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EFFECTS OF ACIDIC, SALINE AND DISTILLED WATER MEDIA ON CORROSION AND MECHANICAL PROPERTIES OF NIGERIAN MILD STEEL

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ABSTRACT

The effects of corrosion on the mechanical properties of mild steel in Hydrochloric acid and Sea water media have been investigated. Samples of mild steel coupons of sizes 36.2 mm long and 4.8 mm diameter and 45.0 mm long and 8.0 mm diameter for tensile and impact tests respectively were immersed separately for 7,14,21,28 and 35 days in 0.5M, 1.0M, 1.5M, 2.0M, 2.5M solutions of *HCl*, sea and distilled water. The weight loss, corrosion penetration rate, yield, ultimate tensile and impact strength were obtained for each sample after their removal from the respective media. At the end of the 35 days exposure time, mild steel specimen inserted in 2.5M *HCl* acid had lost 43.75, 38.89, 49.66 % of their yield, ultimate tensile and impact strength respectively, the specimen inserted in sea water had lost yield, ultimate tensile and impact strength of 12.5, 11.11, 15.36 % respectively while that of distilled water lost 8.75, 8.89, 13.14 % of their yield strength, ultimate tensile strength and impact strength respectively. Results of this work would be useful for corrosion engineers in managing mild steel products for used in structures in the sea.

Keywords: ***acidic, saline, corrosion, tensile, impact***

1.0 INTRODUCTION

Most industrial media are usually rich in elemental gases, inorganic salts, and acidic solutions most of which influence corrosion rates, and mechanisms (Abu and Owate, 2003; Abiola and Oforka, 2005).Steel is one of the major construction materials used in most construction industries for handling of acid, alkali and salt solutions. Hydrochloric acid is the most difficult of the common acids to handle from the standpoints of corrosion and materials of construction. Extreme care is required in the selection of materials to handle the acid even in relatively dilute concentrations or in process solutions containing appreciable amount of the acid. This acid is very corrosive to most of the common metals and alloys. The wide use of this acid has led to the concentration of this study on the corrosive effects of this acid on mild steel, which is a versatile component in many industrial structures. Mild steel are also used in the fabrication and manufacturing of oil field operating platforms because of their availability, low cost, ease of fabrication, and high strength (Umezurike, 1998; Nwoko and Umoru, 1990).Most of the operation platforms upstream in the oil and gas industries are exposed to sea water which is generally considered to be a corrosive environment.Shifler (2005) described some of the factors leading to accelerated degradation of materials exposed to the various marine environments (such as sea water). Khadom, et al.(2009) and Noor (2008) investigated the effects of *HCl*acid concentration and temperature on mild steel corrosion while Osarolube (2008) researched on the corrosion behavior of mild steel and high carbon steel in various concentrations of nitric acid (HNO_3), hydrochloric acid (*HCl*), and perchloric acid ($HClO_4$). The work on the corrosion behavior of low carbon steel in seawater was carried out by Moller, et al (2006). The pH value of solutions that mild steels are exposed to also have a strong influence on its corrosion rate.

For pH values below 4.0, Iron-oxide (FeO) is soluble. Thus, the oxide dissolves as it is formed rather than depositing on the metal surface to form a film. In the pH range of 4 to 10, the corrosion rate is relatively independent of the pH of the solution. In this pH range,the corrosion rate is governed largely by the rate at which oxygen reacts with absorbed atomic hydrogen, thereby depolarizing the surface and allowing the reduction reaction to continue. For pH values above 10,the corrosion rate is observed to fall as pH is increased. This is believed to be due to an increase in the rate of the reaction of oxygen with $Fe(OH)_2$ in the oxide layer to form the more protective Fe_2O_3. Most of the work reviewed investigated the effect of HCl acid and sea water on the corrosion of mild steel without considering its effect on the mechanical properties. Hence, the present research is aimed at investigating the effects of HCL acid, sea waterand distilled water on thecorrosion and mechanical properties of mild steel.

