Corrosion in Underground condition of Mild Steel plates in various soil varying textures

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Abstract: **The effect of soil and its mechanical properties on the steel metal plates is studied by using weight loss methods and electrochemical impedance spectroscopy. It is observed that intensity of attack and corrosion rate are dependent on soil texture and content of moisture in it. Corrosion rate is higher in clayey soil than in mixed and sandy soils. It is observed from the study that mild steel undergoes only less violent surface-level corrosion in studied duration when buried underground.**

Keywords: **Soil, Corrosion, Texture, Metal, Underground Condition, Mild Steel.**

Introduction

Soil is one of the most corrosive medium found in World, but it is very difficult to study its nature of its corrosivity because of its diversification. Corrosion is one of the most challenging problems in many industry as well as in construction and infrastructure industries where metals are directly gets in contact to various soil environments throughout their designed life. Several studies on corrosion in soil[1-7] havs given useful information on soil's overall properties and physico-chemical properties such as chloride ions, sulfate ions and organic matter, and conductivity, which influence the rate of the corrosion of the soil, making corrosion a rapid and firm process [8-11.] The physico-chemical characteristics of soil vary by geo-environmental nature of the soil, characterized by a porous heterogeneous and discontinuous environment, which consists of an organic phase including various minerals or solids, liquid phase of water and gas phase consist of air or gas. The most common types of corrosion in general environment are pitting, which is the result of material inhomogeneities; chloride- or sulfate- induced corrosion; concentration cell corrosion arising due to the difference in oxygen concentrations of the soil in contact with the metal at different regions; and microbial corrosion. Studies have shown that localized corrosion such as pitting depends on environmental and soil parameters, which may be littlebit different from normal corrosion occurring due to less moisture content. The relationship between physicochemical properties and soil corrosivity is very complex, making the evaluation of soil corrosiveness by these parameters unreliable.

Many factors like soil moisture, ionic salts concentrations , water or moisture content, soil resistivity and texture-related properties such as sand, clay, depth to clay pans or sand layers are found to highly influence corrosion [12-18]. Several methods and techniques that attempted to define the relationship between soil parameters and corrosivity [19-21] unable succeed because soil chemistry parameters were indicative of only the tendency of the soil that is corrosive or not in nature. Above factors were impotent of providing information on the corrosion rate accurately in the field conditions. This clearly inform that there are other more factors significantly controlling the conditions of variations in soil corrosion. To understand the exact problems and design an proper protection system, considerable research under field conditions was conducted[5, 8, 15, 24] . Many studies has defined corrosivity of the soil in terms of moisture content, soil types and soil aggressiveness based on laboratory test results. However, apart from these vital parameters, the corrosivity of the same soil varies in the field conditions due to seasonal fluctuations up to 50% on precipitation and 20% due to temperature. Though the influence of individual factors and their impact on the corrosivity have been studied in detail, research on how the interactions of these factors infiuence corosivity is scant.

In the recent past, no detailed field study on soil corrosion has been performed in Indian soil conditions. Gupta etal. have examined the corrosion of mild steel in the native soils for a short duration in a few places in northern part of India. The extent of corrosion due to variation of moisture content at a depth of 1m from the ground level was reported in their study in the late 1970s. Previous researchers have successfully investigated soil corrosion by employing the weight loss method for buried coupons under different depths and electrochemical measurements using soil [22-24] or using the soil extract solution (SES) as an electrolyte [25-28]. Electrochemical impedance spectroscopy (EIS) has been successfully used for many years in the study of corrosion of materials and has proven to be an accurate method to determine the corrosion speed. In the present work, mild steel gets in touch with nature and environment at selected location in Maharashtra near Akola assessed by determining the texture of soil, particles size and moisture content at different time periods. This work aims to provide an insight into the extent of corrosion of steel in under ground condition with soil in the field conditions by estimating rate of corrosion and by performing analysis of surface profile and microstructure analysis.

Experimental Work

Geographical Information of Selected Area
The experimental site is located in Akola, Maharashtra in India.

The average annual temperature in Akola is 26.9 °C | 80.3 °F. The driest month is April, with 3 mm | 0.1 inch of rain. Most precipitation falls in July, with an average of 301 mm | 11.9 inch. The highest maximum temperature recorded at Akola was 47.8 C (118.0 F) on May 22, 1947. The lowest minimum temperature was 2.2 C (36.0 F) on February 9, 1887.

