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Comparative Analysis of Mild and Carbon Steel Corrosion in Soil Environment in Niger Delta – Nigeria

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Abstract: **The purpose of this study is to investigate the corrosion behavior of mild steel and carbon steel in soil environment through experimental exposure and comparative analysis. Weight loss measurements, corrosion rate calculations, and surface morphology observations were conducted over a 360day period. Corrosion determining parameters such as pH, electrical conductivity, chloride, sulphate, resistivity, moisture content, and Total Heterotrophic Bacteria (THB) were analyzed for the soil sample collected prior to the burial of the steel coupons. Soil resistivity at the location was taken using Vertical Electrical Sounding (VES). The results of the soil sample analyzed showed that the soil was slightly acidic with a pH of 6.4. The electrical conductivity (EC) of the soil was 630 µS/cm, chloride 96 mg/l, sulphate 20 mg/l, resistivity of 65 Ω.m, moisture content 45%, and THB of 2.5×10^4CFU/ml. Some of the analyzed soil parameter values are within the range of environmental factors that significantly influence corrosion behavior of buried metals. The results of the experiment showed that the soil has a moderate corrosive risk and that both mild steel and carbon steel are susceptible to corrosion in the soil environment, but the degree and form of corrosion differ. Hence, mild steel experienced higher corrosion rates (uniform corrosion) than carbon steel which exhibited localized pitting and crevice corrosion.**

Keywords: **Corrosion, Mild Steel, Carbon Steel, Soil Environment, Niger Delta.**

1. INTRODUCTION

Steel materials are widely used in engineering applications such as pipelines, storage tanks, underground structures, and foundations due to their strength, availability, and cost-effectiveness. Among the commonly used steels are mild steel and carbon steel. Mild steel, which contains low carbon content (typically 0.05–0.25%), is known for its ductility and weldability. Carbon steel, on the other hand, contains higher carbon content (up to about 2%), offering increased strength and hardness [1]. However, both mild and carbon steel are susceptible to corrosion when buried in soil but their corrosion behavior may differ due to micro-structural variations, phase distribution, and impurity levels [2,3].

Corrosion of metals in soil environments is a major concern in engineering, particularly for underground pipelines, storage tanks, and structural foundations [4] because of the extreme localized complexity and heterogeneity of soil. Soil corrosivity when compared to that of the atmosphere or seawater corrosivity is often more difficult to categorize with regards to both pipe specific parameters and surrounding soil properties [5]. As a result, the study of the soil as a corrosive environment has become critically important. Studies on the corrosive nature of soils showed that many soils cause rapid corrosion of the commonly used pipe materials [6].

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Corrosion in soil environments is primarily electrochemical and is affected by factors such as soil resistivity, pH, moisture content, oxygen availability, and microbial activity [7,8,9]. Increased moisture and chloride content accelerate corrosion reactions, particularly in ferrous metals [10]. Understanding corrosion behavior in soil is therefore essential for infrastructure longevity, economic sustainability, and environmental safety [11]. This study aims to comparatively analyze the corrosion behavior and durability of mild steel and carbon steel in soil environments, providing insights for material selection in underground applications. This study provides a comparative evaluation supported by experimental data and real-world application.

2. MATERIALS AND METHOD

2.1 *Study Area*

The study was conducted in the teaching and demonstration farm of the River State University located within Port Harcourt metropolis in the Niger delta sedimentary basin south of Niger. Port Harcourt is the capital city of Rivers State. It is located within latitude 4.754524°N longitude 7.033121°E, latitude 4.748976°N longitude 7.041304°E, latitude 4.747553°N longitude 7.028761°E, and latitude 4.742382°N longitude 7.039525°E. It has an elevation of approximately 12 meters above sea level and has a tropical climate with a mean yearly temperature of 30°C, annual average rainfall of 2000mm and an average relative humidity of 85% [12,13].