2.0 MATERIALS AND METHODS

Materials used for the experiments include Hydrochloric acid HCl collected from the Chemistry laboratory of Ahmadu Bello University Zaria, Sea Water from theBar Beach in Lagos, Distilled water, Veneer Calipers, Beakers, Measuring cylinders, Brush, PipetteElectronic weighing balance of type*Setra BL - 410S*, a lathe machine, Metre rule, Hounsfield tensometer (Tensile Testing Machine) and Izod Impact Testing Machine. The composition of the mild steel used in this work is given in Table 1.

Samples of mild steel coupons of sizes 36.2 mm length and 4.8 mm diameter for tensile test and 45.0 mm long and 8.0 mm diameter for impact tests notched at the centerat a depth of 1.9mm and an angle of 45^o,were machined into appropriate shapes as shown in plates1 and 2 using the lathe machine. The surfaces of all the specimens were thoroughly cleaned to reduce stress raisers. The original weight W_o of each specimen was then obtained using the electronic weighing machine.

Plate1: Tensile test samples

Plate 2: Impact test samples

The corrosive medium (*HCl*) was prepared to the concentrations of 0.5M, 1.0M, 1.5M, 2.0M and 2.5M representing 1%, 2%, 3%, 4% and 5% by volume of the acid solution respectively. The sixth and seventh media were sea water anddistilled water respectively. Distilled .water was used as the control medium.

Five specimens each for tensile and impact tests were immersed completely in beakers containing the respective media of the acids, sea water and distilled water and tagged A,B,C,D,E,F and G respectively. The set up was allowed to stand for 35 days (840 hrs). At interval of 7days (168 hrs), a sample of tensile and impact specimen was removed from each beaker, washed with distilled water, cleaned with acetone and dried. The weight (W_f) of each sample was obtained using the electronic weighing balance and the weight loss W, determinedusing equation 1.

$$W = W_O - W_f \quad (1)$$

The rate of corrosion was calculated using the corrosion penetration rate (mm/yr) relation given in equation 2.

$$CPR = \frac{KW}{A\rho T} \quad (2)$$

where,

K = Constant = 87.6 (Kakani and Kakani, 2004); A = Surface Area (cm^2)

ρ = Density in g/cm^3 = $7.85 g/cm^3$ for mild steel T = Time (hrs), w = weight loss in g

The specimens were then subjected to tensile and impact test (i.e. Mechanical test) using the Hounsfield Extensometer (Tensile Testing Machine) and Izod Impact Testing Machine respectively.

Table 1: Chemical Compositionof Nigerian Mild Steel

Elements	C	Mn	Si	P	S	Cr	Ni	Al	Sn	Fe
Compositions wt (%)	0.15	0.54	0.10	0.042	0.05	0.12	0.11	0.04	0.002	Bal

2.1 Tensile Test

The *Hounsfield tensometer* was used for the tensile test. A graph sheet was inserted into the drum and the test specimen was inserted into the chucks and gripped firmly by the crosshead. The wheel was rotated to apply a tensile force to the specimen till fracture.The head of the pin on a rotating drum bearing was traced on the graph so that the stress strain curve is plotted. The yield strength (σ_y) and ultimate tensile strength (σ_u) were determined using equation 3 and 4 respectively.

$$\sigma_y = \frac{P_y}{A_O} \quad (3)$$

$$\sigma_u = \frac{P_u}{A_O} \quad (4)$$

2.2 Impact Test

The Izod Impact testing machine was used to determine the impact strength (J) of the specimen before and after corrosion. This machine consists of the jaws between which the test sample was fixed, a key which holds the hammer in place before being released for impact and a scale which indicates the impact load. The specimens for impact test were prepared to standard (i.e. diameter = 8mm, length = 45mm, notched at 45^0 with a depth of 1.5mm at the center). They were then placed between the two jaws of the machine and then the hammer was released and allowed to impact on the specimen. The impact strength (J) was taken from the scale.

