EVALUATION OF THE IMPACT OF CORROSION ATTACK IN CARBON STEEL C-1040 MARINE PIPING SYSTEM IN TWO MEDIA

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Authors' contributions:

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

ABSTRACT

The focus of this study was to investigate the impact of corrosion attack in carbon steel C-1040 marine piping system using weight loss method. Two carbon steel specimens (coupons) of cylindrical shape were selected and weighed before they were exposed to two different test solutions (corrosion media) at a concentration of 0.2M and 0.04M in seawater and freshwater respectively at room temperature for eight weeks. The weight loss was taken as the difference in the weight of the coupons before and after immersion in the two different test solutions. The corrosion rates of the coupons were calculated from the weight loss obtained. The experimental result from weight loss method was calculated using engineering equation solver (EES). The weight loss and rate of corrosion of the two coupons varied as higher corrosion rate and weight losses were observed in coupon 2. The weight loss and corrosion rate in 0.2M concentration of coupon 2 in seawater environment increased from 0.04g to 0.53g, 0.007133mmpy to 0.0181mmpy while coupon 1 showed an increase from 0.01g to 0.25g, 0.0035mmpy to 0.005573mmpy was observed in 0.04M concentration in freshwater environment. This shows that carbon steel metal was more susceptible to corrosion attack in seawater environment than in the freshwater environment. The micrograph results of coupon 2 before and after immersion in 0.2M of seawater for about 1344hrs showed evidence of uniform (general) corrosion as the coupon surface was rough and jarring. The grain boundaries of the surface morphology also revealed general corrosion effects on the coupon after immersion as the film present on the surface was cracked as a result of corrosion impact.

Keywords: carbon steel, corrosion rate, two media, weight loss method

1. INTRODUCTION

Trethway et al. [1] defined corrosion as the degradation or decay of a metal by direct attack or by reaction with its environment. According to Ikechukwu et al. [2], corrosion takes place in the presence of an electrolyte; such as freshwater, saltwater or soil. Corrosion is a major concern in marine environments due to the high concentrations of chlorides and sulphur dioxides as well as high mean annual temperature, rainfall, humidity and time of wetness [3]. The high rates of corrosion severely reduce the lifespan of steel structures. A number of industrial designs of materials are not carried out unless keen considerations are given to the effect of corrosion on the materials' life spans Aminu et al. [4]. Thus, a better understanding of the corrosion behavior of steels is required in order to decrease degradation due to atmospheric corrosion. The impact of corrosion on a ship's hull is generally known and recognized by the material industry but the disasters by corrosion attacks in marine piping system and their arrangement used in offshore practices have been recognized by few [5]. According to Rajendran et al. [6], corrosion

degrades the metallic properties of the affected metal. According to Oliver et al. [7], corrosion is the damaging attack on a metal by its environment which results in damage to its metallic properties, such that it can no longer meet the design criteria specified.
Environmental factors have significant effects on the corrosion of metals and other accelerating factors such as the oxygen of the fluid, chemical make-up, velocity of the fluid, temperature and pH values (Anyawu et al. [8]. An example of a corroded pipe affected by seawater as shown in figure 1.

Fig. 1. Corroded Piping System

Pipes corrode internally and externally. Internally, they may be affected by erosion, uniform and abrasive corrosion, fatigue and galvanic action. Externally, corrosion is caused mainly by atmospheric conditions, but pipes can corrode locally where liquids drip onto them or erode where clamps have loosened and fretting occurs [5]. However, in spite of safety and maintenance measures to combat and reduce the effects of corrosion in marine piping system, an estimated sum of 4% of the GNP of the industrial country has been spent Gerhardus et al. [9].
The main focus of this research is to use weight loss method to evaluate the impact of corrosion attack in marine piping system by exposing carbon steel C-1040 for less than a year at room temperature and at different concentrations in freshwater and seawater as environmental media.

