

EXPERIMENTAL STUDY ON CORROSION OF STEEL IN SOIL MEDIUM

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Abstract

There are many practical situation where steel is exposed to soil. Deterioration of steel in such case it depends upon the nature of soil, more especially the types and the concentration of ions present in the moisture within the soil, since soil vary in nature it is necessary to understand the nature of corrosion of steel in each of soil samples. This aspect was taken for the investigation and present in this paper. The weight and electrochemical methods of evaluating the corrosion rate were used in which four types of soil available around SRM university campus were utilized during the experimental work. Steel coupon of 12mm diameter and 100mm length was used, for each soil three artificial environments were created and electrochemical potential measuring was made for five weeks. The test shows that presence of chlorides ions in the soil create very severe environment and the drying of soil reduce the rate of corrosion.

Keywords, Corrosion of steel, Soil, Weight method, Electrochemical potential method

1. INTRODUCTION

Corrosion has been the subject for scientific study for more than 150 years.

It is the destructive attack of a metal by chemical or electrochemical reaction with its environment. Deterioration by physical causes is not called corrosion, but is described as erosion, galling, or wear. In some instances, chemical attack accompanies physical deterioration, as described by the following terms: corrosion – erosion, corrosive wear, or fretting corrosion. Nonmetals are not included in this definition of corrosion. Plastics may swell or crack, wood may split or decay, granite may erode, and Portland cement may leach away. “Rusting” applies to the corrosion of iron or iron - base alloys with formation of corrosion products consisting largely of hydrous ferric oxides. Nonferrous metals, therefore, corrode, but do not rust [9]

Corrosion can cause damage to everything from pipelines, bridge, and public building to vehicle, water and wastewater system and even home appliances. Losses sustained by industry and by governments amount to many billions of dollars annually, approximately \$ 276 billion in the United States, or 3.1% of the Gross Domestic Product (GDP), according to a recent study [5] . It has been estimated that about 25 – 30% of the total could be avoided if currently available corrosion technology were effectively applied[5]Studies of the cost of corrosion to Australia, Great Britain, Japan, and other countries have also been carried out. In each country studied, the cost of corrosion is approximately 3 – 4 % of the Gross National Product [6]

In the world today, mild steel is used in different Engineering applications for the production of some automobile components, structural shapes (I, channel, angle etc.) and sheets which are used in pipelines, buildings, plants, bridges and tin cans. Mild steel pipelines and structures are usually expected to have a long working life. Similarly, Steel which is known for its high carbon content (about 0.2% to 2.1 %) has manganese 1.65%, copper 0.6%, silicon 0.6%. It has outstanding ductility and toughness, high machinability and weldability which make its applications possible in the diverse engineering fields. 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. Many constructions vital to the community are placed underground and thereby exposed to the corrosive action of soil. Water mains and sewers, steel pipelines for natural gas develop perforations, steel tanks for fuel oil and gasoline leak due to soil corrosion, lead sheathed telecommunications cables perforate by soil moisture, steel piling for the foundation of buildings, houses, and bridges in corrosive soils become susceptible to settling; the steel foundations and anchoring stays in power pylons, corrosion will damage pylon foundations and stays which will lead to a drastic disturbance in the supply of electricity to the country. Therefore studying the corrosivity nature of the soil is very important for the efficiency and safety of our infrastructures. The risk of corrosion needs to be estimated before the installation of underground structures.

Iron and many other metals used in underground constructions been coated with a thin film of oxide immediately after being exposed to air. Such a film on iron may be merely a few molecular thickness but, nevertheless, furnishes some degree of protection against further oxidation or corrosion. At sufficiently high temperatures oxygen can diffuse through, around, and under these films so that the film is increasing in thickness, forming scale that may flake off to expose fresh surfaces for the continuing reaction. Most of the corrosion of iron (and other metals) in underground service at normal or moderate temperature is the result of an electrochemical reaction. Numerous problems related to soil impact in embedded steel structures are due to the unfavorable interaction between water and soil. Underground soil corrosion is primarily influenced by the following factors:

- Presence of soil moisture,
- Supply of oxygen,
- Redox potential,
- pH value,
- Soil resistivity, Microbial activity.

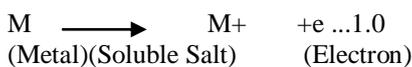
1.1 Mechanism of Soil Corrosion:

The corrosion process consists of four essential elements.

- (a) An anode,
- (b) A cathode,
- (c) An electrolyte, and
- (c) An electrical conductor connecting the cathode to anode.

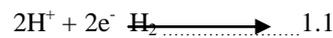
An electrolyte can be any liquid, paste, or gas, which can conduct electricity by the migration of ions. In the case of underground corrosion, the electrolyte is the moist or water in the soil.