3.0 RESULTS AND DISCUSSION

Table 2: Mechanical test results of the un-corroded specimen

Yield Strength σ_y (N/mm^2)	Ultimate Tensile Strength σ_u (N/mm^2)	Impact Strength (J)
442.087	497.348	60.873

Table 3: Weight loss (in g) of mild steel in different media under varying exposure time

Exposure Time (Days)	HCl Concentration (Mol/dm^3)					Sea water	Distilled water
	0.5	1.0	1.5	2.0	2.5		
7	0.303	0.310	0.402	0.412	0.467	0.010	0.012
14	0.329	0.382	0.743	0.833	1.293	0.013	0.017
21	0.344	0.850	1.222	1.413	1.463	0.017	0.023
28	0.371	0.884	1.411	1.572	1.740	0.025	0.036
35	0.491	0.976	1.437	1.648	1.850	0.031	0.043

Table 4:Corrosion penetration rate (mm/yr) of mild steel in different media under varying exposure time

Exposure Time (Days)	HCl Concentration (Mol/dm^3) x 10^{-3}					Sea H_2O x10^{-3}	Distilled H_2O x 10^{-3}
	0.5	1.0	1.5	2.0	2.5		
7	2.292	2.345	3.041	3.11627	3.53227	0.0756	0.0908
14	1.244	1.445	2.810	3.1503	4.88996	0.0492	0.0643
21	0.867	2.143	3.081	3.56253	3.68859	0.0429	0.0580
28	0.702	1.672	2.668	2.97255	3.29023	0.0473	0.0681
35	0.743	1.476	2.174	2.49301	2.79859	0.0469	0.0650

Table 5: The yield strength (N/mm²) of mild steel in different medium under varying exposure time

Exposure Time (Days)	HCl Concentration (Mol/dm³)					Sea Water	Distilled Water
	0.5	1.0	1.5	2.0	2.5		
7	397.878	392.352	381.3	378.537	370.248	419.982	431.034
14	386.826	378.537	359.195	348.143	361.958	408.930	422.745
21	375.774	359.195	350.906	342.617	331.565	397.878	414.456
28	320.513	312.224	314.987	303.935	281.83	392.352	411.693
35	309.461	287.356	281.83	273.541	248.674	386.826	403.404

Table 6: The ultimate tensile strength (N/mm²) of mild steel in different medium under varying exposure time

Exposure Time (Days)	HCl Concentration (Mol/dm³)					Sea H_2O	Distilled H_2O
	0.5	1.0	1.5	2.0	2.5		
7	442.087	436.561	431.034	422.745	419.982	464.191	486.295
14	433.798	431.034	425.508	419.982	417.219	453.139	483.532
21	417.219	408.930	400.641	395.115	392.352	447.613	478.006
28	397.878	392.352	381.300	370.248	331.565	444.850	469.717
35	386.826	339.854	342.617	331.565	303.935	442.087	453.139

Table 7: The impact strength (J) of mild steel in different medium under varying exposure time

Exposure Time (Days)	HCl Concentration (Mol/dm³)					Sea H_2O	Distilled H_2O
	0.5	1.0	1.5	2.0	2.5		
7	56.2657	55.3166	52.0627	50.4358	48.8088	59.384	59.6552
14	54.5032	53.4185	49.7579	46.2328	44.4702	57.4859	58.435
21	52.8762	52.1983	46.0972	44.6058	42.5721	55.5878	57.7571
28	51.656	49.2155	44.1991	42.8433	40.674	53.6897	55.1811
35	50.8425	46.3684	37.2845	34.1662	30.6411	51.5204	52.8762

