Investigation Of The Effect Of Corrosion On Mild Steel In Five Different Environments

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Abstract: Mild Steel is one of the major construction materials used in the industries. It has a young modulus of $200GNm^{-2}$. This paper focuses on the experimental study of the corrosion behavior and mechanism for mild steel in five different media namely: 0.1M of Hydrochloric acid, Underground (soil), Atmosphere, Salt water, Fresh water. Mild steel of diameter 1.2cm and 8.5cm long was used for this experiment and studied for a period of five weeks interval weighing and re-immersing. The weight losses were tabulated and analyzed graphically. It was observed that mild steel corroded in the different environments with decreasing intensity in the order of 0.1M of Hydrochloric acid, Underground (soil), Atmosphere, Salt water, Fresh water. It was then concluded that the laboratory immersion test remains the best method of screening of metal, it remains the quickest and most economical means for providing a preliminary selection of best suited materials for engineering applications as there is no simple way to extrapolate the results obtained from this simple test to the predictions of systems service lifetime.

Index Terms: Atmosphere, Corrosion, Different Environments, Engineering applications, Fresh water, Hydrochloric acid, Metals, Mild steel, Salt water, Underground (soil).

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1 INTRODUCTION

IN the world today, mild steel is used in different Engineering applications for the production of some automobile components, structural shapes (I beam and angle iron) and sheets that are used in pipelines, buildings, plants, bridges and tin cans [1]. Mild steel is known for its high carbon content of about 0.2% to 2.1%, manganese (1.65%), copper (0.6%), silicon (0.6%). It is produced from steel which is extracted from pig iron it is also less expensive to produce and is readily available. It has outstanding ductility and toughness, high machinability and weldability which make its applications possible in the engineering fields. The application for which mild steel was developed generally did not involve corrosion resistance as a primary consideration; corrosion resistance of metals and alloys is a basic property related to the ease with which these metals react with a given environment. With the increased utilization of this metal in the manufacturing and construction firms, one of the major problems encountered is the control of corrosion rate when exposed to different corrosive environments. Corrosion is a natural process that reduces the binding energy in metals with the end result involving a metal being oxidized as the bulk metal looses one or more electrons. The lost electrons are conducted through the bulk metal to another site where they are reduced.

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In corrosion, the site where the metal atom looses electron is called the anode and the reducing species is called the cathode. Also, corrosion can be said to be the degradation of metallic materials properties due to interactions with its environments. Corrosion of most metals is inevitable while primarily associated with metallic materials, all material types are susceptible to degradation. Most metals in contact with water (and moisture in air), acids, bases salts, oils, oppressive metal polishes and other solid and liquid chemicals corrode as well as when exposed to gaseous materials like acid vapors, ammonia gas and sulphur containing gases. Corrosion processes are usually electrochemical in nature, having the essential features of a battery. When metal atoms are exposed to an environment containing water molecules they can give up electrons becoming themselves positively charged ions provided an electric circuit can be well extended across a wide area to produce general wastage. All metals exhibit the tendency to oxidize, some more easily than the others. A tabulation of the relative strength of this tendency is the galvanic series. The knowledge of a metal's position in this series helps in decision making for appropriate potential utility of a metal in structural and other applications. In a corrosion cell, the electron produced by the corrosion reaction will need to be consumed by a cathodic reaction in close proximity to the corrosion reaction itself. The electron and the hydrogen ions react to first form atomic hydrogen and then molecular hydrogen gas. As the hydrogen forms, it tends to inhibit further corrosion by forming a very thin gaseous film at the surface of the metal. This film can be effective in reducing metal to water contact and thus reducing corrosion rate. Dissolved oxygen in water will react with the hydrogen, converting it to water thus destroying the film. When the fresh metal is exposed to water, high water velocities can also sweep film away. Other corrosion accelerating actors includes; pH values and high temperature which increase virtually all chemical reactions. Thus a variety of natural and environmental factors can have significant effect on the corrosion of metals even when no other special conditions are involved [2, 3]. In most situations its serviceability depends on the fact that following the initial corrosive attack, protective films are formed that tend to reduce the corrosion rate to some acceptable level [4, 5]. For the effective use of this steel in different engineering applications, there is the need to consider the corrosion rate engulfing this metal. The approach geared towards this

