

Influence of Mechanical Parameters on Corrosion Behavior of Metal Coupons in Simulated Environmental Conditions

Akpuh Davidson^{1*}, Faith Uchendu Okirie²

Abstract

This study investigates the influence of mechanical parameters—namely, applied stress, surface roughness, and deformation history—on the corrosion behavior of metal coupons exposed to corrosive environments. Mild steel and aluminum alloy specimens were prepared with controlled variations in tensile stress, polishing grades, and cold working levels to simulate real-world mechanical influences. These coupons were immersed in a 3.5% NaCl solution under ambient conditions, and their corrosion rates were monitored over 30 days using weight loss measurements and electrochemical impedance spectroscopy (EIS). Results showed that increased tensile stress significantly accelerated corrosion, particularly in the steel samples, suggesting a synergistic effect of mechanical strain and electrochemical degradation. Similarly, surface roughness enhanced corrosion initiation due to increased surface area and microcrevice formation, promoting localized attack. Cold-worked samples exhibited higher susceptibility to pitting and intergranular corrosion, attributed to strain-induced dislocations acting as anodic sites. Among the tested conditions, the combination of high stress and rough surface yielded the highest corrosion rates. These findings demonstrate the critical role mechanical parameters play in influencing corrosion performance, particularly in structures exposed to simultaneous mechanical and environmental stresses. The study underscores the need to incorporate mechanical considerations in corrosion prediction models and highlights the importance of selecting proper finishing and loading conditions in design to improve material longevity. Further studies are recommended to evaluate these effects under dynamic loading and variable environmental parameters.

Keywords: Corrosion, environmental conditions, metal coupons, metallic materials, tensile stress

INTRODUCTION

The corrosion of metallic materials remains a major challenge in engineering applications, particularly in marine, industrial, and transportation environments. As infrastructure and components are continuously exposed to harsh service conditions, the interaction between mechanical loading and environmental degradation has become increasingly significant. Traditionally, corrosion studies have focused on electrochemical factors; however, the influence of mechanical parameters such as stress, surface roughness, and cold work is equally critical, but often underestimated [1].

*Author for Correspondence

Akpuh Davidson
E-mail: bookings.bestino@gmail.com

¹Lecturer, Mechanical Engineering Department, Federal Polytechnic of Oil and Gas Bonny, Rivers State Nigeria.

²Researcher, Chemical/Petrochemical Engineering Department, Rivers state University, Port Harcourt, Rivers State, Nigeria.

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Mechanical stress can alter the surface energy, disrupt passivation films, and accelerate electrochemical reactions. Similarly, surface roughness influences corrosion initiation owing to

the increased number of active sites and microcrack formation. Cold working introduces dislocations and residual stress, which can create preferential anodic regions and facilitate localized corrosion mechanisms such as pitting and intergranular corrosion [2, 3].

Understanding how these mechanical factors interact with corrosion processes is essential for improving material durability and predicting the service life. This study investigated the effects of tensile stress, surface finishing, and deformation history on the corrosion performance of mild steel and aluminum alloys in a 3.5% NaCl environment, a commonly used medium to simulate marine exposure. These findings provide insights useful for design, maintenance, and corrosion modeling in mechanically loaded systems [4, 5].

MATERIALS AND METHODS

Sample Preparation

Figure 1 illustrates the overall testing workflow adopted for the evaluation of the selected metallic materials. Two commonly used engineering metals, mild steel and aluminum alloy, were chosen to enable a comparative assessment of their mechanical behaviors. For each material, test coupons with dimensions of 20 mm × 20 mm × 3 mm were cut from the bulk specimens and carefully prepared to ensure uniformity in the geometry and surface conditions prior to testing.

Following the specimen preparation, each material group was systematically categorized based on three key mechanical parameters. This classification allowed controlled experimentation and facilitated a detailed analysis of the influence of each parameter on the material response under the prescribed testing conditions. The structured division ensured consistency across tests and enabled a meaningful comparison between mild steel and aluminum alloy with respect to their mechanical performance.

