Behavioural Corrosion Mechanism of Hot Worked Mild Carbon Steel Immersed in various Acidic Environments

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ABSTRACT

Heat treatment of metals is an important operation in the final fabrication process of many engineering components. Hot working help to improve the mechanical properties of the affected metals. In this research work, behavioural corrosion mechanism of hot worked mild steel carbon immersed in various acidic environments were evaluated mainly to determine the weight loss and corrosion rate of the material. In evaluating the corrosion rate of the mild steel in acidic environment, weight loss approach was adopted. The coupons were measured prior to immersion and different weight measurements were taken at interval of 24 hours, over the period of 168 hours. The difference in weight between the original weight and the final weight at each 24 hour interval (weight loss), was estimated and used for the calculation of the corrosion rates. The results obtained reveal an increased in weight loss as concentration of acids increases and this resulted to increase in corrosion rate as experienced by coupons immersed in five samples of acid environment used in this research work. Besides, nitric acid proved to be more aggressive, and this was followed by hydrochloric acid, tetraoxosulphate (VI) acid, phosphoric acid, and acetic acid was the least. Therefore, if acid must be used with mild steel, nitric acid should not be used.

Key Words: Hot Work, Mild Carbon Steel, Weight Loss, Corrosion Rate, Acidic Environment.

1. INTRODUCTION

Mild carbon steels account for a large proportion of the total output of steel [1-2]. Mild carbon steel is a vital alloy used in petroleum and petrochemical industries and it account for over 98% of the construction materials [3]. The wide application of mild carbon steel range from chemical, oil gas storage tanks and transportation pipelines is due to its moderate strength, good weld-ability and formability [4]. Deterioration of materials produced from mild carbon steel as a result of corrosion has come to be accepted worldwide as an unavoidable fact of life. The present degradation of infrastructures particularly in acidic medium has continued to generate a lot of worries to researchers across the world in view to procure lasting solution to the problem. Corrosion remains one of the most severe limitations to the use of mild carbon steel in the chemical, petrochemical industries construction, and manufacturing.

Corrosion is the damage of material due to chemical reaction of the material with its environment. Usually, this destruction takes place on its surface in the form of material dissolution or redeposition in some other forms. Mild carbon steel just like every other metals and alloys are generally prone to corrosion because most of them occur naturally as ores, which is the most stable state of low energy and there is a net decrease in free energy, (AG) from metallic to oxidized state [5]. The corrosion of mild carbon steel in natural environments such as acidic medium is of practical importance. Generally, the chemistry of corrosion processes is shown in equation (1), and equation (2) [6].

$$\text{Fe (s)} \rightarrow \text{Fe}^{2+} + 2\text{e}^- \quad \text{(Material Dissociation)} \quad (1)$$

$$\text{O}_2 + 4\text{H}_2\text{O} + 4\text{e}^- \rightarrow 4\text{OH}^- \quad \text{(Oxygen Dissociation)} \quad (2)$$

The corrosion characteristic of mild carbon steel in acidic medium is the formation and growth of compact and thick layers composed of oxides, insoluble salts and organic materials [7]. The exchange of various species (ions, molecules, gas) between
Heat treatment is a heating and cooling operation applied to metals and alloys in solid state to impact desirable properties to the metal or alloy. Heat treatment of metals is an important operation in the final fabrication process of many engineering components. Heat treatment is of various forms which include annealing, normalizing, tempering, hardening and isothermal operations [12-13]. Heat treatment improves the microstructure of the metal, and this is what gives the metal desired properties for different service conditions. Hot work is the process in which the metal is subjected to forces above recrystallization temperature to give it a desired shape. Above recrystallization temperature, the metal becomes plastic and causing growth in grains. By hot working the grains broke up and forms small new crystals which is refinement of grains. The various methods of hot working are as same as cold working. Hot working is a high temperature thermo mechanical treatment consisting of deforming a metal above its transformation temperature and cooling at a rate to preserve same or all of the deformed structure. It is an activity performed on metals at a temperature high enough to permit recrystallization and strain hardening does not occur. The ingots are preheated in soaking – pits or furnaces in other to bring them to the required temperature which is somewhere in the region between 100-200°C below the melting point. So at such temperature the metal is much more plastic and requires smaller deformation forces than would be necessary at low temperature. The coarse, as-cast structure of the work piece or ingot, would be broken up and distorted during the first stages of hot deformation, however, almost immediately, recrystallization can be carried out. Therefore, a sequence of rolling passes or forging bellows will generally be planned so that final deformation takes place at the temperature close to recrystallization temperature in order without excessive grain growth occurring. Considering the usefulness of hot work on mild carbon steel mainly to improve its mechanical properties and the effect of corrosion on it, it became necessary to study and emulate the effect of hot work and corrosion of mild carbon steel in acidic medium.