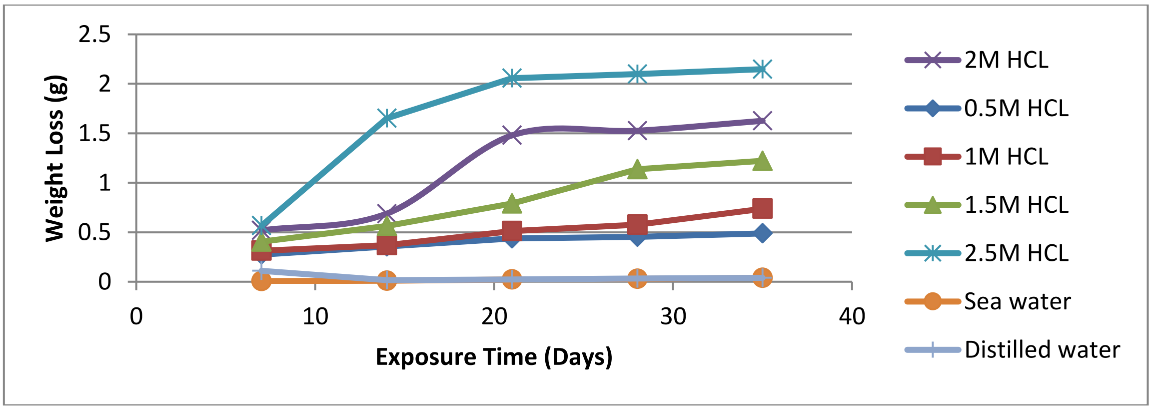

Figure 1: The weight loss (g) of mild steel in different media under varying exposure time

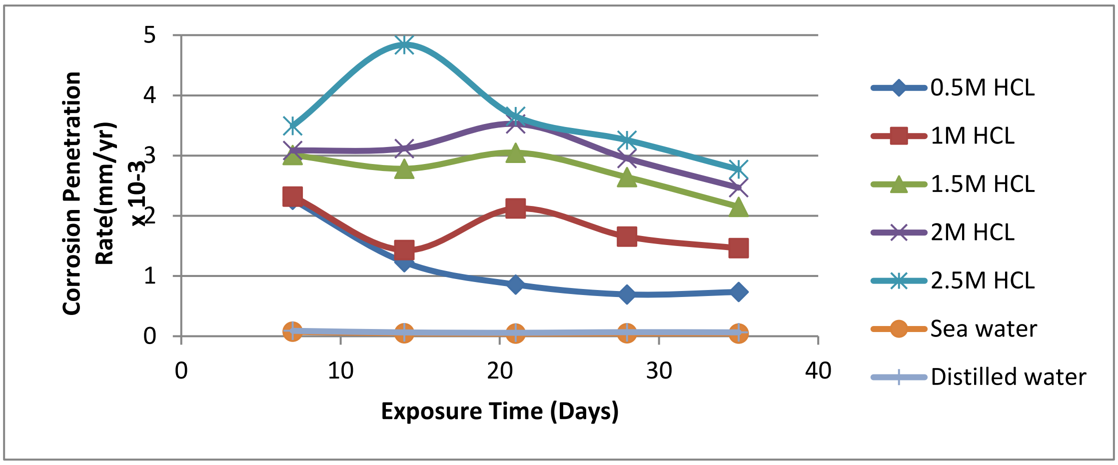

Figure 2: The corrosion penetration rate (mm/yr) of mild steel in different media under varying exposure time.

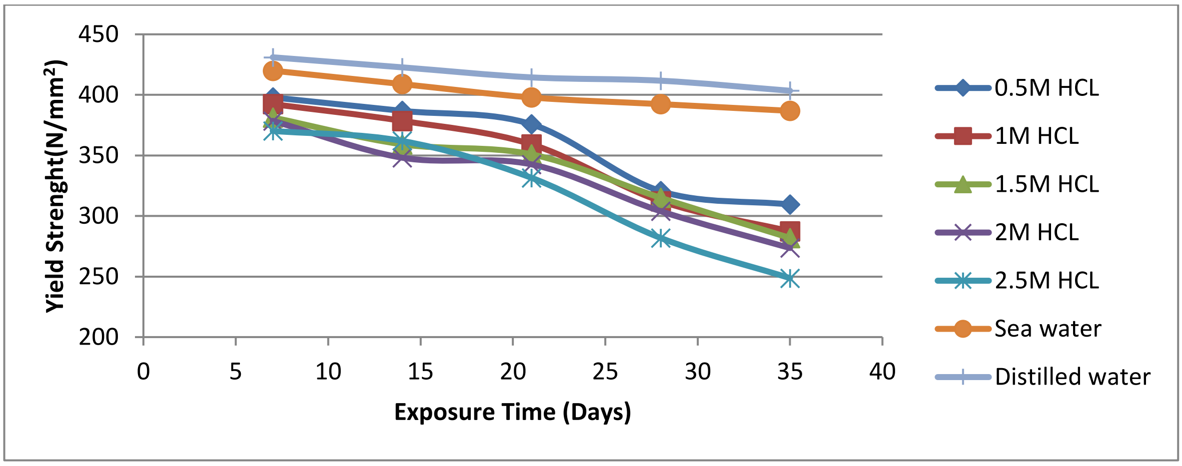

Figure 3: The yield strength (N/mm^2) of mild steel in different media under varying exposure time.

