Investigation on corrosion behaviour of butt welded En-8 steel

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Abstract. Structural components fabricated from carbon steels such as EN-8 are widely employed in engineering applications where they are frequently exposed to corrosive environments. The present investigation focuses on evaluating the corrosion behaviour of butt-welded EN-8 steel joints when subjected to different corrosive media. Three representative environments were selected for this study: 1 M hydrochloric acid (HCl) simulating an industrial acidic condition, synthetic seawater representing marine exposure, and distilled water serving as a neutral environment. Arc welding was employed to fabricate butt joints using E7018 electrodes under controlled parameters. The specimens were exposed to the respective corrosive environments for predetermined time intervals, and the corrosion rates were determined using the weight loss method. Microstructural characterization was performed to analyse the corrosion morphology across the weld zone, heat-affected zone (HAZ), and base metal, while microhardness testing was carried out to assess the degradation in mechanical properties. Results revealed that the corrosion rate was highest in 1 M HCl, moderate in seawater, and negligible in distilled water. The HAZ exhibited the most pronounced corrosion attack owing to its heterogeneous microstructure and residual stresses developed during welding. A gradual stabilization of corrosion rate over time was observed, which may be attributed to the formation of a protective oxide film. Overall, the study highlights that acidic environments significantly accelerate the corrosion of welded EN-8 joints, and careful consideration of operating environment is essential for prolonging the service life of welded components. These findings provide valuable insights for the design and maintenance of welded steel structures in industrial and marine conditions.

1 Introduction

Welded joint with combination of higher strength and reasonably good toughness are possible with arc welded joints of En8.En8-a medium carbon steel that can be comfortably arc welded with proper preheating. I Structural steels like En-19, En-24 etc. are widely used for general

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engineering components and automotive components [1]. Applications of arc welded joints of En8 include shafts, axles and automotive components like connecting rod, spindle.

In engineering applications such as construction, manufacturing and marine corrosion is the major drawback as it may drastically deteriorates life of the components and structural integrity. It is usual phenomenon that, though sufficient care is exercised in selection of appropriate combination of filler material and base metal- adoption of standard welding practice, sometimes welded portion may exhibit higher corrosion resistance than base metal and sometimes base metal may exhibit higher corrosion resistance than welded portion. Factors that may influence corrosion are design of weldments, type of welding, sequence of welding, presence of oxide films, porosity insufficient fusion etc. The welded joint may be autogenous i.e. made without use of filler material or may be made with use of filler material. Filler material having variation in composition with respect to base metal may yield a galvanic couple in presence of corrosion medium. The microstructure of base metal, fusion zone and Heat affected zone may also affect corrosion rate [2].

At times welded joints may be susceptible to stress corrosion cracking in presence of an exclusive environment [3]. Investigation on corrosion of steel bars in reinforced concrete is studied [4]. Employment of suitable technique of welding may yield advantages like high structural strength, economic welding process but it may lead to localised corrosion due to residual stresses and oxide formation [5, 6]. Investigations are made on employment of corrosion inhibitors like Borge Flower extract for corrosion of Mild steel in HCl [7]. Analysis is made with electro impedance spectroscopy and potential- dynamic polarisation. SEM analysis, surface morphology and hydrophobicity are studied. Corrosion studies on mild steel and analysis of surface evolution were made. Effectiveness of corrosion inhibitor like Aster koraiensis leaf extract on corrosion of mild steel were investigated with weight loss as parameter [8].

Polarization curves are drawn indicating that *koraiensis* leaf extract acted as mixed type of inhibitor. It is observed that corrosion inhibitor adsorption on surface of mild steel followed Langmuir isotherm. A review of nontoxic alternatives of corrosion inhibitors is made [9]. Employment of natural plant extracts for inhibition of corrosion of alloys like steel, Stainless steel Copper and Aluminium alloys are presented. Inhibition efficiency, mechanism of their action and evaluation techniques are briefed. Investigation on corrosion of mild steel in different corrosive environments like HCl, NaCl and distilled water were made [10]. Type of welding joint also may trigger corrosion tendency or at times it may act as corrosion inhibitor. Investigation on corrosion of welded joint mild steel, joined using sub merged arc welding, under various corrosion environments are made. The study concluded that butt joints are less preferred compared to lap joint and edge joint for better corrosion resistance. Welding characteristics of En-8 and En-31 steels with Gas Tungsten Arc welding process are reported [11].