2. MATERIALS AND METHODS

2.1 Materials Used
The mild steel used was obtained from Vinupet Steel Company, Warri, Delta State, Nigeria. The elemental composition percentage was carried out at Delta State Company Limited, Ovian-Aladja, Delta State, Nigeria.

2.2 Experiment Overview
The experiment involved the use of 25 pieces of hot worked mild carbon steel coupons in studying their corrosion rate when immersed in various environment of acidic solution: the various acids used include; hydrochloric acid (HCl) of molar mass 36.5g, percentage purity 36%, specific gravity 1.17, and relative density of 1.17g/ml or 1170g/l, nitric acid (HNO3) of molar mass of 63.01g/mol, percentage purity 68%, specific gravity 1.42 and relative density 1420g/l, acetic acid (CH3COOH) of molar mass 60.05g/mol, percentage purity 99.7%, specific gravity 1.04, relative density 1040g/l, phosphoric acid (H3SO4) of molar mass of 98.0g, percentage purity 85%, specific gravity 1.685g/mol or 1685g/l and hydrogen tetraoxosulphate (VI) acid (H2SO4) of molar mass 98g/mol, percentage purity 98%, specific gravity 1.305, relative density 1830.5g/l, with different concentration varying from 0.5 to 2.5 mole per dm$^3$. The method employed for this research was simply the weight loss method, which involve the difference in weight of the coupon before and after exposure to the various corrosion medium at a given time interval and at room temperature. Different tags were used to ensure that the experiment was not mixed-up.

2.3 pH Meter
This enables the acidity and the basicity of the solution to be known.

2.4 Mettler PM II Sensitive Balance
It was used to measure the variation in weight of the coupon at different stages (Figure 1).
2.5 Preparation of Standard Corrosion Solution

The various stock solution used for the experiment were prepared using Equation (3) to Equation (5).

Amount of stock solution in g/dm$^3$ = percentage purity x relative density/100  
Number of moles = mass of substance in g per dm$^3$/molar mass in g per

After knowing the concentration of the stock solution, the volume of the stock solution required to prepare each of the environment was calculated using the dilution formula as shown in Equation (3).

$$V_1M_1 = V_2M_2$$

where,

$M_1$ = Concentration of stock solution

$V_1$ = Volume of stock solution required to make environment.

$M_2$ = Concentration of environment to be prepared.

$V_2$ = Volume of environment to be prepared

For HCl acid

Molar mass of HCl = 36.5g

Percentage purity = 36%

Specific gravity = 1.17

Relative density = 1.17g/ml or 1170g/L

To calculate the amount of the stock solution:

Percentage purity x relative density = 36/100 x 1170 = 421.2g/l

Amount of stock in mol/dm$^3$ = 11.54MHCL

Thus, 36% of hydrochloric acid contains 11.54M of undiluted HCl

For concentration of 0.5M HCl using the dilution formula

$$V_1 = M_2V_2/M_1$$

$M_1$ = 11.53

$M_2$ = 0.5

$V_2$ = 200ml

$V_1 =$?

Hence,

$$V_1 = 0.5x200/11.53 = 8.67ml$$

Then, Volume of distilled water, 200ml – 8.67ml = 191.33ml

Thus, 8.67ml of concentrated HCl acid was dissolved into 19.33ml of distilled water to give an environment of 200ml to 0.5M.

