Proceedings of 8th International Conference on Mechanical Engineering and Renewable Energy 2025
10-12 December, 2025, Chattogram, BANGLADESH
SciEn Conference Series: Engineering Vol. 4, 2026, pp 190-194 https://doi.org/10.38032/scse.2026.4.102

Development and Experimental Assessment of a Controlled Corrosion Testing Apparatus for Mild Steel and ABS Steel

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ABSTRACT

A laboratory-scale corrosion testing apparatus was developed to replicate the hot, salty, and humid conditions present in tropical marine habitats. Both mild steel and ABS steel specimens were electrolyzed and exposed to controlled temperatures of 25, 28, and 40 degrees Celsius. Surface deterioration was characterized using scanning electron microscopy (SEM), and corrosion rates were calculated using corrosion penetration rate (CPR) calculations. The findings showed that mild steel was more prone to corrosion (515 MPY at 40°C) than ABS steel (404 MPY), and that corrosion was increased by 6–8 times by electrolysis. Elevated temperatures exacerbated corrosion and were linked to microstructural features such as pitting, rust layer thickness, and magnetite production. SEM micrographs confirmed localized attack and uneven oxide deposition. These findings show that temperature and electrochemical activity are the main factors causing corrosion in tropical areas. Selecting corrosion-resistant alloys and developing protective coating plans for industrial and marine applications are made simpler by the recommended configuration's reproducible and reasonably priced platform for evaluating material performance. The study innovatively addresses a major research gap and offers a cost-effective and innovative alternative to conventional test chambers by developing a low-cost, region-specific corrosion testing equipment that replicates Bangladesh's tropical saline conditions.

Keywords: Corrosion Penetration Rate, Mils Per Year, Mild Steel, ABS Steel.

1. Introduction

Corrosion is a major issue that threatens the longevity and structural integrity of materials, particularly metals, costing an estimated $2.5 trillion globally each year. One environment that makes material degradation worse is Bangladesh's tropical climate, which is characterized by high humidity (an average of 80%), temperature swings, and significant saline exposure from its coastal and riverine regions.[1]. These conditions create a very hostile environment that accelerates electrochemical processes, making materials like mild steel, commonly used in infrastructure, and ABS steel, commonly used in maritime vessels, more vulnerable to deterioration.[2]. Even though there are numerous methods for testing for corrosion, they usually don't capture the combined impacts of multiple environmental stressors in a particular location. This study closes this knowledge gap by developing and validating a novel corrosion test system that accurately replicates Bangladeshi climatic conditions. The major goal is to provide a reliable method for evaluating how well-liked steels function in these specific situations. We want to quantify corrosion rates, analyze surface morphology, and offer data-driven corrosion reduction recommendations to ensure the durability and safety of industrial applications in similar tropical and saline conditions.

2. Objectives

The following are the study's main goals:

(a) Design and build a corrosion test laboratory that faithfully simulates the ambient conditions of Bangladesh, complete with regulated temperature and electrolysis.
(b) Conduct a systematic examination of the corrosion behavior of mild steel and ABS steel with and without electrolysis at various temperatures (25, 28, and 40 degrees. Celsius).
(c) To determine the extent of material deterioration carefully monitor weight loss and calculate the Corrosion Penetration Rate (CPR).
(d)To identify microstructural changes such as pitting and the formation of corrosion products, analyze the surface morphology of the corroded specimens using scanning electron microscopy (SEM).
(e) Based on the comprehensive study, offer practical, data-driven recommendations for corrosion mitigation strategies and material selection for industrial applications in challenging situations.

3. Theoretical Framework

Fundamentally, corrosion occurs when a metal spontaneously changes back into a more thermodynamically stable state, typically an oxide or salt, through an electrochemical process.
This method involves two linked reactions: oxidation at the anode and reduction at the cathode. The breakdown of iron atoms into ions, which releases electrons, is known as the anodic process in iron-based steels.

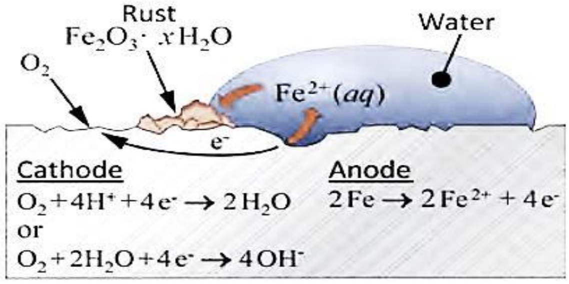

Fig. 1 Chemical Reaction describing the corrosion of steel

Numerous factors affect how quickly this process proceeds. The presence of electrolytes such as chloride ions (Cl^-) from NaCl increases the conductivity of the solution, facilitating ion movement and speeding up corrosion.[3]. Electrolysis—the use of an external electric current—intensifies this further and accelerates the dissolving of metals significantly by driving the oxidation reaction. Temperature is a crucial component of kinetics; higher temperatures hasten the corrosion process by speeding up electrochemical processes and the transport of ions and oxygen in the solution.[4].