Figure 1: Map of the study site in River State University, Port Harcourt (Source: Google Map)

2.2 *Experimental Procedure*

Mild and carbon steel coupons were buried in a natural soil at the study site. The mild and carbon steel coupons used for the study were obtained from a known company in Port Harcourt, Rivers State - Nigeria. Steel corrosion coupons were cut into uniform dimensions (50 mm × 25 mm × 1mm), polished using abrasive papers, degreased with acetone, rinsed with distilled water, and air-dried as seen in literature [14,2]. Initial weights were recorded using a digital weighing balance (Adam Equipment LBK 12a, USA). A total of 12 corrosion coupons were prepared and used for the study. The method used in preparing the corrosion coupons is consistent with literature [11,15]. The soil location for the experiment was marked out as 50 cm x 50 cm and dug to a depth of 50cm with the associated soil (sand) removed. Six different vertical partitions, separated from each other by 50cm. Two prepared corrosion coupons (1 mild steel and 1 carbon steel) were buried in each partition and the removed soil poured back to cover the buried corrosion coupons. Every Sixty (60) days, one partition was opened and the buried coupon each of mild steel and carbon steel were retrieved, cleaned by scraping off the rusty coatings on the surface of the coupon. Thereafter, the coupon is washed with distilled water, dried, and reweighed. The process was repeated until all the buried coupons were exhausted. The experiment lasted for twelve (12) months period.

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Soil analysis was both in-situ and ex-situ. In-situ soil analysis was carried out to determine soil resistivity while ex-situ (at the laboratory) was done to characterize soil pH, moisture content, organic content, microbes, and chloride and sulfate concentrations.

2.3 *In-situ Soil Analysis*

Soil resistivity was determined in-situ using Vertical Electrical Sounding (VES) within the study plot. VES investigates resistivity in relation to depth and soil properties. Current was injected into the ground through two current electrodes, C1 and C2, while the voltage difference was measured at two potential electrodes, P1 and P2, as illustrated in Figure 2. The Schlumberger arrangement of a four-electrode system was applied with 1.5 m electrode spacing and ten (10) points per sounding. The potential difference was measured through two electrodes placed outside but aligned in a straight line with the current electrodes. As the spacing between electrodes increased, deeper penetration of the electric field occurred, yielding different apparent resistivity values. Resistivity values were obtained using the TERCA 3 earth resistivity meter (CA 6470N).

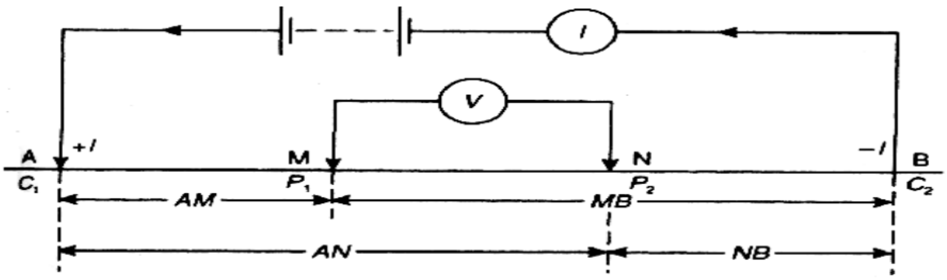

Figure 2: Geophysical Field Configuration at Site

2.4 *Ex-situ Soil Analysis*

Soil samples were collected at different points within 50 cm depth of the mapped-out plot and homogenized to form a composite sample prior to analysis. Soil pH and electrical conductivity were determined using a hand-held multi-parameter tester (pH-W3988). pH and EC were determined by dipping the electrode into a 1:2.5 sample suspension that had been stirred and allowed to equilibrate for 1 h. Moisture content was measured by the gravimetric (oven drying) method, while chloride and sulfate content were determined by Mohr's method and turbidimetric method respectively. The microbial population was determined by serial dilution method.

2.5 Corrosion Measurement Techniques

Corrosion rate was determined using the weight loss method, a widely accepted technique for soil corrosion studies as shown in Equation 1 [3].

$$\text{Corrosion Rate} = \frac{8.76 \, X \, 10^4 \, X \, W}{\rho \, X \, A \, X \, t} \quad . \quad . \quad . \quad . \quad (1)$$

Where:

w = weight loss (g), ρ = density (g/cm³), A = area (cm²), t = time (hours)