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phenomenon involves a basic knowledge of the structural features of the metal, the component data of the corrosion reaction that occurs at the metal environment interface. This enquiry is obviously necessary because corrosion reduces the useful life of plants and equipment and can often result in unscheduled shutdowns or in some cases, catastrophic failure [4, 6, 7]. The control of corrosion presents a considerable challenge to engineers and in spite of our best effort, the annual costs of corrosion damage and maintenance run into many millions of Great British Pounds (GBP), estimated at about 4% of the GNP for an industrial country. This consequence is as a result of the location of these industries, structures and metals which are mostly at marine environments and have their atmosphere polluted by corrosion pollutant gases [8]. Corrosion is a natural phenomenon, which is inevitable; instead it can be controlled to an appreciable extent. For this control to be implemented, certain tests are carried out by placing the metal in the environment to which it's utility is needed and a careful study of the metal is undergone for a specified time, based on the observation and inference drawn, the corrosion rate can be assessed and a proper measure can be made to control the rate of corrosion [9]. This paper tends to study the effects and rate of corrosion of the mild steel in five different environments namely: 0.1M of Hydrochloric acid, Underground (soil), Atmosphere, Salt water, Fresh water and to examine the chemistry and mechanism of mild steel corrosion, to indicate the environment in which a mild steel rod may be used satisfactorily, and to determine the kinetics of corrosion of mild steel so that predictions of service life can be made and contributions can be made towards the utmost control of corrosion processes. The significance of this study is to determine and provide a comparative analysis on the rate at which mild steel corrodes in the five different environments and as a result re-awakening the readiness of the material engineering to control this rate of corrosion thereby increasing the service life of mild steel when used in any of the environments.

2 METHOD AND MATERIAL

Similar sizes of mild steel were exposed to different corrosive environments and were left for a stipulated period of five weeks with a weekly interval of collection, weighing and re-immersing into the various environments. Note; based on standard practice, the liquid media are changed at the time of reweighing and re-immersing. Based on the weight assessment, appropriate corrosion formulae are employed to ascertain reliable analysis.

2.1 Experiment and Method

The laboratory corrosion test revolves around the actualization of facts for the perfect selection of materials for specific environments, determination of environments in which materials are especially suitable, corrosion control methods that can be applied and the study of corrosion mechanisms. In this paper, five different environments were used; 0.1M of hydrochloric acid, salt water (salt solution), fresh water, atmosphere and underground (soil). Mild steel rod of the same dimensions were exposed to the corrosive properties of these environments and monitored on weekly basis. The results obtained were then used for this analysis on the rate of corrosion and its effects on mild steel. The steel standard utilized was the ASTM G31: this Standard is the recommended practice for laboratory immersion corrosion

testing of metals. This recommended practice is based on NACE standard TM - 01 -69 "test method - laboratory corrosion testing of metals for the process industries" which describes the procedures used for specimen preparation, apparatus, test conditions, methods of cleaning specimens, evaluation of results and calculations and reporting of corrosion rate.
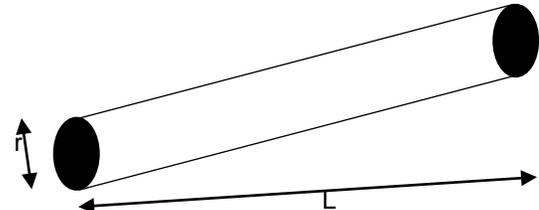

Fig. 1. Shape of Coupon

The shape of the mild steel rod is cylindrical, therefore, the surface area of a cylinder;

