]. The created layer is the outcome of the surrounding environmental circumstances, including the water's oxygen supply, ionic species, bacteria, and organic matter. The kinetics of the entities' Faradaic reactions with the oxides or the metal, as well as their transport characteristics through the various strata of the rust layers, determine the exchange of different species (ions, molecules, gas) between seawater and the rust layers or the metal [19–24]. The corrosivity of water is significantly impacted by salts present in it. Different anions and cations have varying degrees of impact on the water's corrosivity at very low concentrations of dissolved salts. In general, the corrosivity of fluids with dissolved salts rises with increasing salt content until it reaches a maximum, after which it falls. This could be explained by higher electroconductivity due to the higher salt content until the salt concentration is high enough to significantly reduce oxygen solubility, which lowers the rate of depolarization [25–28].

At least 70 elements in a wide range of quantities can be found in seawater, an incredibly complex ionic aqueous solution [29]. At least 4,000 times better than most freshwater, it possesses a very good electrical conductivity of $0.04 \text{ m}\Omega \text{ cm}^{-1}$. Corrosion reactions are strongly influenced by salinity, pH, oxygen concentration, and temperature. The vertical distribution of these elements varies from the seafloor to the surface. While temperature and dissolved oxygen can fluctuate, seawater's salinity and pH are comparatively constant parameters. As the depth rose, the salinity rose as well, making the pH more acidic. Research work had demonstrated that the corrosion rate is faster in seawater, and this is related to the presence of various minerals in seawater composition [30]. The widely accepted definition for corrosion is the destruction of material owing to chemical reactivity of the material with its surroundings. On its surface, this destruction typically manifests as material dissolution or redeposit in different ways. Like all other metals and alloys, low carbon steel is often prone to corrosion since most of them exist naturally as ores, which is the most stable state of low energy, and there is a net drop in free energy (ΔG) from metallic to oxidized state [31].



It is practically significant that low carbon steel corrodes in natural settings like seawater. Equations (1) and (2) often illustrate the chemistry of corrosion processes [31]. Low carbon steel corrodes in natural seawater by forming and growing thick, compact layers made of organic materials, insoluble salts, and oxides [31]. The layer is the outcome of the surrounding environmental factors, including the water's oxygen supply, ionic species, bacteria, and organic matter. The kinetics of the entities' Faradaic reactions with the oxides or the metal, as well as their transport characteristics through the various strata of the rust layers, determine the exchange of different species (ions, molecules, gas) between seawater and the rust layers or the metal [32, 33].

The corrosivity of water is significantly impacted by salts present in it. Different anions and cations have varying degrees of impact on the water's corrosivity at very low concentrations of dissolved salts. In general, the corrosivity of fluids with dissolved salts rises with increasing salt content until it reaches a maximum, after which it falls. This could be explained by higher electro-conductivity due to the higher salt content, up until the salt concentration is high enough to significantly reduce oxygen solubility, which lowers the rate of depolarization [34]. Heat treatment is the process of heating and cooling solid metals and alloys to give them desired characteristics. In the final fabrication process of many technical components, heat treatment of metals is a crucial step. Annealing, normalizing, tempering, hardening, and isothermal procedures are some of the different types of heat treatment [35]. Heat treatment enhances the metal's microstructure, which is what gives it the desired qualities under various service circumstances. In order to induce softness and improve cold work, annealing involves heating to and maintaining a temperature above recrystallization, then cooling at a sufficient rate in a switched-off furnace [36]. Like taxes and mortality, corrosion is unavoidable, particularly in the petroleum, chemical, and manufacturing sectors. Therefore, this study project is a positive move if one takes into account the enormous sum of money spent on combating corrosion and the catastrophic effects that follow corrosion disasters. In order to determine the best path or routes for the best service performance of materials made from low carbon steel in seawater, research was conducted on the susceptibility of as-welded and annealed low carbon steel to corrosion in a seawater environment.