3. RESULTS AND DISCUSSION

3.1 *Influence of Soil Properties*

The soil characteristics that are related with corrosion are presented in Table 1. A high electrical conductivity value of 630µS/cm was observed. The high electrical conductivity of the soil indicates the presence of high dissolved ions in the soil. High electrical conductivity has high potential of enhancing soil corrosivity of metals [15,14]. The results of the soil sample analysis for chloride and sulphate are 96 mg/l and 20 mg/l respectively. The combined effect of these ions in soil leads to increase in corrosion rate of metals [14]. The process of corrosion pitting is induced by aggressive anions, such as chlorides (Cl) and sulfates (SO_4) [17]. Chloride ions in particular can introduce pitting corrosion of the protective layer (passive film) decreasing the overall protection of the buried metal asset [17]. Chloride is argued to be the leading cause of corrosion of steel reinforcement in concrete structures [18]. Both chloride and sulphate contents are said to be of low corrosion risk if the chloride content is less than 100 mg/kg and the sulphate content is less than 200 mg/kg [19]. With chloride and sulphate concentrations of 96 mg/kg and 20 mg/kg respectively the soil may be described as a low corrosion risk soil.

Table 1: Soil Analysis result

S/No	Parameter	Result
1	pH	6.40
2	Moisture Content	45%
3	Resistivity	65 Ω.m.
4	Conductivity	630 µS/cm
5	Chloride (Cl^-)	96 mg/kg
6	Sulphate (SO_4^-)	20 mg/kg
7	Total Heterotrophic Bacteria (THB)	2.5 x 10^4 CFU/ml

However, the soil moisture content and resistivity seem to give a different description of the soil's corrosive potential. The soil moisture content was determined to be 45% and according to the Modified 10-Point (CIPRA/NACE) Method of soil corrosive potential classification, moisture content greater than 20% is high and represents high corrosive risk [19]. The relationship between soil moisture content and soil corrosivity is well documented and studies have shown that increase in moisture content decreases the resistivity of soils, thereby increasing their corrosive potential, hence; lower resistivity often indicates higher corrosivity [20,21]. The soil resistivity of 65 Ω.m is therefore consistent with the soil moisture content. Mapping this value with the ASTM G57 criteria, the soil resistivity is between 20 Ω.m and 100 Ω.m, which classifies the soil as moderately corrosive. This is further validated by the soil pH value of 6.4 and according to the ASTM G51 [22] a soil with a pH value of 6.4 is moderately corrosive. The Total Heterotrophic Bacteria (THB) (such as sulfur reducing bacteria), in the soil are other indicators of soil corrosive potential [23,4]. Studies have shown that bacteria (aerobic and/or sulphate reducing bacteria) level of 10^4 is a clear indication of possible corrosion problem [24,25].

3.2 *Weight Loss and Corrosion Rate Analysis*

The soil characteristics generally describes the soil's corrosive potential as low to moderate and to determine the actual situation on the buried steel coupons, the weight loss method was applied. Figures 3 and 4 show the graphical interpretation of weight-loss and corrosion rate analysis of mild and carbon steel buried in soil environment. The results generally showed that the soil is moderately corrosive as both mild steel and carbon steel corroded but the degree and form of corrosion differed.