Corrosion is an electrochemical process that involves the passage of electrical currents on a micro or macro scale. The change from the metallic to the combined forms occurs by an “anodic” reaction:

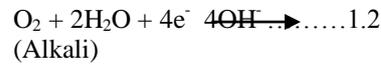


This reaction produces free electrons, which pass within the metal to another site, on the metal surface (the cathode), where it is consumed by the cathodic reaction shown below:

In acidic soils, the cathodic reaction is:



In neutral soils, the cathodic reaction involves the consumption of oxygen dissolved in the soil moisture.



Corrosion thus occurs at the anode but not at the cathode (unless the metal of the cathode is attacked by alkali). The OH⁻ ions react with Fe²⁺ ions to form ferrous hydroxide (corrosion products) according to equation:



When the cathode and anode are closely situated and the pH value of the soil is greater than about 5, the corrosion product can form a coating which will provide some protection to the steel surface. Under certain conditions, however, the anode and cathode can be more widely separated and in extreme cases on a pipeline or a cable by as much as one or two kilometers. The metal ions formed at the anode will migrate with the current towards the cathode and the OH⁻ ions formed at the cathode will migrate towards the anode. The corrosion products are then precipitated somewhere between the anode and Cathode. They therefore do not provide any protective coating to the anode. As a result pitting can occur at the anode, with the surfaces showing shiny metal. If the cathode area is much larger than that of the anode then the anodic current density will be high resulting in a high rate of pitting. Localized corrosion can lead to perforation and major damage; for example, oil tanks or pipes whereas single pits are of less importance for load-bearing structures such as steel piling.

In order to understand the nature of soil around the campus with the reference to its corrosion nature, sample of different location were drawn and used for embedding the steel specimen. The nature of corrosion was monitored by the loss of weight of the steel coupon and measuring the electrochemical potential of corrosion using Cu/CuSO₄. Accelerated corrosion rate of steel was introduced by adding sodium chloride solution to the soil. These tests data relates to observation for the period of 12 weeks for weight methods and five weeks for electrochemical potential method.

Table – 1: Detail of soil samples in grams

Sample ID	Location of sample	Nature of soil classification as per ASTM D 2487 - 06	Coefficient of uniformity
S1	Lake soil	Sand	8.57 > 6
S2	East Potheri	Gravels	6.0 > 4
S3	Main building	Sand	8.51 > 6
S4	Aerospace laboratory	sand	8.95 > 6

2. DETAIL OF EXPERIMENTAL WORK

2.1 Soil Media

About 9kg of each soil sample was collected from four location described in table 1

2.2 Steel Coupon

Steel coupon used was HSD bar of 12mm and 100mm length. Each test specimen was cleaned with brush before putting the coupon in the soil.

2.3 Placing the Steel Coupon in the Soil Sample for Corrosion Measurement by Weight Method.

4.5kg of each of the sample was placed in the plastic tray (220 x 100 x 140) mm. the depth of the soil in each was about 80mm and the steel coupon was placed at the mid depth of the soil as shown in figure 1



Fig – 1: Soil sample

2.4 Placing the Steel Coupon in the Soil Sample for Corrosion Measurement by Electrochemical Potential Method.

For each soil sample following exposure condition were generated

- (i) Natural soil condition
- (ii) Soil mix with water corresponding to optimum moisture content(OMC)
- (iii) Soil mixed with 5% of sodium chloride solution (5% solution was prepared by dissolving 5grams of sodium chloride (salt) in 95 grams of water.

2.5 Weight Measurement on Steel Coupon

A digital balance of 200 grams capacity and having an accuracy of 0.1 milligrams. Initial weight of steel coupon was taken before placing the coupon in the soil media. After interval of two weeks the specimens were taken out from the

tray and manually cleaned with wire brush to remove the corrosion product.

2.6 Electrochemical Potential Measurement

Cu/CuSO₄ reference electrodes was prepared using a plastic tube of diameter 20mm and 1005mm length and filled with saturated Cu/CuSO₄ solution copper rod of 3mm diameter was used as an electrode, the end of the tube was sealed with wooden plug the wooden material being forests gives electrical conductivity between the reference electrode and the soil. The copper electrode is connected through conventional wire electrochemical potential reading was recorded on high impedance voltmeter as shown in figure 2



Fig – 2: Open Circuit Potential Test

3. TEST RESULT AND DISCUSSION

3.1 Corrosion Rate through Weight Method

For each exposure time t , weight loss of each test coupon was computed by the following equation

$$CR = (k \times \Delta w) / A \times T \times \rho \dots \dots \dots 2.0$$

Where:

CR= corrosion rate mm/yr.

k = Constant for unit conversion (8.76×10^4)

Δw = weight loss in gm.(weight at the beginning of the test - weight at the end of the test)