2. Sample Preparation and Analysis

Two carbon steel C-1040 coupons were exposed in freshwater and seawater environments. The freshwater was obtained from Amassoma River in Southern Ijaw L.G.A., Bayelsa State while the seawater was obtained from Elia-Gina River, Ogonokom Abua/Odurl L.G.A. Rivers State. Coupon 1 and coupon 2 were exposed for a period of eight weeks in freshwater at a concentration of 0.04M and seawater at a concentration of 0.2M respectively at the university laboratory. Before exposure, the carbon steel coupons of cylindrical shape were cut and filed; their areas were obtained along with the length and radius as shown in Table 1. The coupons comprise of the same length and radius, however, their weights varied when weighed on an ultra-sensitive balance. Before exposure, the coupons were mechanically polished with P800 grit paper to ensure surface smoothness, chemically cleaned with 9% hydrochloric acid solution, rinsed with clean water and then dried with a smooth towel.

Table 1. Shape, Size and Area of the Specimen

Specimen	Shape	Radius (mm)	Length (mm)	Area (mm^2)
Carbon steel	Cylindrical	6.0	80	3243

Each coupon was suspended in a known volume (250ml) of corrosion media through a supporting rod and a thread. This was with a view to ensuring uniform contact of the coupons with the medium as shown in fig. 2.

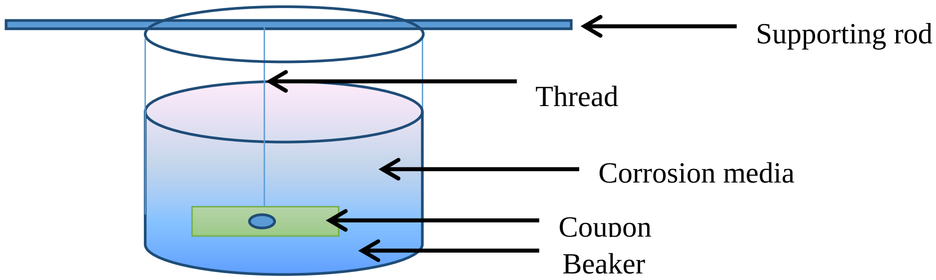

Fig. 2. Beaker used as corrosion media

Fig. 3. Ultra-sensitive weighing balance used for weighing the carbon steel coupon

The salinity (concentration) and other parameters were obtained from the university laboratory. The constituents of seawater and freshwater are shown in Table 2.

Table 2. Constituents of seawater and freshwater

Constituent	P^H	Salinity (M)	NO_3	Cl	SO_3	Ca	Mg	Na	Fe	K
Seawater	8.11	0.2	7.641	975	54.60	568	142	264	0.54	72
Freshwater	6.25	0.04	0.214	27.0	4.86	18.54	4.50	7.62	–	3.42

In this work, weight loss analysis was used as an experimental method for the immersion test using samples of carbon steel C-1040. This was done to determine the weight difference of the coupons in order to calculate their corrosion rates. The specimens also called coupons were weighed using the ultra-sensitive weighing balance shown in fig. 3 before they were exposed to two different test solutions (corrosion media) at a concentration of 0.2M and 0.04M in seawater and freshwater respectively for eight weeks. The weight loss in grams (g) was taken as the difference in the weight of the coupons before and after immersion in the two different test solutions. The corrosion rates of the coupons were calculated from the weight loss obtained. The initial weights of the carbon steel coupons obtained from the weighing balance are shown in Table 3.

Table 3. Initial Weights of the Coupons

Carbon steel C-1040	Coupon 1	Coupon 2

Weight (g)	15.79	15.78

The corrosion rate is calculated using:

$$Corrosion\ rate\ (C.R) = \frac{Weight\ Loss\ (W) \times K}{D\ (\frac{g}{mm^3}) \times A\ (mm^2) \times T\ (yr)} \quad (1)$$

Where,

K = Rate constant= 87.6

ΔW = Weight in grams

D = Density of metal

A = surface area of metal in (mm^2)

T = Time of exposure in yrs.

$$Corrosion\ rate\ (mm/y) = \frac{87.6 \times \Delta W}{D \times A \times T} = \frac{g}{\frac{g}{mm^3} \times mm^2 \times yr} = \frac{mm}{yr}\ \text{or mmpy} \quad (2)$$

Calculations of the sample area, weight loss and corrosion rate were coded and solved using engineering equation solver and plotted at the two different concentration on MS excel spreadsheet. The results from engineering equation solver (EES) are shown in the appendix.