Soil Sampling

Subsoil Properties. Soil profile analysis involved the study of gradation properties and geotechnical properties, which comprise moisture content, liquid limit, plastic limit and plasticity index, carried out as per BS 1377:1990 (BSI 1998). Moisture content was determined as per ASTM D2216 by calculating the loss of water by heating the pre-weighed sample At 105 C at 24h. The difference in the mass of the sample was taken as % moisture content (MC). A moisture meter (EX TECH soil moisture meter MO 750) was also employed for measuring moisture. Atterberg limit tests (liquid limit, plastic limit and plasticity index) were conducted on 30 samples collected from different depths. Gradation analysis of 30 soil samples was conducted according to ASTM D 422. A known mass of dry soil was transferred into a stack of sieves ranging from 0.075 to 2 mm. The stack sieve was run through a shaker for 10-15 min, and the amount of soil retained on each sieve was weighed and recorded. Quantification was done using the simple statistical method. The mean size by average was calculated for all the natural soils collected, and the texture of the soil at each site was determined. Hydrometer analysis was carried out to record the grain size of the soil, which was in the range 0.073 to 0.0004 mm.

Distribution of Particles size in the Soil.

Particle size distribution (PSD) in soil is one of the most fundamental physical factors that directly contribute to underground soil corrosion because of its strong influence on water-holding capacity and oxygen movement. The sampling in this study involved obtaining steel samples buried at three different zones: at depths of 1 m (N1), 2 m (N2) and 4 m (N3). In general, the soils in the district are slightly alkaline in reaction. Alkalinity increases with depth in the case of deep soils. They are clayey in texture and contain sufficient free calcium carbonate. They are base saturated, divalent ions constituting more than 90 per cent of the total exchangeable bases. The soils are well supplied with nitrogen but the medium to poor in available phosphate and available potash.

Table 1 Soil profile, mechanical properties.

Sample No.	Depth of Metals	pH	Mechanical Properties (%)		
			Clay	Slit	TSS
N1	0.5m	8.6	49	18	0.20
N2	1m	8.8	52	19	0.22
N3	1.5m	8.9	54	11	0.22

In the present study, the selection of site varied extensively based on the type of soil and the particle size of the soil system, namely N1, N2, N3. Hence, the corrosive system for the metal is expected to be different in each zone. The city can be classified in majorly three regions based on the nature of the soil: i) sandy areas along the river banks and coasts, ii) other areas with clayey texture and iii) some areas that are hard rock. The nature of samples of soil collected from the study site is generally clayey in nature. However, the cross-sectional subsoil profile of the sample across the field has been found to be different. As we see from Table 1, the soil in the test site is slightly alkaline with a pH of 8.6-8.9. The conductivity of the soil, measured in terms of electrical conductivity, which is mostly depends on the dissolved salt contents in it. It was observed to be in the range 100- 170 mho/cm. Aggressive chloride ions induce the onset of corrosion on the metal and strongly influence the corrosivity. The measured chloride content in the soil varied between 200 and 400 ppm, which is assumed to be mildly corrosive. The classification of soil aggressivity in the study area is based on soil conditions and was done according to the Murray standard[22]. As per this standard, the soil was found to be mildly corrosive. The moisture content of the natural soil is in the range of 20-25% in the N1 zone and 30-40% in the N2 zone, whereas the S3 zone was below the water table. Total organic matter in the study site is less than 10% with negligible content of the sulfate and carbonate.

Techniques
Gravimetric Weight Loss Measurement.
The entire experiment was conducted between October 2020 and November 2017 (13 months). The coupons were retrieved from each borehole site with the help of a crane at a time interval of 3 months, and the weight of the coupon after retrieval was determined after chemically removing the corrosion products following the procedure stated in ASTM G103(ASTM 2004). Every sample was assumed to be uniform in terms of strength and corrosion resistance. Hence, metal weight loss measurements are used to calculate average corrosion rate:

Corrosion rate $kWA=ADT$

where k is a constant, W the weight loss, A the surface area, D the density of the metal, and T the exposure period.

Result and Discussion
Weight Loss Measurement
The weight loss of the coupons was observed to increase linearly with time initially, and the corrosion rate also increased with time initially. Thereafter, the corrosion rate started to decline gradually with time. This could be because weight loss represents a

cumulative effect and is a more gradual process. After the samples were buried in 2020 (the rainy season), the first set of samples were retrieved after 3 months (winter). The rate of the corrosion in N1 after first 3 months as calculated from Eq 1 was 4.53 mpy. The corrosion rate in N2 and N3 after 3 months was 1.06 and 0.18 mpy, respectively. This clearly shows that the samples in N1 zone affected faster than those in N2 and N3 regions. It is observed that corrosion started to occur, as evident from rust formation, only after 6 months. The trend of change in corrosion rate is declined rapidly. We infer that the higher corrosion rate observed in the samples in N1 zone is because of the higher water-holding capacity of clayey soil as it carries a higher charge density, as compared to N2 and N3 soils, and a higher moisture content (20-25%).