Same procedures were adopted for all reagents used. Table1 shows the volume of the stock solution (acid) required to prepare each concentration of the different environment.

| Concentration (M) | H$_2$SO$_4$ | HCl | HNO$_3$ | CH$_3$COOH | H$_3$PO$_4$ |
|------------------|-------------|----|----------|------------|------------|
| 0.5              | 8.67        | 6.53 | 5.79     | 6.84       | 5.46       |
| 1.0              | 17.35       | 13.05 | 11.58    | 13.69      | 10.92      |
| 1.5              | 26.02       | 19.58 | 17.37    | 20.53      | 16.38      |
| 2.0              | 34.69       | 26.11 | 23.16    | 27.38      | 21.85      |
| 2.5              | 43.37       | 32.64 | 28.95    | 34.22      | 37.31      |
2.6 Experimental Procedures

Fifty (50) sets of clean beakers were tagged with the name of the various acids, with HW, denoting hot worked specimen. Each of the five (5) corrosion environment having ten (10) beakers each with various concentration ranging from 0.5M to 2.5M. Prior to immersion, the approximate pH value of each solution was taken using a pH meter, and the value obtained recorded. The specimens were properly washed with distilled water, dried with clean piece of cloth, and then the initial weight was taken, using the Meter PM II Sensitive Digital weigh balance, and then recorded. Total immersion in 200ml test solution of the specimens into the various environment, was aided with the use of a nylon rope tied to a clean to a clean flattened steel rod of about 3mm diameter, placed on top of each beaker, for support. The experimental setup is shown in Figure 2.

![Figure 2: Experimental Setup](image)

3. RESULTS AND DISCUSSION

The carbon mild steel material elemental composition from the spark test analysis result is as follow; 0.15%C, 0.22% Si, 0.5%Mn, 0.66%P, 0.057%S, 0.02%Mo, 0.25% Cr, 0.1%Ni, 0.26%0.009%V, 0.001%Al, 0.021%Sn, 0.001%Ti and 98.34%Fe. Table 2 shows the weight in grams (g) obtained from the measurement taken at twenty four (24) hours intervals.

| Time (hrs.) | 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
|-------------|------|------|------|------|------|
| Wi          | 18.3262 | 18.2074 | 18.2683 | 17.9454 | 18.3917 |
| 24hrs       | 18.2146 | 18.0759 | 18.0480 | 17.8351 | 17.9327 |
| 48hrs       | 18.1267 | 17.9470 | 17.9656 | 17.7248 | 17.3978 |
| 72hrs       | 18.0422 | 17.8180 | 17.7832 | 17.3390 | 17.0230 |
| 96hrs       | 17.9814 | 17.6021 | 17.4813 | 17.2143 | 16.9565 |
| 120hrs      | 17.7769 | 17.4427 | 17.2143 | 16.5577 | 16.5980 |
| 144hrs      | 17.6700 | 17.1719 | 16.9143 | 16.3188 | 15.4899 |
| 168hrs      | 17.5615 | 17.0010 | 16.8315 | 16.1215 | 15.4009 |

Table 2. Weight (g) of Hot Worked Coupons in Hydrochloric Acid (HCl) Environment

| Time (hrs.) | 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
|-------------|------|------|------|------|------|
| Wi          | 18.0997 | 18.4112 | 18.2103 | 18.1467 | 18.2078 |
| 24hrs       | 17.0409 | 15.3155 | 11.9924 | 11.2612 | 9.9744 |
| 48hrs       | 15.9758 | 15.1864 | 11.5498 | 10.7876 | 9.5696 |
| 72hrs       | 15.7106 | 14.0378 | 11.2072 | 10.1139 | 9.0648 |
| 96hrs       | 15.5116 | 14.0378 | 11.0880 | 9.40720 | 8.2307 |
| 120hrs      | 15.5116 | 14.0378 | 10.7139 | 8.98720 | 9.5109 |
| 144hrs      | 15.4106 | 13.6888 | 10.4199 | 7.16180 | 7.4966 |
| 168hrs      | 15.3458 | 13.3445 | 9.92580 | 8.26710 | 6.5577 |

Table 3. Weight (g) of Hot Worked Coupons in Nitric Acid (HNO₃) Environment Weight
Table 4. Weight (g) of Hot Worked Coupons in Acetic Acid (CH₃COOH) Environment

| Time (hrs.) | Concentrations (M) | 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
|-------------|---------------------|------|------|------|------|------|
| Wi          |                     | 17.9890 | 17.8517 | 18.1358 | 18.4135 | 18.3773 |
| 24hrs.      |                     | 17.9367 | 17.7986 | 18.0745 | 18.3397 | 18.3773 |
| 48hrs.      |                     | 17.9195 | 17.7754 | 18.0509 | 18.3076 | 18.5298 |
| 72hrs.      |                     | 17.9023 | 17.7521 | 18.0172 | 18.2855 | 18.2376 |
| 96hrs.      |                     | 17.7415 | 17.9880 | 17.9562 | 18.2360 | 18.1839 |
| 120hrs.     |                     | 17.8664 | 17.7190 | 17.9465 | 18.2253 | 18.1648 |
| 144hrs.     |                     | 17.8452 | 17.6856 | 17.9308 | 18.2117 | 18.1389 |
| 168hrs.     |                     | 17.8240 | 17.6722 | 17.1193 | 18.1980 | 18.1229 |