Arc welded joints of En8 steel are frequently used in automotive and structural applications. Understanding the corrosion resistance of different welding joints of En-8 steel is crucial for ensuring the longevity of welded structures. It is necessary to provide insights in to Influence of different welding joints on corrosion susceptibility under various corrosion environments. Literature search hardly reveals investigations on corrosion behaviour of arc welded En-8 steel. In the light of the above this article emphasises on corrosion resistance of arc welded En-8 steel. Findings of this investigation can be applied to real-world industrial applications where EN-8 steel is used, such as in bridges, pressure vessels, shipbuilding, and automotive components. The results will aid in selecting the most suitable welding method for environments prone to corrosion, ultimately enhancing material durability and safety. In this view, the present study focuses on investigation of the corrosion behaviour of Butt welded EN-8 steel joints and evaluate their degradation under different corrosive

environments. The study aims to systematically analyse the impact of corrosion atmosphere on corrosion rate.

2 Materials and methods

EN-8 steel was chosen for this study due to its desirable mechanical properties and extensive use in industrial applications. En 8 is a medium-carbon steel. The material exhibits high strength and wear resistance, making it suitable for mechanical and structural applications. However, EN-8 steel has moderate corrosion resistance, making it an ideal candidate for corrosion studies. analysis of En-8 is given in Table-1.

Table 1. Chemical analysis of En-8 steel.

Name of Element	Carbon (C)	Manganese (Mn)	Silicon (Si)	Phosphorous (P)	Sulphur (S)
Percentage	0.43	0.85	0.25%	<0.05%	Traces.

Experimentation includes preparation of butt welded joint, selecting and preparing appropriate corrosive environments and exposing the En-8 butt welded joints to corrosion atmosphere. Base plates of En-8 steel with the required dimensions -100 mm × 50 mm × 6 mm are prepared. Edges are cleaned and smoothened to remove burrs and irregularities. Samples are then prepared for welding by ensuring they are free from dirt, rust, and oxidation. Arc Welding process is chosen for welding. A suitable electrode (E7018) is used for welding EN-8 steel. The electrode is selected based on compatibility with EN-8 steel and ensuring good weld penetration and strength. Butt joints of En-8 steel prepared through arc welding are considered in this study. Proper fusion is ensured by choosing optimised values of welding current, voltage and welding speed. Post-weld cleaning is done to remove slag and impurities. Butt joint of En-8 steel is given in Figure-1.

Fig. 1. Butt Welded joint of En-8 teel**.**

Major objective of this investigation is to compare the extent of corrosion of butt, welded joints of En-8 steel prepared using arc welding under various types of corrosive environments. Three different corrosive solutions are prepared in separate containers; 1M Hydrochloric acid solution representing acidic industrial environment; Seawater (Synthetic or Natural) – Simulates marine exposure conditions. Corrosion atmosphere is prepared by taking 35 grams of raw salt per 1 litre of distilled water and mixing the salt until it gets dissolved completely; Distilled Water – representing neutral atmosphere. Commercially available distilled water is considered. Each of the corrosion solution is prepared in a separate glass container and proper care is exercised to make the solution contamination free.