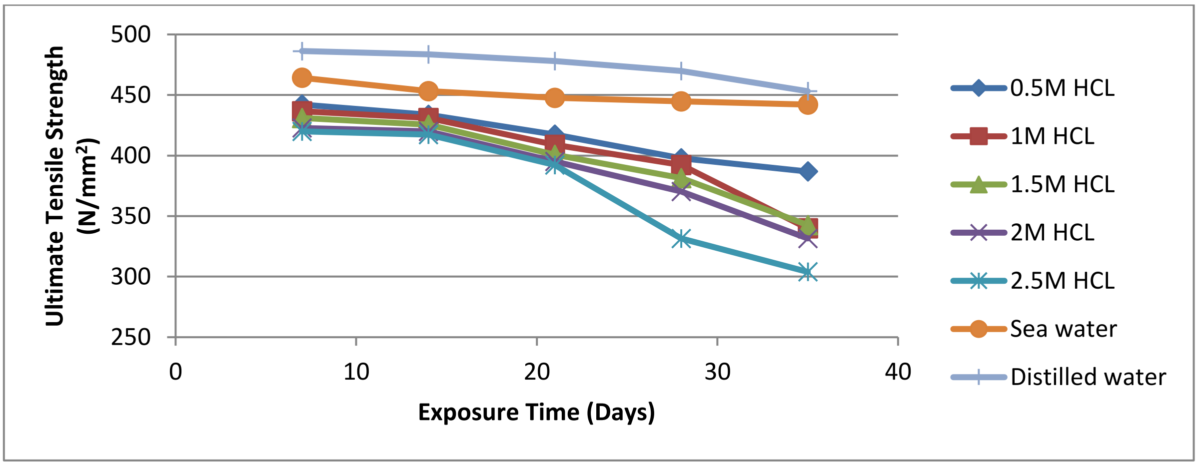

Figure 4: The ultimate tensile strength (N/mm^2) of mild steel in different media under varying exposure time.

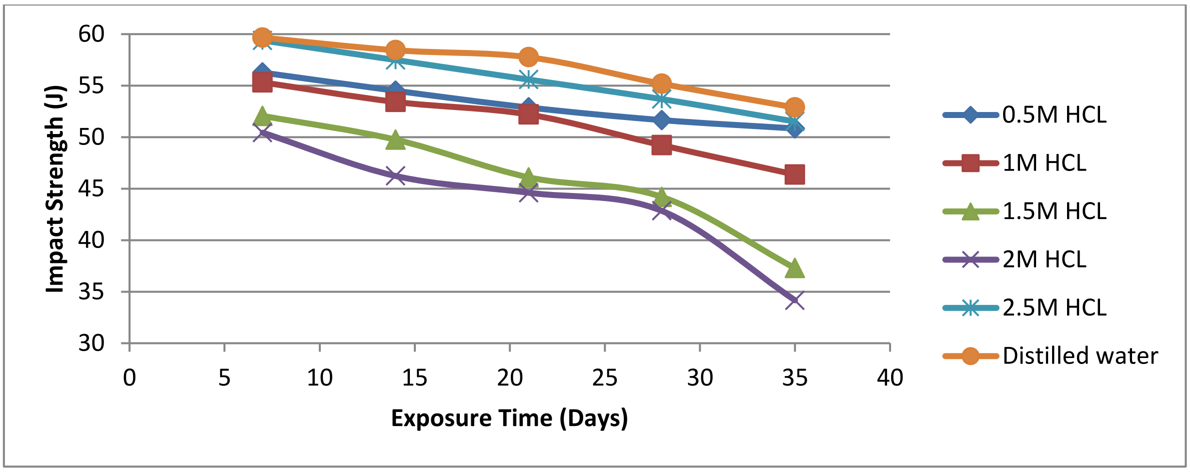

Figure 5: The impact strength (J) of mild steel in different media under varying exposure time.