Table 5. Weight (g) of Hot Worked Coupons in phosphoric Acid (H₃PO₄) Environment

| Time (hrs.) | Concentrations (M) | 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
|-------------|---------------------|------|------|------|------|------|
| Wi          |                     | 18.3528 | 17.9893 | 18.1183 | 18.6374 | 18.4238 |
| 24hrs.      |                     | 18.2632 | 17.8797 | 17.9936 | 18.4831 | 18.2468 |
| 48hrs.      |                     | 18.2262 | 17.8567 | 17.9748 | 18.4758 | 18.2273 |
| 72hrs.      |                     | 18.1891 | 17.8136 | 17.9359 | 18.4284 | 18.1977 |
| 96hrs.      |                     | 18.1385 | 17.7588 | 17.8717 | 18.3772 | 18.1468 |
| 120hrs.     |                     | 18.0774 | 17.6908 | 17.7754 | 18.2765 | 18.0484 |
| 144hrs.     |                     | 18.0256 | 17.6413 | 17.7414 | 18.2392 | 17.9990 |
| 168hrs.     |                     | 17.9737 | 17.5918 | 17.7074 | 18.1918 | 17.7995 |

Table 6. Weight (g) of Hot Worked Coupons in Hydrogen Tetraoxosulphate (VI) Acid (H₂SO₄) Environment

| Time (hrs.) | Concentrations (M) | 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
|-------------|---------------------|------|------|------|------|------|
| Wi          |                     | 18.2418 | 18.1092 | 18.3087 | 18.0717 | 17.8058 |
| 24hrs.      |                     | 18.1482 | 17.9533 | 18.1209 | 17.9264 | 17.6050 |
| 48hrs.      |                     | 18.0726 | 17.8540 | 18.0127 | 17.7463 | 17.4409 |
| 72hrs.      |                     | 18.0069 | 17.7946 | 17.8624 | 17.6862 | 17.2167 |
| 96hrs.      |                     | 17.9063 | 17.6998 | 17.7342 | 17.2557 | 16.3842 |
| 120hrs.     |                     | 17.8164 | 17.6134 | 17.6254 | 17.2557 | 16.0350 |
| 144hrs.     |                     | 17.6915 | 17.4926 | 17.3765 | 16.7995 | 15.6858 |
| 168hrs.     |                     | 17.4218 | 17.4058 | 17.3654 | 16.5653 | 15.6858 |

The measured weight depicted in Tables 2 to Table 6 shown the weight loss of coupons as calculated which is the difference between the initial weight before immersion and the final weight after immersion at a given time. From the normal weight obtained, the normalized table was formed as shown in Table 7-Table 11, the normalized is the ratio of the weight at a particular time to the original weight.

Table 7. Normalized Values for Hot Worked Coupons in HCl Environment

| Time (hrs.) | Normalized Values for Hot Worked Coupons in HCl Environment | 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
|-------------|------------------------------------------------------------|------|------|------|------|------|
| Wi          |                                                           | 0.9940 | 0.9928 | 0.9879 | 0.9843 | 0.9750 |
| 24hrs.      |                                                           | 0.9891 | 0.9895 | 0.9834 | 0.9782 | 0.9632 |
| 48hrs.      |                                                           | 0.9845 | 0.9786 | 0.9734 | 0.9722 | 0.9460 |
| 72hrs.      |                                                           | 0.9812 | 0.9668 | 0.9569 | 0.9510 | 0.9256 |
| 96hrs.      |                                                           | 0.9700 | 0.9580 | 0.9423 | 0.9300 | 0.9083 |
| 120hrs.     |                                                           | 0.9642 | 0.9431 | 0.9259 | 0.9070 | 0.8862 |
| 144hrs.     |                                                           | 0.9583 | 0.9337 | 0.9214 | 0.8950 | 0.8422 |
| 168hrs.     |                                                           | 0.9583 | 0.9337 | 0.9214 | 0.8950 | 0.8422 |
Table 8. Normalized Values for Hot Worked Coupons in HNO$_3$ Environment