The rate of corrosion is measured using a widely used standard measurement called the Corrosion Penetration Rate (CPR). It determines the average thickness of a material lost due to corrosion over a year, expressed in millimeters per year (MPY)[5].
The formula for CPR is:

$$CPR = \frac{K.W}{D.A.T} \quad (1)$$

Where,
W = Weight loss after exposure time 'T', (mg)
D = Density of specimen (gm/cm^3)
A = Exposed surface area of the specimen ($inch^2$ or cm^2)
T = Time of exposure (hours)
K = Constant;
(a) K = 534, when C.P.R is mils per year (1 mil = 0.001 inch)
(b) K = 87.6, when C.P.R is mm per year.

This approach provides the basis for understanding the replication of Bangladesh's distinct environmental conditions, including its high salinity and humidity, as well as the quantification and interpretation of the materials' responses.

Table 1 Chemical composition of mild steel[6]

Element	Composition(wt%)
C	0.19
Al	0.031
Si	0.13
Mn	0.62
P	0.02
Cu	0.01
S	0.007
Ni	0.01
Cr	0.01
Mo	0.01
Fe	Balance

Table 2 Chemical composition of ABS steel[7]

Element	Composition(wt%)
Mn	0.49
C	0.17
Mo	0.01
Si	0.14
S	0.005
P	0.018
Cr	0.03
Cu	0.02
Ni	0.02

4. Literature Review

Mild steel corrosion in CO_2-saturated brines diminishes with NaCl content up to 20 weight percent because of the production of magnetite scale, which acts as a diffusion barrier and reduces flow dependency.[8]. ABS-grade steel welds in marine vessels showed location-specific pit growth during a 2.5-year period, with alloying and microstructure having an impact on corrosion kinetics[9]. The structural integrity of reinforced concrete beams was called into doubt when severe corrosion reduced ductility more than strength. The amount of hydrogen that can be produced during the electrolysis process is greatly influenced by temperature and electrode composition. Stainless steels (SS 316, 409, 410, and 430) have different levels of corrosion resistance, and SS 410 produces the most hydrogen at 90 °C. High temperatures boost the rates of oxygen transport and corrosion. AC current in saltwater accelerates mild steel corrosion even with cathodic protection (CP); rusting is evident at >10 A/m^2 for −780 mV CP and >20 A/m^2 for −1100 mV CP[10]. Machining parameters have a significant impact on corrosion resistance; on mild steel, passive films are formed more readily at higher cutting speeds and positive rake angles. While essential flow velocities in chloride solutions influence corrosion mechanisms in 13Cr stainless steel, with Cl^- effects declining above threshold speeds, cold rolling (~30% reduction) enhances corrosion resistance through grain refinement [11].

5. Experimental Procedures

5.1. Apparatus Design and Fabrication

The experimental Apparatus consists of a custom-built corrosion chamber (20" × 14" × 14") constructed from stainless steel. The developed apparatus is ideal for simulating localized corrosion in tropical regions because it combines temperature and electrolysis control into a single,

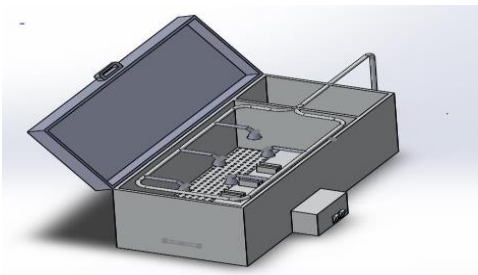

Fig.2 Design of the Apparatus

affordable system, unlike conventional expensive salt-spray or humidity chambers.

Fig. 3 Fabrication of the Apparatus

5.1.1. Methodology

Two steel specimens were made, six of each type of material: ABS steel and mild steel. The starting weight of each sample was recorded using a precision balance. After that, the specimens were immersed in the 5% NaCl solution for a predetermined period of time, 24 hours, under the following conditions: (i) at 25°C without electrolysis, (ii) at 28°C without electrolysis, (iii) at 40°C without electrolysis, (iv) at 25°C with electrolysis, (v) at 28°C with electrolysis, and (vi) at 40°C with electrolysis.

In compliance with ASTM guidelines, the samples were meticulously removed after the test, dried, reweighed, and cleared of any corrosion products. The weight loss (W) and the Section 3 algorithm were used to determine the CPR. The corroded surfaces were then examined using a Scanning Electron Microscope (SEM) at a 20 kV working voltage and up to 5000× magnification to identify microstructural changes such as pitting, cracking, and the form of corrosion products.