Visual observation of the metal specimens revealed rust formation (dark brown color) over the metal surface with spotted pits. It is well known that the corrosion rate of the metal in the soil increases with an increase in moisture content till a critical moisture content (CMC) is reached. In the N2 zone, silty clay mixed soil has a plasticity index of 27%. The moisture content in the range of 30-35% is above the CMC, which indicates water saturation. The mixed silty clay, when spread over the surface, increases liquid dispersion, which accelerates corrosion. On the other hand, corrosion affects dissolution and diffusion in the bulk solution so that the water forms a liquid membrane around the silty clay, facilitating the diffusion of oxygen, which turns the sandy soil system more corrosive. However, the corrosion rate is low at the N3 zone, which is below the water table, because water surrounding the metal primarily controls the rate of diffusion of dissolved oxygen in the sandy soil system, which lowers the corrosion rate. Then the corrosion process is controlled by the charge transfer process, and then the overall process is controlled by a combination of activation and diffusion control. During the whole exposure period, the diameter of the arc at the higher-frequency region increases with an increase in depth level. This trend clearly indicates that the resistance of the metal is inversely related to the corrosion rate. The corrosion rate of the metal exposed to soil when placed underground was in the order N1 > N2 > N3.

In this current study, one time constant was observed for all the corroded specimens collected from the study site. This is because the distribution of corrosion products occurs over the metal surface, but the corrosion product formed over the metal is not sufficient to form a complete corrosion protective film. Hence, the film cannot play a protective effect on the metal substrate. During the whole exposure period, only a small amount of rust was formed on the metal surface, and no thick protective rust layer was formed. The EC parameters can be obtained by fitting the EIS are tabulated in Table 2.

Table 2. Parameters obtained by experimental data.

Sample No.	R_f			R_{ct}		
	R1, Ω cm^2	R2, Ω cm^2	C1	R3, Ω x cm^2	Q2, Sn Ω cm^{-2}	W3,S-0.5Ωcm^{-2}
N1	32.38	32.44	9.254E-9	32.87	1.324	1.87E-2
N2	101.14	87.24	1.014E-9	96.65	2.345	3.76E-3
N3	158.32	88.42	8.921E-9	167.43	0.462	6.35E-3

Surface Analysis

The affected specimens due to corrosion can provide some insight into the behavior of corrosion in different environments. The visual observation of all the coupons was performed, and few rusted samples from N1, N2 and N3 are shown in Fig1. It is found that most of the shiny surface of the specimens had turned dark brown, indicative of the adsorption of rust over the metal. However, corrosion pits were observed in a few spots of the coupons from N1 and N2.

Depth Profile

The depth profiles of the de-rusted surfaces of the steel coupons were analyzed by using a profilometer (Zeiss surfcom 1400G). They were used to calculate the surface roughness (Ra), the values of which are given in Table 3. To compare the distribution of pit on the surface of the coupons, we defined Lpit as the pit-covered length in millimeters. The results indicated that the number of pits and roughness value (Ra) were higher in case of the specimens from N1 than those from N3.

Table 3 Surface roughness (Ra) of the mild steel coupons measured by using profilometer.

Sample No.	Average surface roughness Ra value, lm
N1	9.5315
N2	7.2389
N3	5.6765

Conclusion

The corrosion behavior of mild steel exposed to native soil for a long period in the tropic region of India was studied at selected sites of varying depths from the ground level. The nature of the soil was found to be different in different zones, namely clay (N1) to sandy (N3) and mixed soil of clay and silt in the middle level. The instantaneous corrosion rate of the rusted mild steel after 13 years of exposure was measured in the soil electrolyte medium by electrochemical impedance spectroscopy (EIS). The results obtained allowed us to propose a qualitative model for their surface structures. Rate of corrosion decreases with an increase in time in all the metal coupons as can be inferred from the technique weight loss measurements. Generally corrosion with localized pitting happened during the exposure period. The composition of the corrosion products analyzed. PDP test revealed that I_{corr} decreases in the samples going from N1 to N3. The results of EIS reveal that the R_{ct} value increases in samples going from N1 to N3, which is related to charge transfer control of the corrosion process (R3) and decreasing trend of film resistance (R2) related to metal coverage by an in homogeneous, porous and defective layer. The appearance of a Warburg element in the equivalent circuit (EC) is correlated with the diffusion of reactive species through the pores of the rust layer. It is also found that physical blocking of the active sites has not happened even during this longer exposure period.

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