Positive material identification (PMI) was used in the study to determine the chemical compositions of the corroded metal before carrying out weight loss analysis. The location to be tested is cleaned to remove dirt, rust or adhering grease. The X-MET7000 series has factory settings which are applicable to many measurements. X-met is however tested for by measuring the sample specimen. The chemical composition of the selected material (carbon steel C-1040) obtained from Turret Engineering Services Ltd is shown in Table 4.

Table 4. Carbon Steel C-1040 Chemical Composition

Material	Composition, wt. (%)										
	Ti	**V**	**Cr**	**Mn**	**Fe**	**Ni**	**Cu**	**Nb**	**Mo**	**W**	**Pb**
Carbon steel C-1040	**0.06**	**0.03**	**0.2**	**0.17**	**98.08**	**0.03**	**0.23**	**0.00**	**0.01**	**0.02**	**0.00**
	0.012	**0.05**	**0.008**	**0.010**	**0.024**	**0.008**	**0.010**	**0.001**	**0.002**	**0.008**	**0.001**
	0.00	**0.50**	**0.004**	**94.61**	**0.27**	**0.03**	**0.34**	**1.03**	**0.04**		
	0.003	0.010	0.004	0.047	0.010	0.003	0.026	0.032	0.008		

The Inverted Metallurgical Microscope was used as a surface analysis tool for the inspection of grain size. Metallographic samples of carbon steel were inspected using a dedicated microscope to assess the grain size and phase of the coupons. Samples of carbon steel C-1040 surface were analyzed before and after immersion into the seawater environment of 0.2M concentration. Before the coupons were inspected with the microscope, the following preparatory steps were taken to ensure the visibility of the microstructure:

- **Sampling:** This involves cutting of the coupons to sizes that will fit into the mold for mounting. The coupons were cut into smaller dimensions using a hacksaw.
- **Mounting:** The coupons were placed in a mold that has a punch; phenolic powder (thermosetting material) was poured into the mold and a heater placed around it. Pressure was applied on the content of the mold with a hydraulic press and the coupons were heated in a heater until the light indicator went off.
- **Grinding:** This was done to ensure smooth finish and uniformity of the surface of the specimens to be scanned. Hence, five different abrasive papers were used ranging from P220, P320, P400, P600 and P800. The mounted surface to be scanned was thoroughly scrubbed on the abrasive paper starting from the P220 till the P800 to ensure surface smoothness.
- **Polishing:** Using a polishing machine, velvet clothe and a polishing reagents (diamond suspension and lubrication), the sample was inverted while the polishing wheel moved round until a mirror like surface was achieved.
- **Etching:** Etching reagent was used on the metal specimens.
- **Scanning:** The prepared samples were then placed under the microscope for scanning.

All these were carefully done to prevent the destruction of the coupons surfaces.

3. RESULTS AND DISCUSSION

3.1 Presentation of Results

The experimental result obtained using weight loss technique was calculated using engineering equation solver (EES). The coupons showed evidence of corrosion attack after eight (8) weeks of exposure. In Tables 6 and 7, the coupons showed evidence of increased weight loss and corrosion rate while figures 4 and 5 graphically illustrated the different responses of the coupons to the impact of corrosion in seawater and freshwater environments.

Table 6. Weight loss results of coupons immersed after eight (8) weeks in freshwater and seawater media.