A = Exposed surface area of Coupon cm^2

T = Time of exposure in hours,

ρ = Density of mild steel ($7.86\text{g}/\text{cm}^3$)

Table - 2a: Weight of steel coupon in grams

Soil media	Exposure time (Week)						
	(0)	(2) (336HR)	(4) (672HR)	(6) (1008HR)	(8) (1344HR)	(10) (1680HR)	(12) 2016HR
S1	88.9178	88.8178	88.5512	87.4845	85.9814	83.8803	81.2484
S2	88.9178	88.7178	88.3415	87.3914	85.7402	83.2287	80.2116
S3	88.9178	88.6177	88.3000	87.5412	86.1402	84.3061	81.6290
S4	88.9178	88.5627	88.4399	87.6098	86.0065	83.7711	80.8830

Table - 2b: Weight loss of Coupons in grams

Soil media	Exposure time (Week)						
	(0)	(2) (336HR)	(4) (672HR)	(6) (1008HR)	(8) (1344HR)	(10) (1680HR)	(12) 2016HR
S1	0.0000	0.1000	0.2666	1.0667	1.5031	2.1011	2.6321
S2	0.0000	0.2000	0.3763	0.9501	1.6512	2.5115	3.0171
S3	0.0000	0.3001	0.3172	0.7588	1.4010	1.8341	2.1771
S4	0.0000	0.3551	0.3779	0.8301	1.6033	2.2354	2.8881

Table - 2c: Rate of Corrosion in mm/yr

Soil media	Exposure time (Week)					
	WEEK 0 to 2 (336HR)	WEEK 2 to 4 (672HR)	WEEK 4 to 6 (1008HR)	WEEK6 to 8 (1344HR)	WEEK 8 to 10 (1680HR)	WEEK10 to 12 (2016HR)
S1	0.0830	0.1106	0.2951	0.3119	0.3488	0.3641
S2	0.1660	0.1562	0.2629	0.3426	0.4169	0.4174
S3	0.2491	0.1319	0.2099	0.2907	0.3044	0.3703
S4	0.2948	0.1568	0.2297	0.3327	0.3711	0.3999

Table - 3: Corrosion rate result for the total duration

Soil media	INITIAL WEIGHT(g)	FINAL WEIGHT(g)	WEIGHT LOSS FOR THREE MONTH (2016HR)	CORROSION RATE mm/yr
S1	88.9178	81.2484	7.6694	1.060
S2	88.9178	80.2116	8.7064	1.204
S3	88.9178	81.6290	7.2888	1.0
S4	88.9178	80.8830	8.0348	1.111