$$A = 2\pi r L + 2\pi r^2 \qquad (1)$$

Were; L = Length of Coupon = 85mm, r = Radius of specimen = 6mm, A = Total Surface area of the Cylinder = $2\pi x 6 x 85 + 2\pi x 85^2$ = 3430.619mm^2 $\approx$ 34.31cm^2. The surfaces of the specimen were finished with abrasive paper, rinsed in water, degreased in Acetone and air dried. After drying, the coupons were immediately weighed. Five coupons were used for the experiment. Coupons were pulled out for weighing with ropes tied to them. The ropes were also looped about wooden sticks. On each string and test bottles, a masking tape with label name of the corrosive medium was pasted. The following are the labeled names; 0.1M hydrochloric acid, Soil (Underground), Atmosphere, Salt water: The salt water used for this research work was gotten from a simple solution of table salt and water, Fresh water: The fresh water was gotten from River Niger, Onitsha.
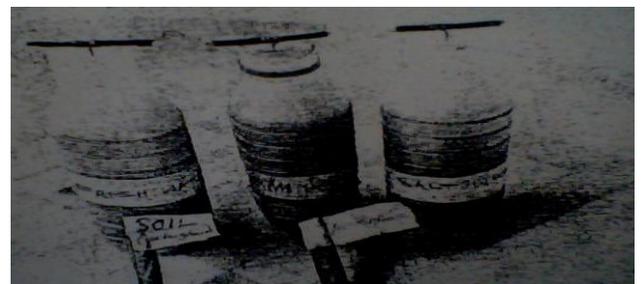
Fig. 2. Number of Specimen and their labels (Fifth Week)

Fig. 3. Coupon buried in the soil

2.2 Measurement of Weight Loss

The weight loss for each week was obtained using the weighing balance and the difference in weigh for each of the week was then calculated that is the difference between the weight of each coupon before and after each week of the immersion of the sample in the different environments.

I. Determination of Corrosion Rate

The most common method for estimating a corrosion rate from mass loss is to weigh the corroding sample before and after exposure and divide by the total exposed area and the total exposure time making sure that appropriate conversion constants are used to get the rate in the required units. The method in mm/yr can be represented by the following equation [10].

$$C_R = \frac{k \times \Delta w}{A \times T \times \rho} \qquad (2)$$

C_R = Penetration (corrosion) rate (mm/yr), Δw = Weight loss in gram, A = Exposed surface area of Coupon = $34.21 \times 10^{-2} cm^2$, ρ = Density of mild steel (g/cm^3) = $7.86 g/cm^3$, T = Time of exposure in hours, k = Constant for unit conversion = 8.76×10^4. The rate of corrosion for the first week for each of the various environments is thus calculated below:

For the HCl; $C_R = 2.5563$
For Soil; $C_R = 0.0170$
Atmosphere; $C_R = 0.0085$
For Salt water; $C_R = 0.0597$
For Fresh water; $C_R = 0.0139$

For the second week
For the HCl; $C_R = 1.4997$
For Soil; $C_R = 0.0341$
Atmosphere; $C_R = 0.0197$
For Salt water; $C_R = 0.9464$
For Fresh water; $C_R = 0.0689$

For the third week
For the HCl; $C_R = 2.1850$
For Soil; $C_R = 0.7345$
Atmosphere; $C_R = 0.0302$
For Salt water; $C_R = 1.1242$
For Fresh water; $C_R = 0.4686$

For the fourth week
For the HCl; $C_R = 2.5519$
For Soil; $C_R = 1.5473$
Atmosphere; $C_R = 0.2275$
For Salt water; $C_R = 1.3201$
For Fresh water; $C_R = 0.8267$

For the fifth week
For the HCl; $C_R = 2.99770$
For Soil; $C_R = 1.5880$
Atmosphere; $C_R = 0.1977$
For Salt water; $C_R = 1.0622$
For Fresh water; $C_R = 1.0010$

To provide minimum uncertainty in the corrosion rate, this method implicitly assumes: the corrosion rate does not vary with exposure time, the area does not change as mass is lost to corrosion, the projected and actual surface areas are the same, the penetration rate is uniform over the entire surface, the weight is unaffected by corrosion product removal, and Even assuming that the above criteria are fulfilled, errors can still be propagated because of the uncertainty in the measurement of time, mass, and dimensions [10].

3 EXPERIMENTAL RESULTS AND DATA ANALYSIS

3.1 Experimental Results

The weight loss and corrosion rate of metal depend to a large extent on a number of factors. The weight loss and the corrosion rate of the different mild steel samples were calculated and shown in tables 1-3. These values where then graphically represented in fig. 4 and fig.5.