Applied Tensile Stress

- Unstressed (control)
- Low applied stress
- High applied stress

Surface Roughness

- Fine polishing (600 grit)
- Medium polishing (320 grit)
- Rough polishing (120 grit)

Cold Working Level:

- No cold work (annealed)
- 10% cold work
- 20% cold work

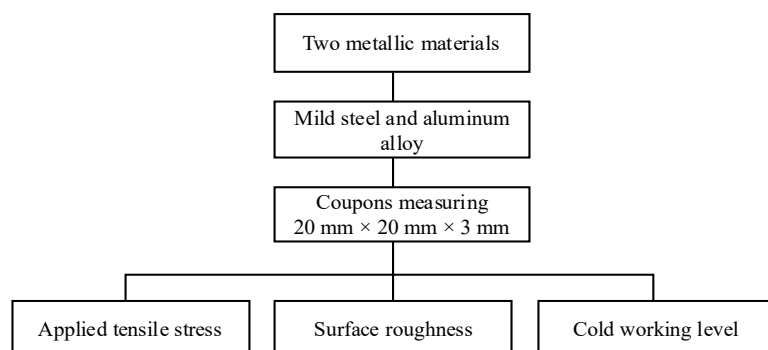


Figure 1. Experimental workflow diagram.

Application of Mechanical Conditions

Tensile stresses were applied to the specimens by using a calibrated mechanical loading frame to ensure accurate and repeatable loading conditions. The applied load was carefully monitored and controlled so that the desired stress levels were achieved without introducing unintended deformation or misalignment effects.

The surface roughness was regulated through a systematic sequential polishing process. The specimens were progressively polished using a series of abrasives with decreasing grit sizes, resulting in consistent and well-defined surface finishes across all the samples. This approach minimized surface-related variability and ensured that the differences in the material response could be attributed primarily to the intended testing parameters.

Cold work was introduced by subjecting the samples to rolling operations, during which they were reduced in thickness by a predetermined percentage. These controlled thickness reductions were selected to induce specific levels of plastic deformation, thereby modifying the dislocation density and mechanical state of the materials reproducibly.

Corrosive Environment

All the samples were immersed in a 3.5% NaCl solution prepared using analytical-grade NaCl and distilled water. The containers were maintained at ambient laboratory temperatures (27–29°C) for the duration of the experiment.

Electrochemical Impedance Spectroscopy

Electrochemical impedance spectroscopy (EIS) was conducted using a high-precision potentiostat configured in a conventional three-electrode electrochemical cell. In this setup, the prepared metallic specimen served as the working electrode, a suitable reference electrode ensured stable potential control, and a counter electrode completed the circuit to allow current flow. All measurements were performed under controlled experimental conditions to ensure the reproducibility and reliability of the electrochemical data.

The resulting impedance spectrum was recorded over a wide range of frequencies and subsequently analyzed using appropriate equivalent circuit models. From this analysis, key electrochemical parameters such as charge-transfer resistance were extracted to assess the resistance of the metal–electrolyte interface to corrosion reactions. In addition, the characteristics related to surface film stability were evaluated, providing insight into the protective nature and integrity of the passive layers formed. The impedance response also enabled the assessment of corrosion kinetics, allowing the comparison of the corrosion behavior of the tested materials under different mechanical and surface conditions.

Analysis of Management Actions, Human Behavior, and Process Reliability

Engineering management actions are necessary to ensure their significant impact on process reliability, unreliability, profitability, availability, and maintainability. This study focuses on understanding the human characteristics of environmental risks and safety involvement. A Mathematical model was developed based on the concept of the influence of human characteristics on behavior in risk and safety management [6].

This significant reliability can be attributed to the engineering management of environmental conditions. A mathematical approach was used to explain the concepts involved in the analysis of management actions due to failures caused by human behavior or illegal crude oil operations. In this case, data are generated and gathered as a result of the various conditions experienced in our environment [7].

Studies on the hierarchical levels of system interactions on the industrial operational steps were investigated in terms of the concepts of the significance of the engineering management system (EMS),

system operation (SO), physical system (PS), and the contribution of these functional parameters to the failure state of the system (Figure 2). It was observed that the EMS, PS, and SO directly influence the analysis of the failure state (FS) experienced in the system [8].