| Time (hrs.) | 0.5M  | 1.0M  | 1.5M  | 2.0M  | 2.5M  |
|------------|-------|-------|-------|-------|-------|
| 24hrs.     | 0.9415| 0.8318| 0.6586| 0.6206| 0.5478|
| 48hrs.     | 0.8827| 0.8248| 0.6342| 0.5945| 0.5256|
| 72hrs.     | 0.8680| 0.7635| 0.6154| 0.5573| 0.4979|
| 96hrs.     | 0.8570| 0.7624| 0.6089| 0.5241| 0.4520|
| 120hrs.    | 0.8550| 0.7573| 0.5883| 0.5184| 0.4117|
| 144hrs.    | 0.8514| 0.7435| 0.5722| 0.4953| 0.3933|
| 168hrs.    | 0.8478| 0.7242| 0.5451| 0.4556| 0.3602|

Table 9. Normalized Values for Hot Worked Coupons in CH$_3$COOH Environment

| Time (hrs.) | 0.5M  | 1.0M  | 1.5M  | 2.0M  | 2.5M  |
|------------|-------|-------|-------|-------|-------|
| 24hrs.     | 0.9971| 0.9970| 0.9966| 0.996  | 0.9949|
| 48hrs.     | 0.9961| 0.9957| 0.9953| 0.9942 | 0.9936|
| 72hrs.     | 0.9957| 0.9944| 0.9935| 0.9930 | 0.9924|
| 96hrs.     | 0.9952| 0.9938| 0.9919| 0.9904 | 0.9895|
| 120hrs.    | 0.9940| 0.9926| 0.9901| 0.9898 | 0.9884|
| 144hrs.    | 0.9932| 0.9907| 0.9896| 0.9890 | 0.9870|
| 168hrs.    | 0.9908| 0.9899| 0.9887| 0.9883 | 0.9862|

Table 10. Normalized Values for Hot Worked Coupons in H$_3$PO$_4$ Environment

| Time (hrs.) | 0.5M  | 1.0M  | 1.5M  | 2.0M  | 2.5M  |
|------------|-------|-------|-------|-------|-------|
| 24hrs.     | 0.9951| 0.9939| 0.9931| 0.9917 | 0.9904|
| 48hrs.     | 0.9931| 0.9926| 0.9921| 0.9913 | 0.9893|
| 72hrs.     | 0.9911| 0.9902| 0.9899| 0.9888 | 0.9877|
| 96hrs.     | 0.9883| 0.9872| 0.9864| 0.9860 | 0.9850|
| 120hrs.    | 0.985 | 0.9834| 0.9811| 0.9806 | 0.9796|
| 144hrs.    | 0.9822| 0.9807| 0.9792| 0.9786 | 0.9769|
| 168hrs.    | 0.9793| 0.9779| 0.9773| 0.9786 | 0.9661|

Table 11. Normalized Values for Hot Worked Coupons in H$_2$SO$_4$ Environment

| Time (hrs.) | 0.5M  | 1.0M  | 1.5M  | 2.0M  | 2.5M  |
|------------|-------|-------|-------|-------|-------|
| 24hrs.     | 0.9949| 0.9914| 0.9898| 0.9920 | 0.9887|
| 48hrs.     | 0.9795| 0.9907| 0.9859| 0.9838 | 0.9821|
| 72hrs.     | 0.9871| 0.9826| 0.9801| 0.9787 | 0.9669|
| 96hrs.     | 0.9816| 0.9774| 0.9756| 0.9675 | 0.9433|
| 120hrs.    | 0.9767| 0.9726| 0.9686| 0.9548 | 0.9202|
| 144hrs.    | 0.9698| 0.9660| 0.9627| 0.9422 | 0.9005|
| 168hrs.    | 0.9646| 0.9593| 0.9491| 0.9296 | 0.8809|