TABLE 1
WEIGHT OF COUPONS IN GRAMS

Media	Initial	Week 1 168 hr	Week 2 336 hr	Week 3 3504 hr	Week 4 672 hr	Week 5 840 hr
0.1MHCL	76.5325	75.2104	74.9812	73.1423	71.2532	68.7823
Soil	76.5325	76.5237	76.4972	75.3928	73.3316	72.4259
Atmosphere	76.5325	76.5281	76.5121	76,4857	76.0619	76.0212
Saltwater	76.5325	76.5016	75.5536	74.7882	73.8015	73.7856
Freshwater	76.5325	76.5253	76.4612	75.8054	74.8223	73.9441

TABLE 2
WEIGHT LOSS OF COUPONS

| Media	Week 1 168 hr	Week 2 336 hr	Week 3 3504 hr	Week 4 672 hr	Week 5 840 hr
0.1MHCL	1.3221	1.5513	3.3902	5.2793	7.7502
Soil	0.0088	0.0353	1.1397	3.2009	4.1066
Atmosphere	0.0044	0.0204	0.0468	0.4706	0.5113
Saltwater	0.0309	0.9789	1.7443	2.7310	2.7469
Freshwater	0.0072	0.0713	0.7271	1.7102	2.5884
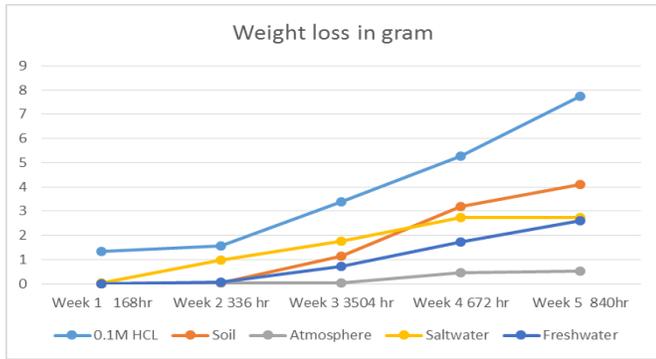
Fig. 4. The graph of Weight loss against Time

TABLE 3
WEIGHT LOSS OF COUPONS

| Media	Week 1 168 hr	Week 2 336 hr	Week 3 504 hr	Week 4 672 hr	Week 5 840hr
0.1MHCL	2.5563	1.4997	2.1850	2.5519	2.9970
Soil	0.0170	0.0341	0.7345	1.5473	1.5880
Atmosphere	0.00851	0.0197	0.0302	0.2275	0.1977
Saltwater	0.0597	0.9464	1.1242	1.3201	1.0622
Freshwater	0.0139	0.0689	0.4686	0.8267	1.0010
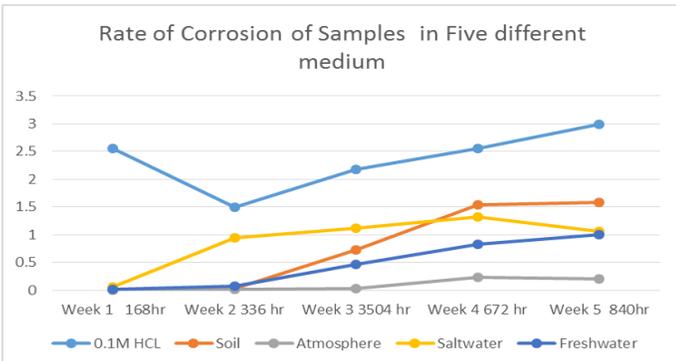
Fig. 5. The graph of Rate of corrosion against Time

3.2   Physical Changes Observed on the Coupons during the Experiment

The specimens exhibited different features in terms of color, texture, surface appearance, type and size of the corrosion products on the metal. The physical features observed in the different media are discussed.

I. Salt Water (Salt Solution)

By the end of the first week the mild steel rod showed patches of grey and black on its surface. Between the third (3rd) to fourth (4th) week about 50 -80% of the surface became 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 inside. The base of the pits was grey in color. The remaining surface was black. Generally at the fourth (4th), the water appeared dark yellowish brown with brown particles at the bottom.

II.   Fresh Water

By the end of the first and second week the mild steel rod showed patches of grey corrosion products with light brownish water color. Also, the mild steel rod had shinny smooth grey surfaces with black patches at the edges. At the third to the end of the fourth (4th) week the water appeared dark yellow with brown corrosion patches at the bottom.