The investigation carried out [9] revealed the accident probability estimation model as follows:

$$P_A = \sum_a \sum_b \sum_c \sum_t P_A(a,b,c,t)^A P_A(Accident|a,b,c,t) \tag{1}$$

Where, P (a, b, c, t) represents the probability of the event involving stages in the concept with the EMS) b (the concept of system operation), c (the concept of physical system PS-E), t (concept of PS-SS), and P_A (Accident | a, b, c, t) is the accidental probability in the concepts of conditional scenario in terms of a, b, c, and t. The model was modified further [10].

$$P_A | a, b, c, t = \int_{-\alpha}^{\alpha} f_{abct}(z) P_{abct}(z) dz \tag{2}$$

$$f_{abct}(z) = \left(\frac{2}{m^2}\right)z + \frac{2}{m} \tag{3}$$

$$P_{abct}(z) = \beta_1 e^{\beta_2 z} \tag{4}$$

Where, *f_{abct}* is the task–distribution demand, m is related to the proportional operation system, and β1 and β2 represent linear impacts attributed to ability and exponential impact, respectively. The impacts of the various scenarios were formulated for the EMS, SO, physical system equipment (PSE), and physical system safety (PS-SS). The overall solution model for the accident probability is formulated as follows:

$$Imact_{QLE} = \frac{P_{QLE}}{P_{QLE} + P_{SLE} + P_{WLE}} \tag{5}$$

$$Imact_{SLE} = \frac{P_{SLE}}{P_{QLE} + P_{SLE} + P_{WLE}} \tag{6}$$

$$Imact_{WLE} = \frac{P_{WLE}}{P_{QLE} + P_{SLE} + P_{WLE}} \tag{7}$$

Where, SLE represents the engineering and management team’s emphasis on the low training of workers in terms of safety.

QLE represents the engineering and management team’s emphasis on low training of workers in terms of improvement.

WLE represents the engineering and management team’s emphasis on the training of workers in terms of improvement.

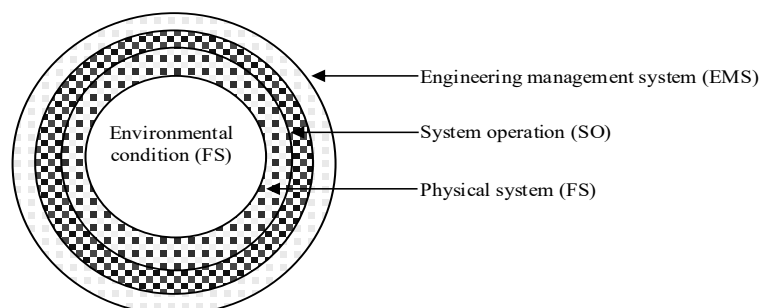


Figure 2. Diagram of hierarchical stages of interaction systems in the operational steps.

The PQLE represents the probability of engineering and management teams emphasizing the low training of workers in terms of improvement.

PWLE represents the probability of engineering and management teams emphasizing highly trained workers in terms of improvement.

The PSLE represents the probability of engineering and management teams emphasizing low training workers in terms of safety.

RESULTS AND DISCUSSION

Figure 3 shows the environmental conditions and year of occurrence as a result of the corrosion. To evaluate the expected number of corrosion meltdowns, the state of the environment in terms of corrosion failure was analyzed.

From Figure 4, we obtain a linear fit of our data using the Weibull distribution, thus generating our linear equation and solving for our shape parameter $\beta = 1.3208$.