Corrosion Rate:
Corrosion rate is computed using the formula given in equation-1

$$Corrosion\ rate\ \left({}^{mm}/_{year}\right) = \frac{K \times W}{A \times T \times D} \ldots\ldots\ldots\ldots\ldots (1)$$

where:

W = weight loss (mg)
A = exposed surface area of the specimen (cm^2)
T = exposure time (hours)
D = density of EN-8 steel (g/cm^3), taken as **7.85 g/cm³**
K = constant, equal to **87.6** (when W is in milligrams, A in cm^2, T in hours, and D in g/cm^3)

This constant K=87.6K = 87.6K=87.6 converts the rate to millimeters per year (mm/year), providing a standardized comparison of corrosion rates across different materials and exposure conditions. Three butt welded joints of En-8 steel are accurately weighed and weight of each joint is noted. The prepared welded joints are exposed to corrosion atmospheres namely 1M HCl solution, Salt water and Distilled water. The joints are exposed to the corrosion atmosphere for various length of times. The times considered are 2hours,4hours,6 hours,8 hours and 10 hours for corrosion atmospheres of 1M HCl solution and Sea water. At the times considered it is observed that corrosion rate is negligible when corrosion atmosphere is distilled water and hence the times considered for distilled water is longer i.e. 2days,4 days,6 days and 7 days.

3 Results and discussions

Corrosion rate of butt welded En-8 steel exposed to 1M HCl solution is presented in Table-2. Table-3 & 4 gives corrosion rate of butt welded En-18 steel exposed to Sea water and distilled water respectively. Variation of corrosion rate of butt welded En8 steel as a function of time in 1M HCl solution, sea water and distilled water is given in Figure-2, 3 and 4 respectively. Butt welded En8 steel exposed to 1M HCl solution for various length are given in Figure-5 whereas butt welded En-8 steel exposed to Sea water and distilled water are given in Figure-6 and 7 respectively. It can be observed that the corrosion rate is fast initially and over a period of time rate of increase of corrosion rate decreases and after some time the corrosion rate, more or less, gets stabilised. Formation of passive oxide film could be attributed to this stabilisation of corrosion rate. Similar trend is observed in 1M HCl solution and Sea water. In distilled water the corrosion rate reaches a maximum and then drop-in corrosion rate is registered. However, the rate of corrosion in distilled water is mild and can be neglected for all practical purposes. The corrosive attack in acidic medium is more intense compared to sea water and distilled water. Perhaps rapid dissolution of oxide film in acidic medium may lead to galvanic cell formation between weld joint and base metal. Figure 5 and 6 shows evidence of similar intense attack of 1M HCl solution compared to sea water.

Table 2. Corrosion rate of Butt welded En-8 steel when exposed to 1M Hydrochloric acid solution.

S.No	Time of Exposure (No of hours)	Weight Loss(mg)	Corrosion Rate(mm/year)
1	0	0	0
2	2	38	0.48
3	4	96.5	0.61
4	6	158.3	0.67
5	8	221.5	0.695
6	10	278	0.7

Table 3. Corrosion rate of butt welded En-8 steel when exposed to salt water.

S.No	Time of Exposure (No of hours)	Weight Loss(mg)	Corrosion Rate(mm/year)
1	0	0	0
2	2	8.1	0.103
3	4	20.1	0.12
4	6	31.4	0.132
5	8	42.7	0.134
6	10	53.1	0.135

Table 4. Corrosion rate of butt welded En-8 steel when exposed to distilled water.

S.No	Time of Exposure (No of Days)	Weight Loss(mg)	Corrosion Rate(mm/year)
1	0	0	0
2	2	34.5	0.018
3	4	46.2	0.024
4	6	52.4	0.009
5	7	42.7	0.008