Concentration	Initial weight before immersion	Wt. after 1st week	Wt. after 2nd week	Wt. after 3rd week	Wt. after 4th week	Wt. after 5th week	Wt. after 6th week	Wt. after 7th week	Wt. after 8th week
0.02M of seawater	14.79g	14.75g	14.70g	14.63g	14.56g	14.50g	14.41g	14.33g	14.26g
0.04M of freshwater	14.78g	14.77g	14.74g	14.70g	14.67g	14.64g	14.62g	14.59g	14.54g

Table 7. Weight loss of coupons after eight (8) weeks of immersion

Concentration	Wt. loss aft wk. 1	Wt. loss aft wk. 2	Wt. lost aft wk. 3	Wt. loss aft wk. 4	Wt. loss aft wk. 5	Wt. loss aft wk. 6	Wt. loss aft wk. 7	Wt.loss aft wk.8
0.2M of seawater	0.04g	0.09g	0.16g	0.23g	0.29g	0.34g	0.46g	0.53g
0.04M of freshwater	0.01g	0.04g	0.08g	0.11g	0.14g	0.16g	0.1g	0.24g

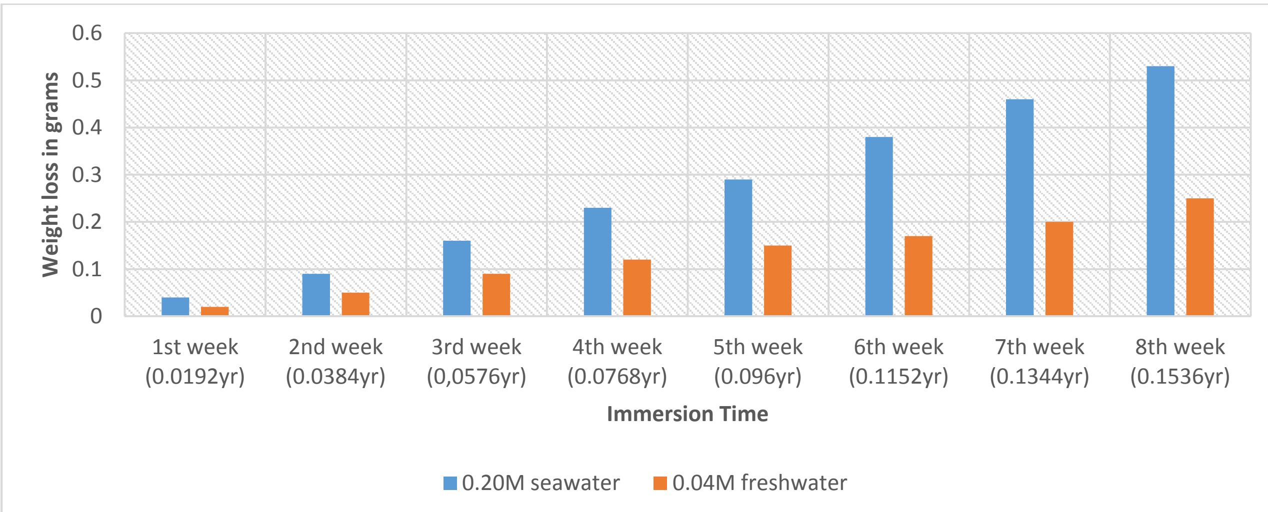

Fig. 4. Weight loss results of coupons in 0.2M of seawater and 0.04M of freshwater exposed for eight weeks against Time

Table 8. Corrosion rate of coupons immersed after eight (8) weeks in freshwater and seawater media

Concentration	CR after 1st week	CR after 2nd week	CR after 3rd week	CR after 4th week	CR after 5th week	CR after 6th week	CR after 7th week	CR after 8th week
0.2M of seawater	0.007133 mmpy	0.008025 mmpy	0.009511 mmpy	0.01025 mmpy	0.01034mmpy	0.01129mmpy	0.01172mmpy	0.01181mmpy
0.04M of freshwater	0.003567mmpy	0.004458 mmpy	0.00535 mmpy	0.00535 mmpy	0.00535mmpy	0.005053 mmpy	0.005095 mmpy	0.005573 mmpy