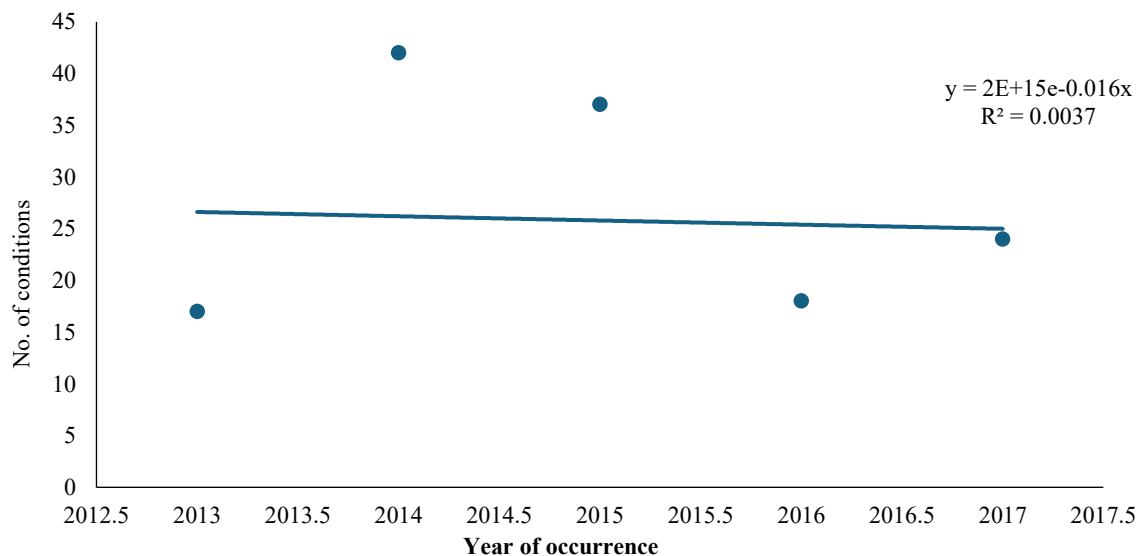


Figure 3. Plot of environmental conditions using a linear function for corrosion.

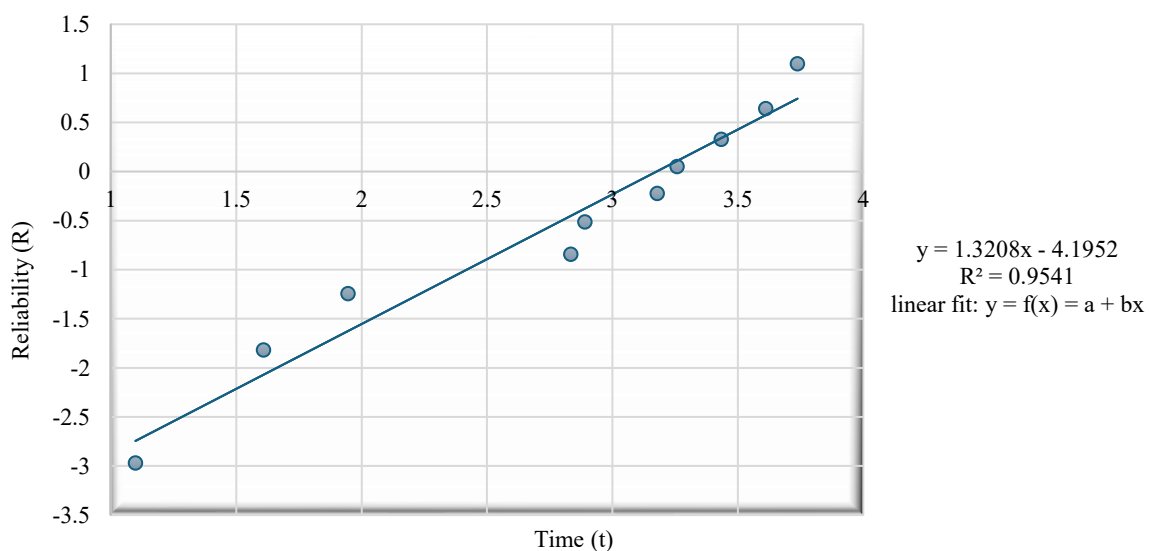


Figure 4. Weibull plot of corrosion incidents.