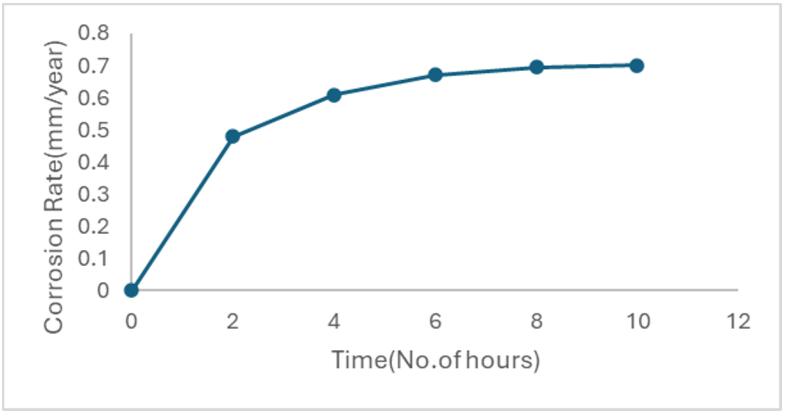

Fig. 2. Variation of corrosion rate of butt welded En-8 steel in 1M HCl solution.

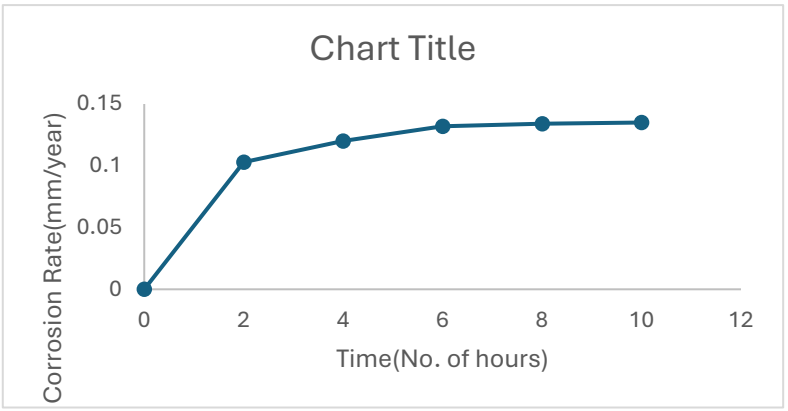

Fig. 3. Variation of corrosion rate of butt welded En-8 steel in sea water.

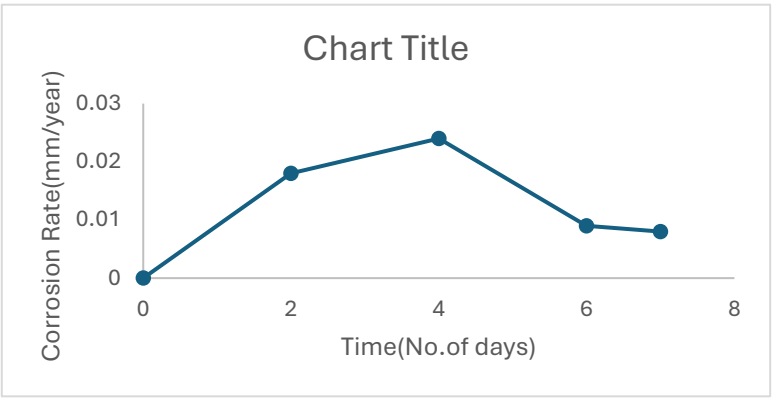

Fig. 4. Variation of corrosion rate of butt welded En-8 steel in distilled water.

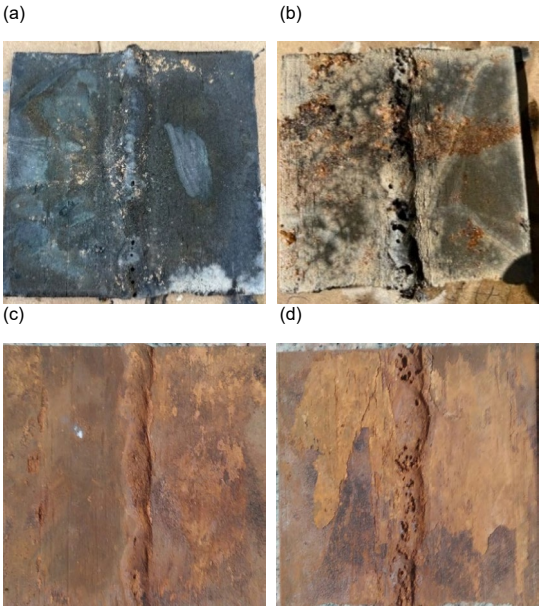

Fig. 5. Welde joints of En-8 exposed to 1M-HCl solution at room temperature for various length of times(a) 2 hours (b) 4 hours (c) 8 hours, and (d) 10 hours.