Charts for weight loss and corrosion rate for the experiment

Weight loss

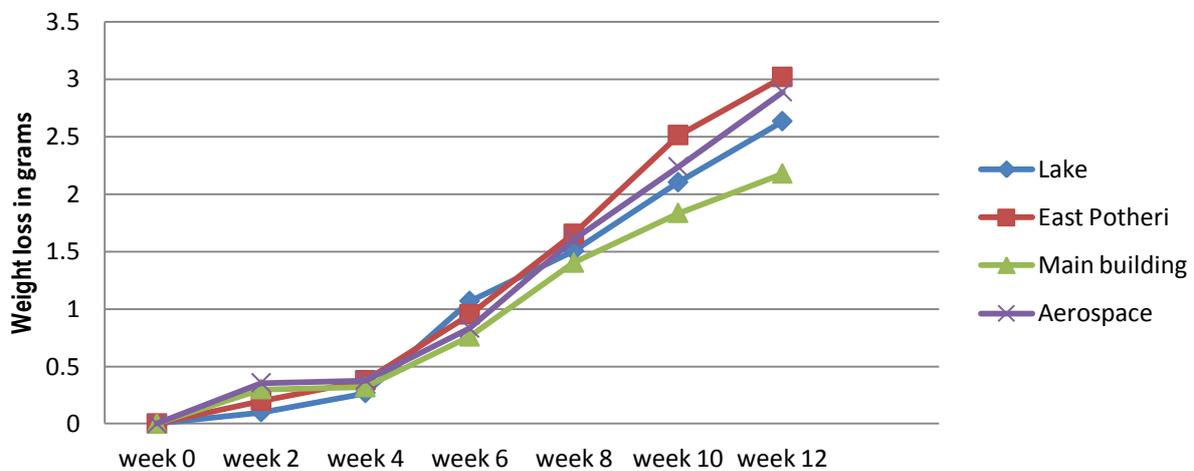


Chart - 1: graph of Weight loss against Time

Corrosion rate

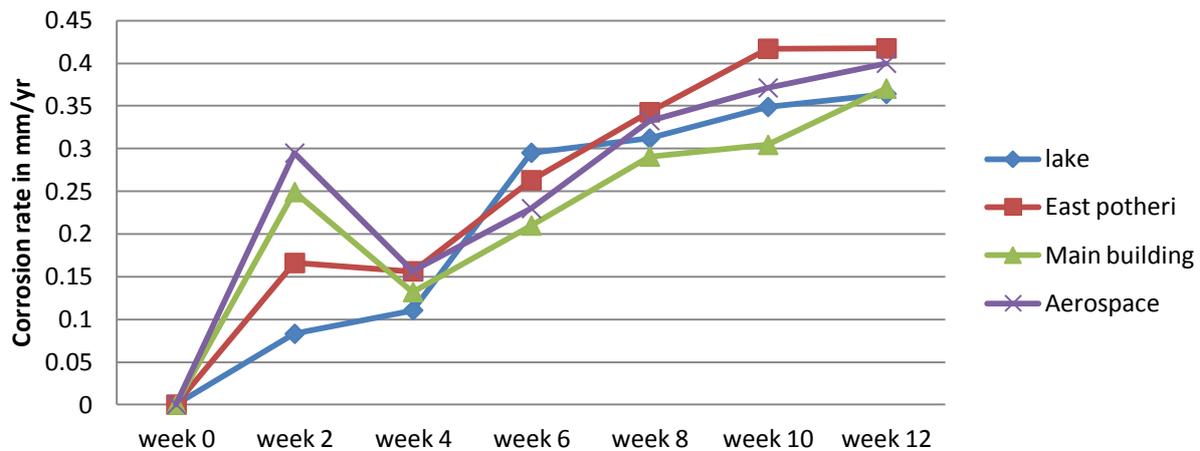


Chart - 2: graph of corrosion rate against Time

The test given in table 3 indicates that the corrosion rate in the soil is around 1mm/yr. This rate is very high compared to corrosion rate given in published literature. In one of the references the corrosion rates in moving sea water (i.e. flowing water) is around 8mil/yr corresponding to 0.2mm/yr by Table SP-B1 of ASME B31.8S. The reason for this is being explored; it looks that the methods of removal of corrosion product from the test specimen need to be modify suitably the use of cleaning procedure given in ASTM G1.

3.2 Electrochemical Potential Measurement

Electrochemical potential result for corrosion rate (mV).using copper/copper sulphate half-cell electrode. The probability of the corrosion activity was given by ASTM C-876 using a copper/copper sulphate half-cell ,For readings of -350mV and greater there is a 95% chance of active steel corrosion, For readings -200 to -350mV there is a 50% chance of active steel corrosion, For readings less than -200mV there is only 5% chance of active steel corrosion.

Table - 4: Electrochemical potential measurement in millivolt (mV)

WEEKS	STATE	POTHERI SOIL	AEROSPACE SOIL	LAKE SOIL	MAIN BUILDING
0.	NATURAL	-347	-420	-280	-370
	OMC	-490	-449	-530	-509
	Nacl	-568	-525	-539	-551
1.	NATURAL	-225	-300	-149	-187
	OMC	-599	-565	-557	-500
	Nacl	-610	-589	-560	-619
2.	NATURAL	-227	-205	-157	-185
	OMC	-434	-442	-468	-496
	Nacl	-524	-590	-560	-600
3.	NATURAL	-185	-165	-165	-197
	OMC	-350	-249	-233	-306
	Nacl	-468	-540	-509	-513
4.	NATURAL	-170	-121	-131	-154
	OMC	-327	-184	-150	-234
	Nacl	-414	-491	-483	-472
5.	NATURAL	-147	-104	-113	-141
	OMC	-282	-165	-134	-218
	Nacl	-380	-466	-429	-412

- (1) The data given in table 4 indicate that soil in natural moisture condition is less compared to OMC and salt water.
- (2) Soil mixed with sodium chloride solution recorded most negative electrochemical potential values indicating probability of higher corrosion rate
- (3) For each exposure condition there seem to be non-significant different between electrochemical potential measured in the four types of soil taken, thus it looks the nature of corrosion of steel is almost similar in the entire soil sample taken because the classification of the three soils sample is the same. However, the actual exposure condition determines the rates of corrosion.

4. CONCLUDING REMARKS

- (1) Weight change as the measure of corrosion rate requires carefully preparation of specimen before exposing them to corrosion media and proper cleaning procedure to remove the corrosion product forms so that the base metal is not removed during the cleaning process.
- (2) Electrochemical potential measurement are suitable enough to record the degree of corrosivity of the soil media Cu/CuSO₄ reference electrode was found to be useful to evaluate the corrosion of steel in soil media
- (3) The soil sample in the SRM campus seems to be similar with reference to corrosion of steel.
- (4) Table 3 shows that the gravel soil has the higher corrosion rate.

RECOMMENDATION

The experimental procedure described in this paper can be used to evaluate the different soil sample for the corrosivity particularly related to steel.

However the procedure need to be refine to get practically usable test reading

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