The weight loss (g) of mild steel removed from the different media (0.5, 1.0, 1.5, 2.0 and 2.5M *HCl* acid, sea and distilled water) are given table 3. It was observed that the weight loss increased with increasing concentration of HCl acid and exposure time. The sharp increase in weight loss in acid medium in the first 21 days with a marginal increase thereafter can be attributed to the initial aggression of the acid on the surface of the metal which later decreased because of dissolution of the iron oxide (FeO) in the acid medium and its possible reaction with HCl acid to reduce its pH value. The weight loss of mild steel inserted in sea and distilled water were very low and nearly constant when compared to those subjected to the acidic medium. Figure 1 is a graphical representation of the weight loss in different media.

The corrosion penetration rate (CPR) in mild steel inserted in different media (0.5, 1.0, 1.5, 2.0, 2.5M HCL acid, sea and distilled water) are given in table 4. The CPR was generally dependent on the exposure time and amount of weight loss over an exposure period. It wasobserved to be nearly constant for sea and distilled water over the exposure time under study which is justified by the nearly constant weight loss given in figure2, and increasing with increasing molar concentration of the acid (see figure 1). CPR for mild steel inserted in 0.5M HCL decreased with increasing exposure time while that of 2.5M HCl increased to a peak of 4.84 mm/yr and decreased thereafter. The initial increase could be attributed to the initial aggressiveness of the acid on the surface of the mild steel at higher molar concentration. At 1.0, 1.5 and 2.0 M *HCl*, the CPR followed a sinusoidal pattern.

The yield strength is the stress at which material begin to deform plastically. The yield strength of mild steel specimens after their removal from different medium (0.5, 1.0, 1.5, 2.0, 2.5M *HCl*acid, sea and distilled water) are given in table5 and figure 3. It was generally observed that yield strength of the specimens decreased with increasing exposure time in the entire medium. The change in yield strength of specimen in sea and distilled water was marginal over the 35 days exposure period while the specimens in acid solutions deteriorated significantly with the specimen inserted in 2.5M *HCl*having 248.674 N/mm^2 compared to sea and distilled water specimen with yield strength of 386.826 and 403.404N/mm^2 respectively over the same exposure period. The un-corroded specimen has yield strength of 442.087N/mm^2. Increasing molar concentration of the acid also decreased the yield strength of the specimen over all the exposure period. Similarly, the ultimate tensile and the impact strength of mild steel specimens after their removal from different medium (0.5, 1.0, 1.5, 2.0, 2.5M *HCl* acid, sea and distilled water) followed the same pattern as those of yield strength as presented in figure 5 and 6 respectively.

The ultimate tensile strength of mild steel specimen in 2.5M HCl acid, sea and distilled water after 35 days exposure period were 303.935,442.087 and 453.139 N/mm^2 respectively while that of the un-corroded specimen was 497.348N/mm^2.Similarly, the impact strength of mild steel specimen in 2.5M HCl acid, sea and distilled water after 35 days exposure period were 30.6411, 51.5204 and 52.8762J respectively while the impact strength of the un-corroded specimen was 60.873J.It was generally observed that the ultimate tensile, yield and impact strength were dependent on the corrosion rate of the mild steel samples. The higher the corrosion rate the higher the weight loss and the less the ultimate tensile, yield and impact strength.The increase in molar concentration of the *HCl*acid increased the *CPR*(See figure 1) and consequently decreased the yield, ultimate tensile and impact strength.

6.0 CONCLUSIONS

The effects of corrosion on the mechanical properties (yield, ultimate tensile and impact strength) were carried out and the following conclusions were drawn.

1. Corrosion of mild steel increased with increase in the exposure time for the entiremedium.
2. The mechanical properties (yield, ultimate tensile and impact strength) of mild steel decreased with increasing weight loss, exposure time and molar concentration of HCL acid.
3. At the end of the 35 days exposure time, mild steel specimen inserted in 2.5M HCL acid had lost 43.75, 38.89, 49.66 %of their yield, ultimate tensile and impact strength respectively, the specimen inserted in sea water had lost yield, ultimate tensile and impact strength of 12.5, 11.11, 15.36 % respectively while that of distilled water lost 8.75, 8.89, 13.14 % of their yield, ultimate tensile and impact strength respectively.

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