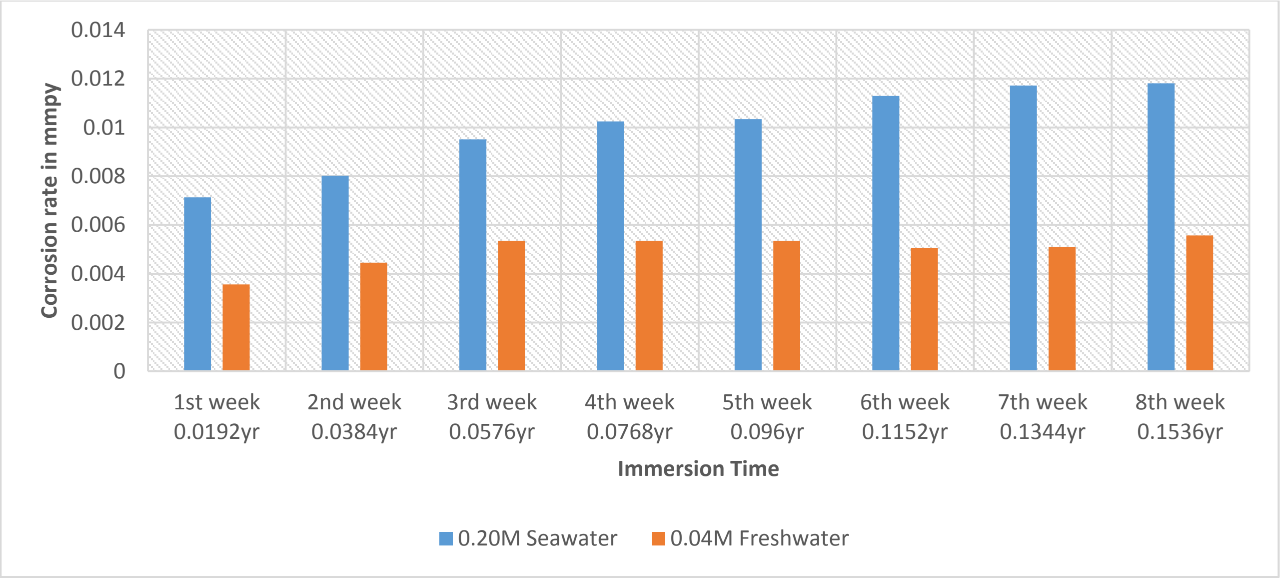

Fig. 5. Corrosion rate results of coupon 2 in 0.2M of seawater and coupon 1 in 0.04M of freshwater exposed for eight weeks against Time