This study confirms that the mechanical conditions significantly alter corrosion behavior. Tensile stress accelerates corrosion by affecting the stability of passive films and promotes strain-assisted dissolution. The roughness of the surface increases the number of active sites and enhances the micro-environmental variations that trigger localized corrosion. Cold work introduces dislocations and residual stress fields, lowers energy barriers for anodic dissolution, and enhances susceptibility to pitting and intergranular corrosion.

The pronounced effect observed in mild steel compared with aluminum aligns with their respective microstructural responses to stress and deformation. The synergistic role of the combined mechanical parameters underscores the need for integrated corrosion-mechanical design considerations in structural applications.

Effect of Tensile Stress on Corrosion Rate

The corrosion rates increased with the applied stress in both materials. Mild steel exhibited the highest sensitivity, with heavily stressed samples showing more than double the corrosion rate of the unstressed controls. The EIS spectra showed reduced charge-transfer resistance, indicating a weakened protective film integrity under mechanical strain.

Influence of Surface Roughness

More aggressive corrosion was observed in rough-polished samples. The increased roughness resulted in larger electrochemically active surface areas and enhanced crevice formation. Pitting initiation was more frequent in aluminum alloy coupons with coarse surface finishes.

Impact of Cold Working

The cold-worked specimens displayed higher corrosion susceptibility, particularly at 20% deformation. Optical examination revealed localized attack along the strain bands, which served as anodic pathways. Mild steel showed significant intergranular attacks in the high cold work samples.

Combined Mechanical Effects

The combination of high tensile stress and rough surface yielded the highest corrosion rates. Coupons exposed to all three extreme mechanical parameters exhibited the most severe degradation, confirming the synergistic influence of mechanical and electrochemical factors.

CONCLUSION

This study demonstrates that mechanical parameters—applied tensile stress, surface roughness, and cold work—play a critical role in determining corrosion performance in simulated marine conditions. Higher stress, increased surface roughness, and greater deformation intensify corrosion attacks, especially in mild steel. These findings highlight the importance of controlling the mechanical history and finishing processes to enhance material longevity. Future research should consider dynamic loading, cyclic stresses, and variable environmental factors to more closely replicate real-world operating conditions.

REFERENCES

1. ASTM International. ASTM G1-03(2017)e1: Standard practice for preparing, cleaning, and evaluating corrosion test specimens. West Conshohocken (PA): ASTM International; 2017.
2. Revie RW, Uhlig HH. Uhlig's Corrosion Handbook. 3rd ed. Hoboken (NJ): John Wiley & Sons; 2011. p. 1179–1201. doi: 10.1002/9780470872864.
3. Fontana MG. Corrosion Engineering. New Delhi: Tata McGraw-Hill Publishing; 2005.
4. Raja VS, Shoji T. Stress Corrosion Cracking: Theory into Practice. Oxford; Philadelphia: Woodhead Publishing; 2011.
5. Gloria A, Montanari R, Richetta M, Varone A. Alloys for aeronautic applications: State of the art and perspectives. *Metals (Basel)*. 2019;9(6):662. doi:10.3390/met9060662.

6. Sedriks AJ. Corrosion of Stainless Steels. 2nd ed. New York: John Wiley & Sons; 1996.
7. Jones DA. Principles and prevention of corrosion. New York: Pearson Education; 1996. p. 5.
8. Daroonparvar M, Yajid MAM, Yusof NM, Bakhsheshi-Rad HR, Hamzah E, Kamali HA. Microstructural characterization and corrosion resistance evaluation of nanostructured Al and Al/AlCr coated Mg–Zn–Ce–La alloy. *J Alloys Compd.* 2014;615:657–671. doi:10.1016/j.jallcom.2014.06.077.
9. Frankel GS. Pitting corrosion of metals: a review of the critical factors. *J Electrochem Soc.* 1998;145:2186–2198. doi:10.1149/1.1838615.
10. Antony Jose S, John M, Misra M, Menezes PL. Peening techniques for mitigating chlorine-induced stress corrosion cracking of dry storage canisters for nuclear applications. *Materials (Basel).* 2025;18(2):438. doi:10.3390/ma18020438. PubMed PMID: 39859909.