III.   0.1M Hydrochloric Acid

The mild steel rod coupon showed severe uniform corrosion. At the end of the first (1st) week the mild steel rod had shinny smooth grey surfaces and the 0.1M hydrochloric acid turned to light green, up to the second (2nd) week with grey patches underneath the media. At the end of the third (3rd) week the color of the 0.1M hydrochloric acid turned to brown yellow up to the end of the fifth (5th) week with heavy brown corrosion patches which settles underneath the media.

IV.   Underground (Soil)

The sample appears to have high corrosion rate starting from the fourth to fifth week when compared to the first three weeks of the experiment.

V.   Atmosphere

This also appears to have formed oxide films in the middle of the first week, which reduces the rate of corrosion. The corrosion rate and weight lost were very low , hence decreases as the time increases.

3.3 Kinetics and Mechanisms of Corrosion observed

Three of the mild steel coupons were exposed to liquid environments, which include changing the content of the test media every seven days before re-immersing. One of the mild steel rod coupons was exposed to the atmosphere while the remaining one was buried in the soil.

3.4 Result Analysis

The results of the experiment obviously show that corrosion occurred, because weight losses were evident. But interestingly the rate of corrosion for the various specimens varied increasingly in the following trend: 0.1M hydrochloric acid, underground (soil), salt water, fresh water and atmosphere. The specimen in hydrochloric acid experienced what is considered in engineering literature as chloride aggressiveness. The presence of halide ions breakdown any passive films available and can sometimes prevent passive films from forming on the mild steel rod.From fig.4, the specimen in the soil also experienced high corrosion rates towards the third week because of the presence of anaerobic bacteria and available oxygen accounted. It is believed that in the first two weeks the micro-organisms present where making available the necessary corrosive media combined with the available oxygen and soil pH, corrosion increased at a rapid rate. The soil had a pH of 5. The corrosion rate observed for the specimen in the atmosphere was low; this was as a result of the components of the atmosphere, Constant processing of chemicals do not take place in the place where the mild steel rod was kept and so the emissions of various corrosion stimulating gases was reduced. In table 3, from the first three weeks, the corrosion rate was really slow then became rapid between the third and fourth week, this occurred when the passive films that were formed between the first and third week broke down and thus corrosion commenced, but the

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weight loss in general was small when compared to the specimens in the rest of the environments. The types of salts present in salt water (salt solution) media were critically not accounted for and the corrosion rate was not too intense.For the fresh water the corrosion was slightly high at the start of the experiment then continued at an approximate constant rate with a small increase at the last week of the experiment, the low amount of ions in the water was responsible for this behavior since the available oxygen and the medium will form a corrosion cell and initiate the corrosion process until passive films were formed when the rate became constant.

4　OBSERVATIONS AND CONCLUSION

4.1 Observations
At the end of the experiment the following observations were made;
- Corrosion will proceed at a faster rate in the presence of ions.
- In the absence of potential pollutants in the atmosphere, corrosion will proceed at a controllable rate.
- Micro-organisms by their metabolic activities tend to provide corrosion stimulating ions especially in swampy areas and hence increase corrosion rate.
- In the presence of an acid, corrosion can prove detrimental in a short period of time.
- Corrosion rate in the acidic medium is faster than in salt water, atmospheric, fresh water and salt soil medium.
- The rate of corrosion is proportional to the time of exposure.
- The rate of corrosion of mild steel in the various media decreases in the following manner: 0.1M Hydrochloric acid, underground (soil), salt water, fresh water and the atmosphere.

4.2 Conclusion
The laboratory immersion test remains the best method of screening and eliminating from further consideration of those metals that should not be used for specific applications. But while these tests are the quickest and most economical means for providing a preliminary selection of best suited materials, there is no simple way to extrapolate the results obtained from this simple test to the predictions of systems service lifetime. Hence the following recommendations; Mild steel should not be used in an acid environment, Mild steel is suitable in atmospheric environment, Mild steel to be used in salt water environment should be coated to achieve a useful service life and with minimum maintenance, Preventive measures can be used in order to slow down the rate of corrosion of mild steel in different environments.

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