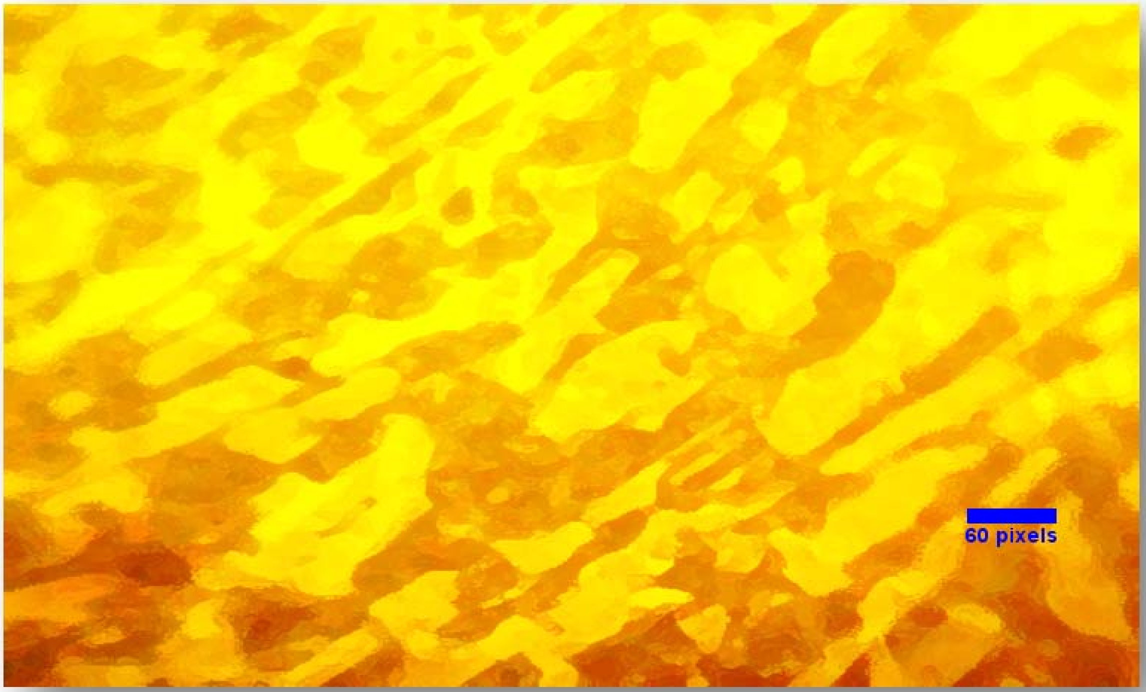

Fig. 6. Micrograph of coupon 2 before immersion X 400 in 0.2M of seawater

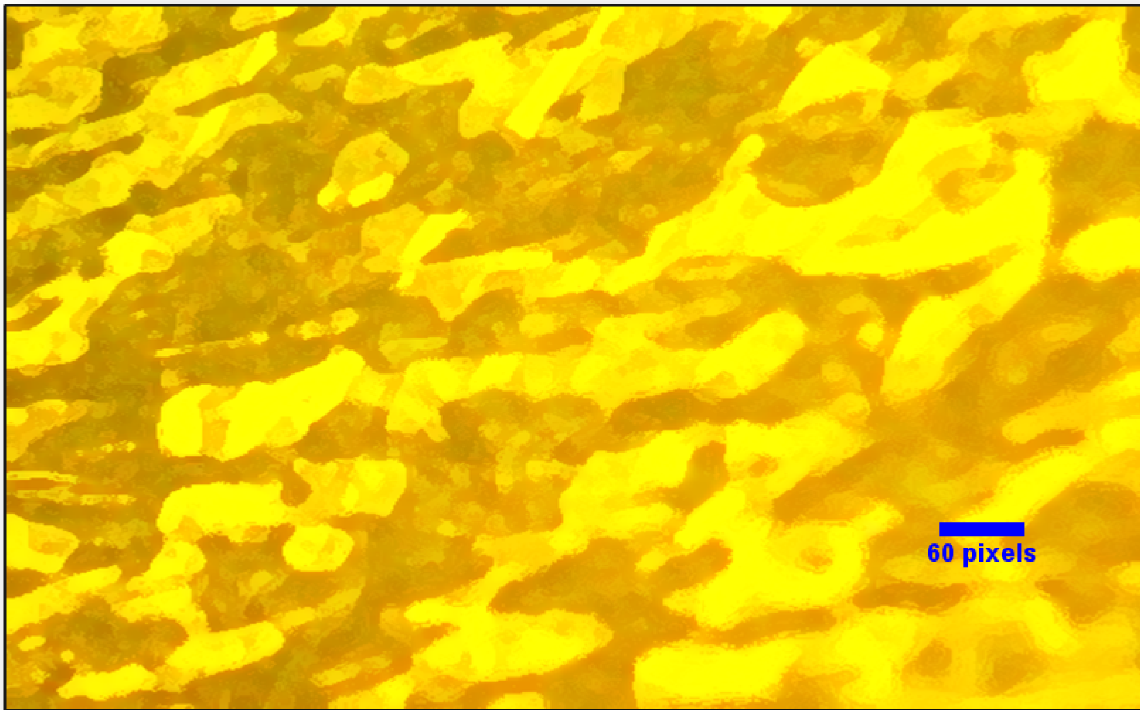

Fig. 7. Micrograph of coupon 2 after immersion X 400 in 0.2M of seawater

3.2 Discussion of Results

The coupons exhibited different features in terms of color, texture, surface appearance, type and size of the corrosion products on the metal. By the end of the first week, coupon 2 exhibited patches of grey and black on its surface. Between the seventh (7th) and eighth (8th) weeks, about 60 to 80% of the surface was rough, with a hard brownish corrosion product which when washed off left the surface with more black patches than the grey patches. Towards the end of the experiment, circular bumps were formed on the surface which when washed off exposed circular pits on the surface of the metal. The base of the pits was grey in color. The remaining surface was black. While at the eighth (8th) week, the water appeared dark yellowish brown with brown particles at the bottom inside the beaker used as a corrosion medium which was found to be similar to that of Bebeteidoh et al. [10]. The results from the experiment revealed that corrosion occurred as metal weight loss. The weight loss and corrosion rate of coupon 2 in seawater and coupon 1 in freshwater varied as higher corrosion rate and weight loss were observed in coupon 2 as shown in Figs. 4 and 5. From week one (1) to week eight (8), the weight loss and corrosion rate of coupon 2 increased steadily as shown in Tables 4 and 5. Both coupons showed increase in weight loss and corrosion rate. The weight loss of coupon 2 increased from 0.04g to 0.53g while its corrosion rate showed an increase of 0.007133mmpy to 