Carbon steel is essential to almost every facet of human endeavor. Metals are essential to human civilization, but corrosion is their weakness. One of the biggest obstacles to the use of low carbon steel in the manufacturing, building, chemical, petrochemical, and other industries is still corrosion. Corrosion causes millions of naira to be lost annually. Iron and steel corrosion accounts for a large portion of this loss, while many other metals can also corrode. Low carbon steel, like many other metals and alloys, suffers from pitting because the oxide produced by oxidation does not stick firmly to the metal's surface and flakes off readily. One of the main issues is the corrosion-related failure of engineering-origin parts and components in many sectors. Throughout human engineering history, corrosion has been the cause of several accidents. Heat treatment and alloying are the two main causes of steel's exceptional adaptability. A metal with an alloying ingredient composed of very little carbon is known as low carbon steel. Its carbon content typically falls between 0.002% and 0.025% [37]. Because it is frequently less expensive than other forms of steel, low carbon steel is one of the most popular varieties used for general applications. Because of its process conditions, which include things like temperature and pH, sea water presents a number of corrosion issues. Low carbon steel is widely utilized, and a significant portion of machinery, vessels, tank barges, ships, and other items used in maritime environments are made of low carbon steel. Hence, just like other literature in engineering, that optimize one system/operational condition or the other [38], [39], [40], [41], the susceptibility of as-welded and annealed low carbon steel to corrosion in a seawater environment must therefore be investigated in order to ascertain the material's active life and optimal use in a marine environment.

MATERIALS AND METHODS

2.1 Materials

For this investigation, low carbon steel with a weight percentage of 0.025 carbon was utilized. The steel came from an Effurun, Delta State, local market. The Escravos River in Delta State provided the seawater utilized. Additionally, various tools were used to conduct the necessary experiments. The low carbon steel was chopped into several sizes using a power saw. The steel samples were weighed using an analytical weighing machine. An inert gas welding machine for metal. The steel sample was heated to the required temperature using a muffle heat treatment furnace, and it was then machined to the required sizes and shapes using a lathe. A bench vice, sand

paper, and tongs for inserting and extracting the sample from a plastic bowl containing the corrosive medium were among the additional tools utilized in this investigation.

2.2 Methods

Table-1 displays the chemical makeup of the low carbon steel samples used in this study. Table 1 displays the chemical makeup of the low carbon steel employed in this study.

Table-1 Chemical composition of the Low Carbon Steel Sample (wt. %)

Element Present	Percentage Weight (%)
Carbon (C)	0.025
Silicon (Si)	0.29
Manganese (Mn)	0.85
Phosphorous (P)	0.025
Sulphur (S)	0.027
Titanium (Ti)	0
Copper (Cu)	0.33
Nickel (Ni)	0.04
Chromium (Cr)	0.07
Molybdenum (Mo)	0.004
Vanadium (V)	0
Aluminium (Al)	0.023
Tungsten (W)	0.005
Niobium (Nb)	0
Nitrogen (N)	0.005
Iron (Fe)	Balanced

As seen in **Fig. 1**, the low carbon steel samples were cut into cylindrical pieces with a diameter of 20 mm and a length of 50 mm using a lathe machine. The following groups were created from the cylindrical sections of machined low carbon steel samples:

- i. Sample A: As received five (5) pieces
- ii. Sample B: As welded but not annealed, five (5) pieces
- iii. Sample C: As welded and annealed at 920 °C, five (5) pieces, and
- iv. Sample D: As welded and annealed at 960°C, five (5) pieces.



Fig. 1. Machined low carbon steel

One of the edges of a set of low carbon steel samples was chamfered after it was sliced in half. A bench vice was used to securely bind the opposite edges of the low carbon steel samples together, leaving a 2 mm root gap. Electric arc welding was used to fuse the samples together. The welding process was carried out so that the weld penetrated to the low carbon steel's thickness level. A lathe machine was used to machine out the overlying slag. The aforementioned grouping was used to distinguish the welded samples. The low carbon steel samples, both welded and unwelded, were annealed for 60 minutes at 920°C. The experiment was conducted at room temperature using prepared 0.025% low carbon steel samples and seawater to ascertain the low carbon steel's corrosion rate in a seawater environment. Seawater was placed in four plastic bowls, designated A through D. Before being submerged in their corresponding plastic bowls with labels, the different steel samples were weighed using an analytical weighing balance and noted as (WI). Each steel sample was collected after twenty (20) days, thoroughly cleaned, and given five minutes to dry.