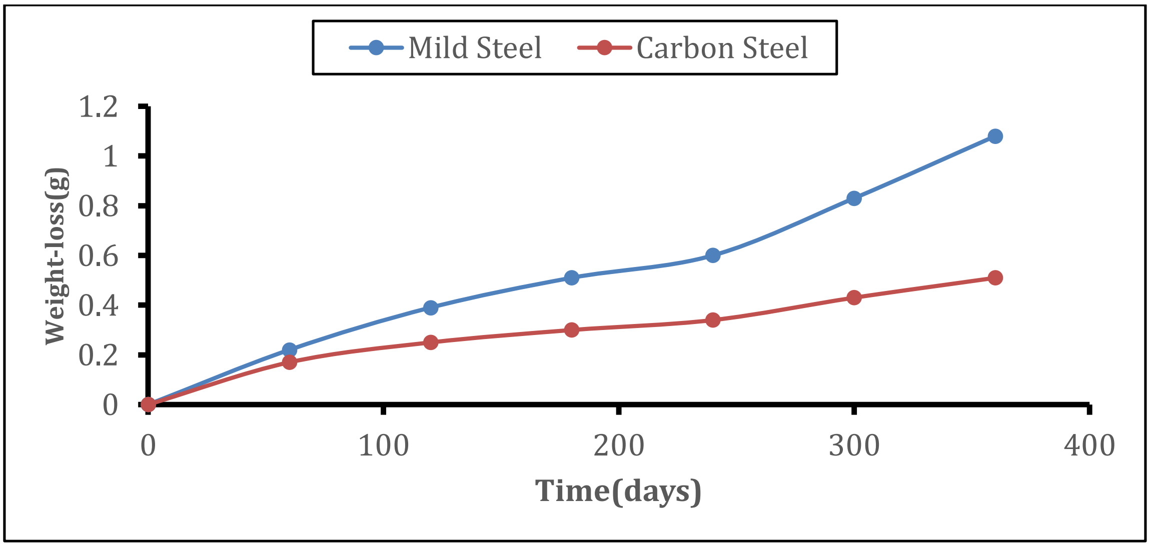

Figure 3: Weight-loss against Time

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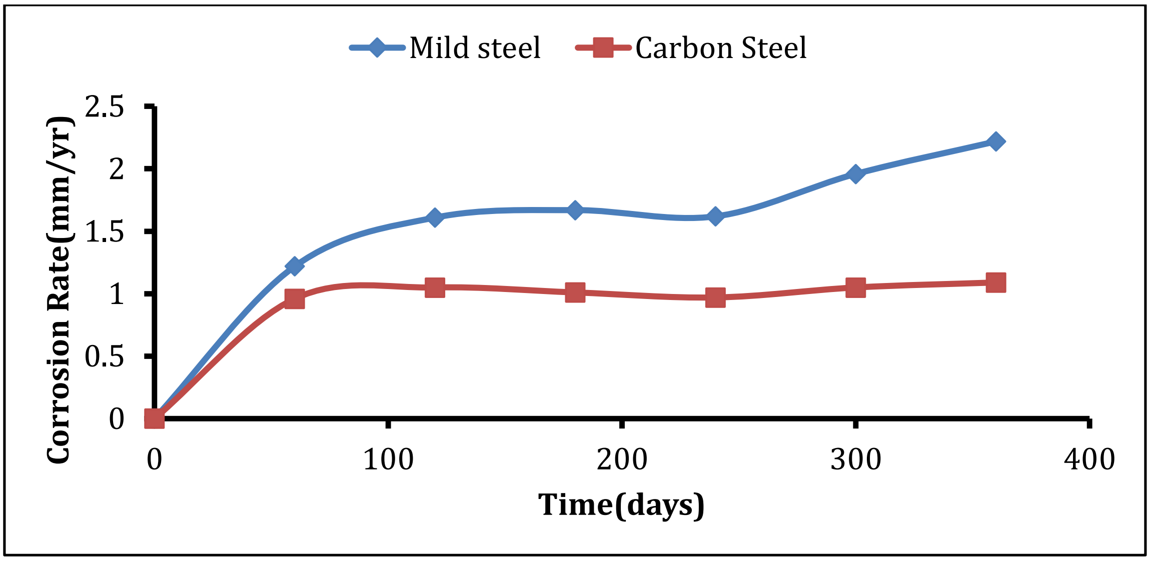

Figure 4: Corrosion Rate against Time

Mild steel typically exhibited a higher corrosion rate than carbon steel as seen from the graphs above. This is due to its lower carbon content and relatively less compact microstructure, which allows easier penetration of corrosive agents. The lower corrosion rate of carbon steel may be attributable to higher carbon content, which tends to increase its hardness and a more refined microstructure, which contributed to reduction in uniform corrosion rates. However, the visual inspection and/or surface morphology showed that there was rust formation, pitting, and uniform corrosion occurred in both mild steel and carbon steel. Though, uniform corrosion was predominant in mild steel, leading to gradual material thinning, whereas, localized corrosion such as pitting and crevice corrosion were predominant in carbon steel.

4. CONCLUSION

The study demonstrates that both mild steel and carbon steel are vulnerable to corrosion in a moderately corrosive soil environment, but their performance differs significantly. Mild steel exhibited higher overall corrosion rates, but tends toward uniform degradation, whereas, carbon steel showed better general resistance but higher risk of localized failure. The choice between mild steel and carbon steel should therefore depend on the specific application, soil conditions, and acceptable risk levels. Also, the use of protective coatings and cathodic protection systems is recommended and where possible soil conditions should be modified to reduce moisture and/or neutralize acidity.

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