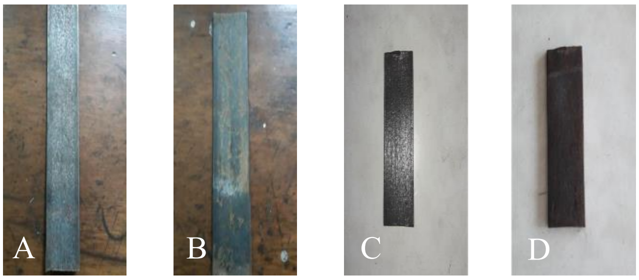

Fig. 4 Visual comparison of test specimens before and after corrosion testing: (A) ABS steel before exposure, (B) ABS steel after corrosion, (C) mild steel before exposure, and (D) mild steel after corrosion

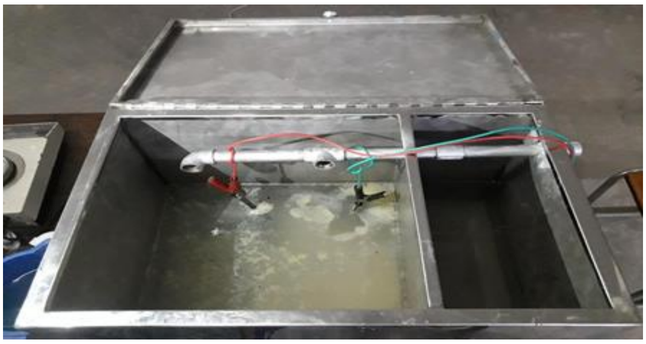

Fig. 5 Electrolysis at different Temperatures

6. Results

6.1. Performance Analysis

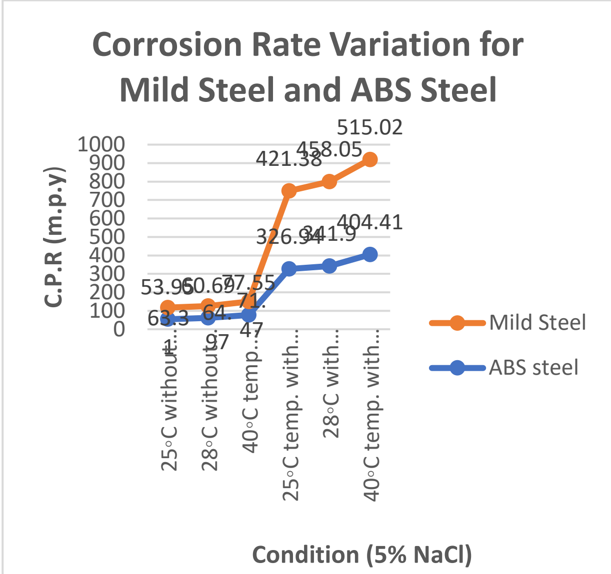

Fig. 6 Corrosion Rate Variation for ABS Steel and Mild Steel at different Temperatures

Table. 3 Corrosion Rate of ABS Steel & Mild steel at different conditions

Condition (5% NaCl)	Metal	C.P.R (m.p.y)
25◦C without electrolysis		53.95
28◦C without electrolysis		60.69
40◦C temp. without electrolysis	ABS Steel	77.55
25◦C temp. with electrolysis		326.94
28◦C with electrolysis		341.90
40◦C temp. with electrolysis		404.41
25◦C temp. without electrolysis		63.31
28◦C without electrolysis		64.97
40◦C temp. without electrolysis	Mild Steel	71.47
25◦C with electrolysis		421.38
28◦C with electrolysis		458.05
40◦C temp. with electrolysis		515.02

Table 4: Relative Corrosion Resistance[12]

Relative Corrosion Resistance	mpy
Outstanding	<1
Excellent	1-5
Good	5-20
Fair	20-50
Poor	50-200
Unacceptable	>200

6.1.1. Surface Morphology Analysis

SEM examination provided visual confirmation of the corrosion process. Mild steel samples from the electrolysis tests showed deep pitting, surface fissures, and severe, nonuniform corrosion, all of which were indicative of vigorous localized attack[13]. Conversely, ABS steel surfaces showed more evenly spaced and less severe corrosion spots, suggesting a more durable surface layer[14]. Grain boundary attack, where corrosion began and propagated along the microstructural boundaries, was also visible in the high-magnification micrographs of the mild steel specimens. Furthermore, XRD analysis and SEM observations verified the existence of crystalline formations known as magnetite (Fe_3O_4) on the surfaces of samples subjected to the maximum temperature and electrolysis—characteristic corrosion products of steel in saline settings[15].