0.0181mmpy. For coupon 1, weight loss increased from 0.01g to 0.25g and the corrosion rate from 0.0035mmpy to 0.005573mmpy. Thus, confirming that carbon steel metal was more susceptible to corrosion attack in seawater environment than in the freshwater environment. From the inverted metallurgical microscope study, the micrograph results for coupon 2 before and after immersion showed that that carbon steel C-1040 samples after 1344hrs (0.1536yr) of immersion in 0.2M of seawater experienced uniform (general) corrosion as the surface was rough and jarring. The grain boundaries of the surface morphology revealed general corrosion effects on the coupon after immersion as the film present on the surface was cracked as shown in Figs. 6 and 7 as a result of corrosion impact.

4. CONCLUSION

In this research work, the impact of corrosion attack in marine piping system and other fluid equipment operating in the downstream and upstream sectors in Nigeria was successfully addressed by applying the weight loss method. Result from our experiment showed that the values of corrosion rate and weight loss were found to be higher in seawater environment than in freshwater environment due to the effects of salinity in seawater. The research work showed the dangers of operating marine piping system in seawater and freshwater by analyzing the metal behavior in both corrosive environments, thus drawing the attention of materials and corrosion engineers on the need to combat corrosion by exploring and seeking for better material designs that will be more resistant to corrosion in marine piping systems.

ACKNOWLEDGEMENT

The authors wish to acknowledge the effort of Chukwuemeka Prince in providing the necessary materials needed for this work.