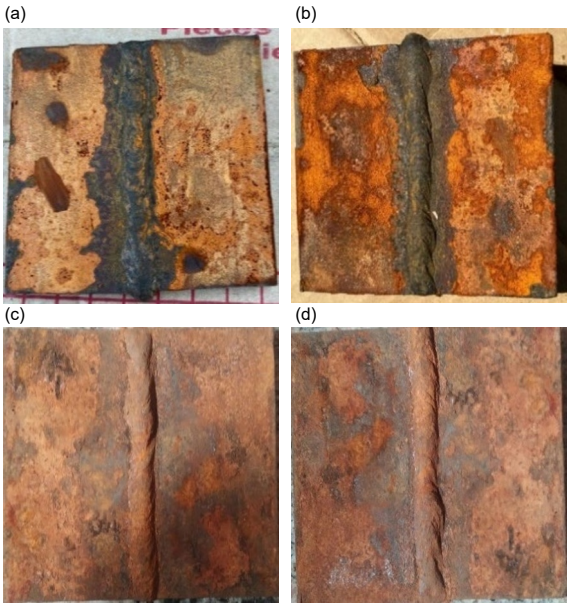

Fig. 6. Welde joints of En-8 exposed to salt water at room temperature for various length of times(a) 2 hours(b) 4 hours(c) 8 hours, and (d) 10 hours.

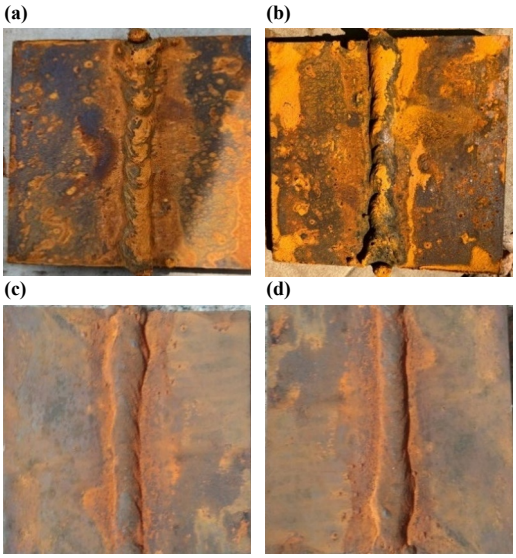

Fig. 7. Welde joints of En-8 exposed to distilled water at room temperature for various length of times (a) 2days (b) 4 days (c) 6 days, and (d) 7 days.

3.1 Microstructural studies

Microstructures of 1) Weld zone 2) Heat Affected Zone 3) Base Metal of butt welded En-8 steel exposed to 1M HCl solution and Sea Water are shown in Figure 8 and Figure 9 respectively. It can be observed that corrosive attack is more intense in Heat Affected Zone due to rapid dissolution of oxide layer. Micro hardness values of base metal, HAZ and weld zone are given in Table 5. Hardness in weld zone is the highest. It is noticed that decrement in hardness values is more in case of 1M HCl solution compared to sea water. In case of distilled water, the hardness values in any zone are comparable to that of base metal of the respective zone and this reveals intense attack of 1M HCl solution in comparison to other corrosive media considered.