After recording their weights (WF) on a weighing balance, they were put back into their own plastic bowls. For one hundred (100) days, this process was repeated every 20 days. The weight decrease was computed using Equation (3).

$$W_L = W_I - W_F \quad (3)$$

where,

W_L = Weight loss

W_I = Initial weight

W_F = Final weight

Equation (4) was used to calculate the corrosion rate of low carbon steel.

$$C_R = \frac{87.6W_L}{DAT} \quad (4)$$

where,

C_R = Corrosion Rate (mm/y)

W = Weight loss (mg)

D = Density of Low Carbon Steel = 7.85g/cm³

A = Area of medium carbon steel samples used (cm²)

T = Exposure time to sea water (days)

RESULTS AND DISCUSSION

Table-2 shows the chemical composition of seawater. From the results analysis, the pH of the sea water was gotten as 8.55 (m), conductivity of 995 (μs/cm), TDS of 541 (mg/l), total alkalinity of 1.83 (mg/l), chloride of 2787.4 (mg/l), sulphate of 271 (mg/l), nitrate of <0.001 (mg/l), phosphate of 0.005, and salinity of 2989 (mg/l).

Table-2 Chemical composition of seawater used

S/N	Parameters	Result
1	pH	8.55
2	Conductivity, μs/cm	995
3	TDS, mg/l	541
4	Total alkalinity, mg/l	1.83
5	Chloride, mg/l	2787.4
6	Sulphate, mg/l	271
7	Nitrate, mg/l	< 0.001
8	Phosphate, mg/l	0.05
9	Salinity, mg/l	2989

For one hundred (100) days, all of the samples were submerged in seawater. Visual observation and weight loss measurement were used to assess the corrosion action and rate on the test samples. After two days of exposure, corrosion products were seen to form on the steel samples' edges and surfaces. Every twenty (20) days, weight loss was tracked. The corrosion rate of the low carbon steel employed in this study was assessed using the results. According to [42], the process began with a color shift to yellow deposits in the first two days, which confirmed the existence of ions in the sea water sample. The yellow deposits surrounding the low carbon steel samples' surface grew dark brown as the exposure went on. When the utilized samples were removed, heavy brown deposits were found on them, confirming that the samples had corroded.

The aggressiveness of the chemical reactivity, the transport characteristics of the corrosion medium, the pH of the corrosion medium, which is within neutral, the concentration of the corrosion species in the used sea water, and most importantly the metallurgy of the alloy sample and the temperature of the sea water that served as the corrosion medium are all responsible for the decrease in the corrosion rate of all the samples between the 40th and 100th days, according to [43–45]. Additionally, according to [40]'s studies, the corrosion rate was initially high but abruptly decreased as the exposure time increased. The results of this study are consistent with their findings. Figure 2 shows the corrosion rate of 0.025% carbon steel as received, welded, unwelded and annealed, and welded and annealed in an exposed seawater environment. The figures show that the corrosion rates of all the samples increase gradually throughout the first forty (40) days, reaching a peak on day forty (40). After this, the corrosion rates of all the samples kept decreasing. Nevertheless, the corrosion rate of the samples becomes fairly constant after sixty (60) days, and the pattern remains unchanged for the following forty (40) days.