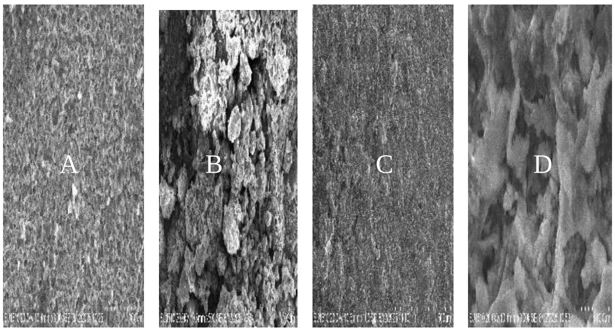

Fig. 7: SEM of ABS Steel and Mild Steel (A)Mild Steel before exposure, (B) Mild Steel after exposure, (C) ABS Steel before exposure, and (D) ABS Steel after exposure

7. Discussion

The experimental results provide significant support for the theoretical framework that temperature and electrolysis are important determinants in steel corrosion. The substantial increase in CPR, which can be up to eight times higher than ambient settings, is directly caused by the external electrical potential causing the metal's anodic dissolution, which is consistent with prior electrochemical corrosion investigations. The temperature effect is significant even if it is not as obvious as electrolysis; the 12% rise in CPR between 28°C and 40°C supports the notion that reactions are accelerated by higher temperatures. The performance differential between mild steel and ABS steel is one significant finding. Mild steel is more vulnerable due to its greater microstructural variability and lower alloy content (CPR of 515 MPY)[16]. It is therefore more vulnerable to concentrated attacks in vulnerable locations. However, ABS steel's stronger resilience (peak CPR of 404 MPY) is likely due to alloying elements like Cr and Ni, which aid in the creation of a denser, more uniform passive layer and slow down the corrosion process. This supports past research on the benefits of alloying marine-grade steels. The estimated uncertainty in mass loss measurement was ±0.002 g, resulting in an average corrosion rate uncertainty of ±2.5%. This variation mainly arises from weighing precision and minor fluctuations in temperature and voltage during electrolysis. The SEM research provided significant new insights into corrosion mechanisms. The mild steel surface under electrolysis exhibits significant pitting and breaking, confirming a shift from uniform to highly localized, aggressive corrosion[17]. SEM and XRD confirm that the development of magnetite crystals under our test circumstances points to a specific corrosion process. These microstructural observations provide a strong visual correlate with the quantitative CPR data and emphasize the importance of both macroscopic and microscopic examination in corrosion studies[18].

8.Conclusion

This study successfully planned and constructed a corrosion test rig to mimic the extreme climatic conditions found in Bangladesh. The results unequivocally demonstrate that temperature and electrolysis are significant factors that significantly accelerate the corrosion of mild steel and ABS steel. With a CPR of 515 MPY under the most severe conditions, mild steel was far more prone to degradation than ABS steel, which displayed a maximum CPR of 404 MPY. This illustrates how ABS steel performs exceptionally well in moist and saline environments. The surface morphological study, which revealed that ABS steel was more durable than mild steel and that the former had aggressive pitting and magnetite production, further corroborated these findings. The findings demonstrate that a one-size-fits-all approach is insufficient and have significant implications for material selection in salty and tropical sectors. The developed setup provides a reliable and affordable pre-service material evaluation tool. Under tropical environmental conditions, this equipment can be used as a benchmark to evaluate the coating performance and corrosion resistance of industrial and marine materials such as hull of a ship.

9.Recommendations

We make the following suggestions for sectors functioning in comparable settings in light of our findings:

9.1.Material Selection:

ABS steel should always be utilized instead of mild steel for structural elements in conditions that are humid, salty, or maritime. Its enhanced corrosion resistance offers long-term endurance and reduced maintenance expenses. When mild steel cannot be avoided, effective preventive measures are essential. These include putting high-end anti-corrosion coatings like epoxy or polyurethane and utilizing cathodic protection devices to lessen electrochemical deterioration [19].

9.1.1. Design Optimization:

Structures should be built to limit places that are prone to pitting and crevice corrosion, such as sharp corners and poorly drained portions, in order to further extend the lifespan of the materials [20].

9.1.1.1. Future Work:

Given that welded connections are frequently weak spots in large buildings, this work should be expanded upon in future studies by:

(i) Examining the impacts of corrosion over time.
(ii) Adding a humidifier to the test configuration to better replicate the high humidity found in a tropical setting.
(iii) Examining how various alloys and cutting-edge corrosion-resistant materials behave in comparable circumstances.

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11. Nomenclature

Symbol	Meaning	Unit
MPY	Mils Per Year	(mils/year)
CPR	Corrosion Penetration Rate	(mils/year) or (mm/year)
ABS	American Bureau of Shipbuilding	
D	Density	(gm/cm^3)
A	Area	($inch^2$) or (cm^2)
W	Weight loss after exposure time	(mg)
T	Time of exposure	(hour)
K	Constant	