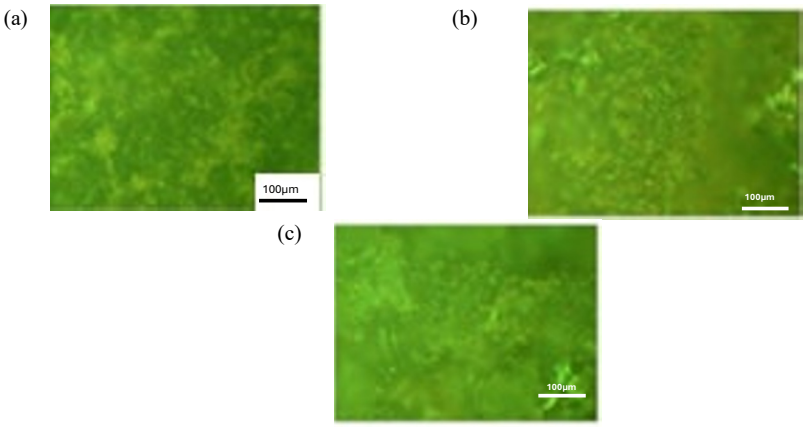

Fig. 8. Microstructures of Butt welded En-8 steel exposed to 1 M HCl solution (a) Weld Zone, (b) HAZ, and (c) Base Metal.

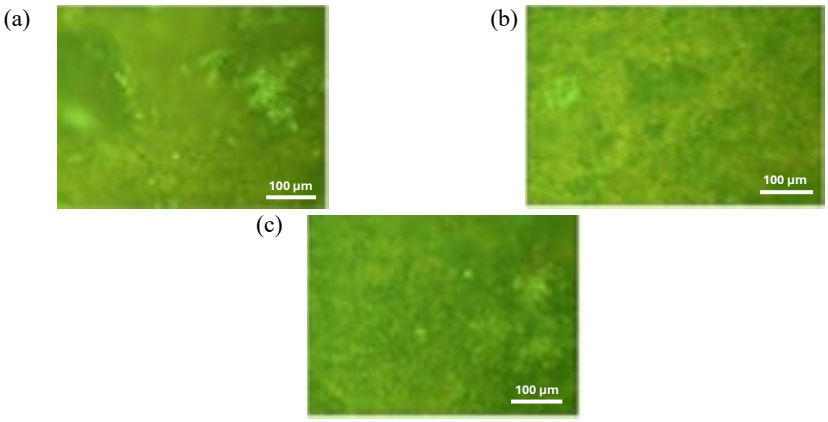

Fig. 9. Microstructures of Butt welded En-8 steel exposed to Sea water (a) Weld Zone (b) HAZ , and (c) Base Metal.

Table 5. Micro hardness values of butt welded En-8 steel.

Zone	Butt welded En-8 (Before exposure to Corrosion Medium)	Butt welded En-8 (After exposure to 1M HCl Solution))	Butt welded En-8 (After exposure to Sea Water)	Butt welded En-8 (After exposure to Distilled Water)
Base Metal	184	178	190	178
HAZ	212	182	182	208
Weld Zone	220	186	194	218

4 Conclusion

The present study comprehensively examined the corrosion behaviour of butt-welded EN-8 steel under three different environments: 1 M HCl, seawater, and distilled water. The results confirmed that corrosion was most severe in the acidic medium, moderate in saline conditions, and negligible in neutral media. The corrosion rate increased rapidly at the initial stages of immersion and then stabilized over time, likely due to the formation of a passive oxide film that hindered further metal dissolution. Microstructural analysis revealed that the heat-affected zone (HAZ) was the most corrosion-prone region, attributable to its heterogeneous microstructure, micro segregation of alloying elements, and residual tensile stresses developed during welding. This localized instability led to accelerated anodic dissolution and hardness degradation compared to the weld metal and base metal. The findings highlight that corrosion resistance in welded EN-8 steel is largely governed by thermal effects during welding and the resulting microstructural variations across different zones. For engineering applications involving aggressive environments, special attention must be given to post-weld treatments and material selection to minimize HAZ corrosion. Future studies will focus on electrochemical characterization using Tafel plots and EIS to quantify corrosion kinetics and validate the mechanistic interpretations proposed in this work.

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