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APPENDIX

Engineering equation solver (EES) code for weight loss calculation and results

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“Determination of Area, weight loss and corrosion rate of carbon steel in SEAWATER environment after immersion for two months"
r=6 [mm]; L=80 [mm]; pie=3.142
A= (2*(pie)*r*L) + (2*(pie)*r^2)
“Weight difference for the first week”
W_R=14.79 [g]; Wone=14.75 [g]
W_1loss=W_R -Wone
“Corrosion rate after immersion for the first week”
K=87.6; T_week1=0.0192 [mmpy]; D=7.89 [g/mm]
Cr_week1= (K*W_1loss)/ (A*T_week1*D)
“Weight difference for the second week"
Wtwo=14.70 [g]
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W_2loss=W_R-Wtwo
T_week2=0.0384 [mmpy]
Cr_week2= (K*W_2loss)/ (A*T_week2*D)
“Weight difference for the third week of immersion"
Wthree=14.63 [g]
W_3loss=W_R- Wthree
“Corrosion rate after the third week of immersion"
T_week3=0.0576 [mmpy]
Cr_week3= (K*W_3loss)/ (A*T_week3*D)
“Weight difference after the fourth week of immersion”
Wfour=14.56 [g]
W_4loss=W_R-Wfour
“Corrosion rate after fourth week of immersion”
T_week4=0.0768 [mmpy]
Cr_week4= (K*W_4loss)/ (A*T_week4*D)
"Weight difference after fifth week of immersion"
Wfifth=14.50 [g]
W_5loss=W_R-Wfifth
“Corrosion rate after the fifth week of immersion"
T_week5=0.096 [mmpy]
Cr_week5= (K*W_5loss)/ (A*T_week5*D)
“Weight difference after six week of immersion"
Wsix=14.41 [g]
W_6loss=W_R-Wsix
“Corrosion rate after six week of immersion"
T_week6=0.1152 [mmpy]
Cr_week6= (K*W_6loss)/ (A*T_week6*D)
“Weight loss after the seventh week of immersion"
Wseventh=14.33 [g]
W_7loss=W_R-Wseventh
“Corrosion rate after seventh week of immersion"
T_week7=0.1344 [mmpy]
Cr_week7= (K*W_7loss)/ (A*T_week7*D)
"Weight loss after eight week of immersion"
Weight=14.26 [g]
W_8loss=W_R-Weight
“Corrosion rate after eight week of immersion"
T_week8=0.1536 [mmpy]
Cr_week8= (K*W_8loss)/ (A*T_week8*D)

"Determination of Area of the cylinder used, weight loss in grams and corrosion rate of carbon steel in **FRESHWATER environment** after immersion for two months"
r=6 [mm]; L=80 [mm]; pie=3.142
A= (2*(pie)*r*L) + (2*(pie)*r^2)
"Weight difference for the first week"
W_R=14.79 [g]; Wone=14.77 [g]
Wloss_wk1=W_R -Wone
"Corrosion rate after first week of immersion"
T_week1=0.0192 [mmpy]; K=87.6; D=7.89[g/mm^3]
Cr_week1= (K*Wloss_wk1)/ (A*T_week1*D)
"Weight loss after the second week of immersion"
Wtwo=14.74 [g]
Wloss_wk2=W_R-Wtwo
"Corrosion rate after the second week of immersion"
T_week2=0.0384 [mmpy]
Cr_week2= (K*Wloss_wk2)/ (A*T_week2*D)

"Weight loss after the third week of immersion"
Wthree=14.70 [g]
Wloss_wk3=W_R-Wthree
"Corrrosion rate after the third week of immersion"
T_week3=0.0576 [mmpy]
Cr_week3= (K*Wloss_wk3)/ (A*T_week3*D)
"Weight loss after the fourth of immersion"
Wfourth=14.67 [g]
Wloss_wk4=W_R-Wfourth
"Corrosion rate after the fourth week of immersion"
T_week4=0.0768 [mmpy]
Cr_week4= (K*Wloss_wk4)/ (A*T_week4*D)
"Weight loss after the fifth week of immersion"
Wfifth=14.64 [g]
Wloss_wk5=W_R-Wfifth
"Corrosion rate after the fifth week of immersion"
T_week5=0.096 [mmpy]
Cr_week5= (K*Wloss_wk5)/ (A*T_week5*D)
"Weight loss after the six week of immersion"
Wsix=14.62 [g]
Wloss_wk6=W_R-Wsix
"Corrosion rate after the sixth week of immersion"
T_week6=0.1152 [mmpy]
Cr_week6= (K*Wloss_wk6)/ (A*T_week6*D)
"Weight loss after the seventh week of immersion"
Wseventh=14.59 [g]
Wloss_wk7=W_R-Wseventh
"Corrosion rate after the seventh week of immersion"
T_week7=0.1344 [mmpy]
Cr_week7= (K*Wloss_wk7)/ (A*T_week7*D)
"Weight loss after the eight week of immersion"
Weight=14.54 [g]
Wloss_wk8=W_R-Weight
T_week8=0.1536 [mmpy]
"Corrosion rate after the eight week of immersion"
Cr_week8= (K*Wloss_wk8)/ (A*T_week8*D)