Tables 12 to Table 16 represent the weight loss for the various environments. The total surface area of the coupon was calculated using the formula stated below owing to its geometry as shown below:

$$A = 2(LW + Wt + Lt)$$

where,
A = Total surface area of the coupon, 
L = Length of Coupon 
W = Width of coupon 
t = Thickness of coupon, and 
The coupons used for the research were of the following dimension: 
L= 50 millimeter (mm) = 1.960 inches (in) 
W = 19.5 mm = 0.768 in 
T = 2.5 mm = 0.098 in 
Therefore; 
\[ A = 2[(1.969 \times 0.768) + (0.768 \times 0.098) + (1.969 \times 0.098)] = 3.561 \text{ sq. inch} \]

Density of mild steel = \(7.85 \text{ g/cm}^3\) 
The corrosion rate was calculated using Equation (7) 
\[ CR = \frac{87.6 W_1}{DAT} \]  
where, 
CR = Corrosion Rate (mm/y); Wl = Weight loss (mg); D = Density of Low Carbon Steel = 7.85 g/cm3; A = Area 
T = Exposure time (hrs.) 

| Table12. Weight (mg) Loss of Hot Worked Coupons in HCl Environment |
|---------------------------------------------------------------|
| Time (hrs.) | Concentrations (M) |
| 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
| 24hrs. | 0.1098 | 0.1315 | 0.2203 | 0.2871 | 0.2998 |
| 48hrs. | 0.1995 | 0.2604 | 0.3027 | 0.3974 | 0.5172 |
| 72hrs. | 0.2840 | 0.3894 | 0.4851 | 0.5077 | 0.8347 |
| 96hrs. | 0.3448 | 0.6530 | 0.7870 | 0.8935 | 1.2095 |
| 120hrs. | 0.7647 | 1.0540 | 1.2760 | 1.5264 | 1.6435 |
| 144hrs. | 0.6554 | 1.0355 | 1.3915 | 1.6948 | 1.9345 |
| 168hrs. | 0.7643 | 1.2064 | 1.4368 | 1.937 | 2.7426 |

| Table13. Weight (mg) Loss of Hot Worked Coupons in HNO₃ Environment |
|---------------------------------------------------------------|
| Time (hrs.) | Concentrations (M) |
| 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
| 24hrs. | 1.0588 | 3.0967 | 6.2179 | 6.8855 | 8.2334 |
| 48hrs. | 3.2258 | 6.6605 | 7.3591 | 8.6382 | 8.8787 |
| 72hrs. | 2.3891 | 4.3550 | 7.0031 | 8.0328 | 9.1430 |
| 96hrs. | 2.5581 | 4.3744 | 7.1223 | 8.6358 | 9.9711 |
| 120hrs. | 2.6244 | 4.4691 | 7.4964 | 8.7395 | 10.711 |
| 144hrs. | 2.6891 | 4.7234 | 7.1904 | 9.1595 | 11.046 |
| 168hrs. | 2.7539 | 5.0777 | 8.2845 | 9.8796 | 11.650 |

| Table14. Weight (mg) Loss of Hot Worked Coupons in CH₃COOH Environment |
|---------------------------------------------------------------|
| Time (hrs.) | Concentrations (M) |
| 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
| 24hrs. | 0.0523 | 0.0531 | 0.0613 | 0.0738 | 0.0944 |
| 48hrs. | 0.0695 | 0.0763 | 0.0849 | 0.1059 | 0.1175 |
| 72hrs. | 0.1078 | 0.1102 | 0.1478 | 0.1775 | 0.1934 |
| 96hrs. | 0.0867 | 0.0996 | 0.1186 | 0.1280 | 0.1397 |
| 120hrs. | 0.1226 | 0.1327 | 0.1796 | 0.1882 | 0.2125 |
| 144hrs. | 0.1438 | 0.1661 | 0.1993 | 0.2018 | 0.2384 |
| 168hrs. | 0.1650 | 0.1795 | 0.2050 | 0.2115 | 0.2544 |