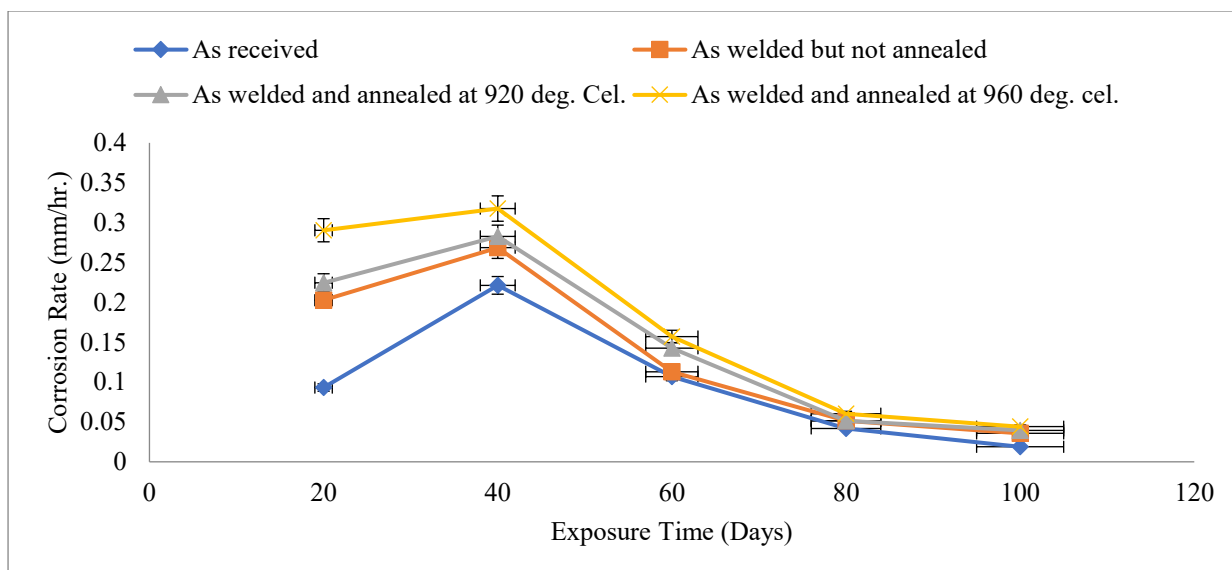


Fig. 2. Evaluation of corrosion rate on 0.025% carbon steel

The weight loss of 0.025% carbon steel is plotted versus exposure time in a sea water corrosion media in Fig. 3. As the annealing temperature increased, it was found that the samples' weight loss increased with exposure time. Additionally, the situation was the same for samples that were received and samples that were welded without annealing, but there was less weight loss than for samples that were annealed at 920 °C and 960 °C, respectively. As received. Additionally, it was shown that when exposed to a sea water corrosion environment, raising the annealing temperature increased weight loss.

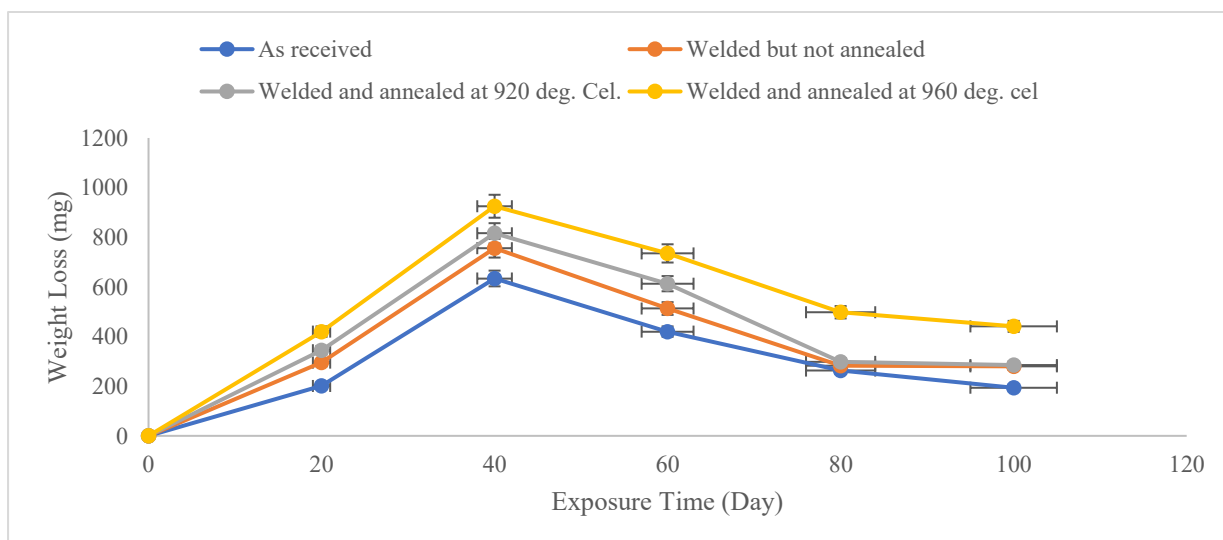


Fig. 3. Evaluation of weight loss of 0.025% carbon steel in seawater

CONCLUSION

This study examined the corrosion susceptibility of both as-received and welded annealed low carbon steel in a seawater environment. The study's findings led to the following conclusions. The as-received and welded annealed samples first corroded quickly in seawater, but as exposure time increased, this rate decreased. Nonetheless, the samples that were received without any indication of welding demonstrated superior corrosion resistance in contrast to the welded annealed samples.

Additionally, the rate at which low carbon steel samples corrode is greatly influenced by the annealing temperature; samples with the greatest annealing temperature of 960 °C are more prone to corrosion, while samples with the lowest annealing temperature of 920 °C exhibit superior corrosion resistance.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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