| Table15. Weight (mg) Loss of Hot Worked Coupons in H₃PO₄ Environment |
|---------------------------------------------------------------|
| Time (hrs.) | Concentrations (M) |
| 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
| 24hrs. | 0.0896 | 0.1096 | 0.1247 | 0.1543 | 0.1773 |
| 48hrs. | 0.1266 | 0.1326 | 0.1435 | 0.1616 | 0.2261 |
| 72hrs. | 0.1637 | 0.1757 | 0.1824 | 0.209 | 0.2261 |
| 96hrs. | 0.2143 | 0.2305 | 0.2466 | 0.2602 | 0.2770 |
| 120hrs. | 0.2754 | 0.2985 | 0.3429 | 0.3609 | 0.3754 |
| 144hrs. | 0.3272 | 0.3480 | 0.3769 | 0.3983 | 0.4248 |
| 168hrs. | 0.3272 | 0.3975 | 0.4109 | 0.4456 | 0.6243 |
Table 16. Weight (mg) Loss of Hot Worked Coupons in H₂SO₄ Environment

| Time (hrs.) | 0.5M | 1.0M | 1.5M | 2.0M | 2.5M |
|------------|------|------|------|------|------|
| 24hrs.     | 0.0936 | 0.1559 | 0.1878 | 0.1953 | 0.2008 |
| 48hrs.     | 0.1692 | 0.2552 | 0.2760 | 0.3254 | 0.3648 |
| 72hrs.     | 0.2349 | 0.3146 | 0.3643 | 0.3855 | 0.5891 |
| 96hrs.     | 0.3355 | 0.4094 | 0.4463 | 0.5873 | 0.0087 |
| 120hrs.    | 0.4254 | 0.4958 | 0.5745 | 0.8160 | 0.4216 |
| 144hrs.    | 0.5503 | 0.6166 | 0.0833 | 0.0441 | 1.7708 |
| 168hrs.    | 0.6452 | 0.7375 | 0.9322 | 1.2772 | 2.1200 |

Table 17 shows the summary of the corrosion rate of hot worked coupons.

Table 17. Summary of the Corrosion Rate of Hot Worked Coupons in Acidic Environment

| Time (hrs.) | HCl  | HNO₃  | CH₃COOH | H₃PO₄ | H₂SO₄ |
|------------|------|-------|---------|-------|-------|
| 24hrs.     | 238.6 | 6553.4 | 75.1    | 140.9 | 159.8 |
| 48hrs.     | 205.8 | 3437.8 | 46.8    | 78.2  | 145.2 |
| 72hrs.     | 221.5 | 2425.8 | 37.1    | 60.0  | 156.3 |
| 96hrs.     | 240.8 | 1985.3 | 38.5    | 55.1  | 200.7 |
| 120hrs.    | 243.0 | 1705.1 | 33.8    | 59.8  | 226.3 |
| 144hrs.    | 230.1 | 1465.4 | 31.6    | 56.4  | 234.9 |
| 168hrs.    | 311.9 | 1324.7 | 28.9    | 70.9  | 241.1 |

From Table 12-Table 16, the calculated weight losses obtained for hot worked coupons increases with increasing acid concentration for all five acids. This was equally reflected in the normalized results (Table 7-Table 11), indicating accelerated behaviour for the metal dissolution. This result is expected because, with increasing acid concentration, both acidity and Cl⁻ ion concentration will also increase. Also, there was increased in weight loss as concentration of used acids increases and this resulted to increase in corrosion rate as experienced by coupons immersed in five samples of acid environment used in this research work. Comparing the corrosion rate in the different acidic environment shown that nitric acid proved to be more aggressive, and this was followed by hydrochloric acid, tetraoxosulphate (VI) acid, phosphoric acid, and acetic acid was the least. Considering the corrosion rate with time, the corrosion rate for nitric acid decreases with time, while that of the other four acids show a trend of decreasing and increasing corrosion rate. This can be attributed to environmental factors such as, fluctuation in temperature with time.

4. CONCLUSIONS

In this research work, behavioural corrosion mechanism of hot worked mild carbon steel immersed in various acidic environments was investigated to ascertain the corrosiveness of the acid used and it effect on mild steel. The outcome of the research work revealed that corrosion rates increased with increased in acid concentration and with nitric acid (HNO₃) prove to be a more corrosive among the five acids considered in this research work. This was followed by hydrochloric acid (HCl), hydrogen tetraoxosulphate (VI) acid (H₂SO₄) and phosphoric acid (H₃PO₄). However, acetic acid (CH₃COOH) proved to be the least corrosive acid. Visual inspection of the coupons after immersion in the various acidic solution environments of different concentrations showed general and pitting corrosion, and the latter became more pronounced at higher level of the various acidic solution environment concentrations.

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