

ON CORROSION OF FERROUS METALS IN TYPICAL INDIAN SOILS PART II—MILD STEEL

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Corrosion of mild steel in ten Indian soils, employing Schwerdtfeger's soil corrosion cell procedure, has been studied. The results have been analysed and correlated with various factors. The study reveals that the rate of corrosion in non-acidic soils is maximum at the beginning gradually decreasing with time. The soils of moisture equivalents ranging 25-30% are most corrosive. Direct chemical corrosion has been found to be very predominant in acidic soil.

Carbon and alloy steels are very extensively employed for the construction of materials in underground service. The most important applications are storage installations, distribution and transmission pipelines (for water, gas and petroleum), pilings, drill pipes, casings (for water and oil wells) and guy ropes^{1,4}. The plain carbon steels are the most important group of engineering materials. They represent by far the major percentage of steel production⁵.

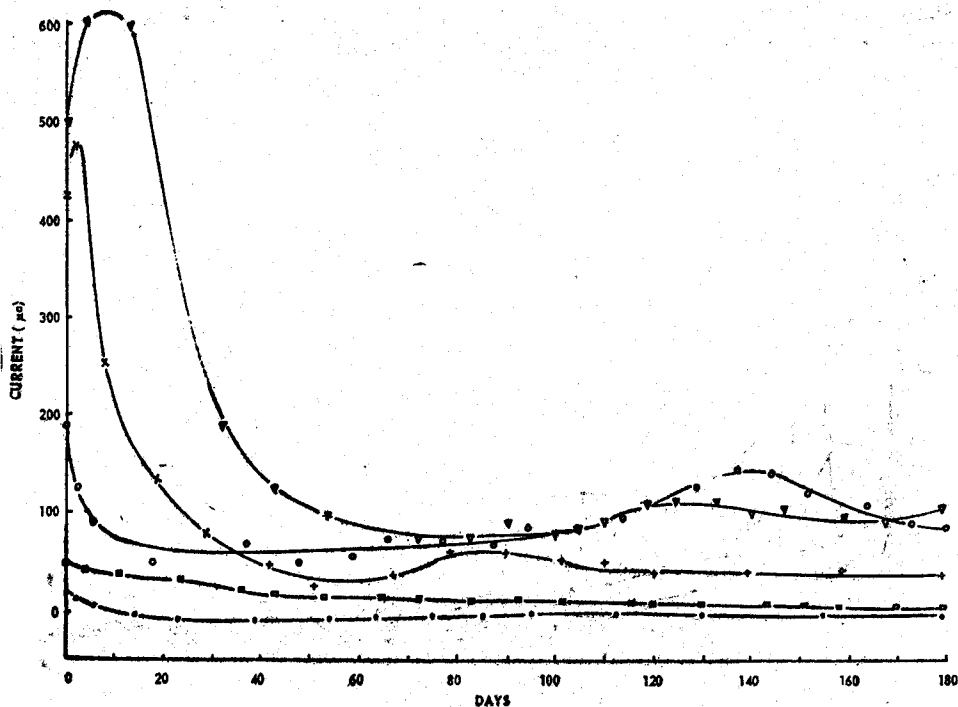


FIG. 1—Cell current Time-curves

All plain and low alloy ferrous metals show similar pattern and nearly the same rate of corrosion under the same soil environment^{6,7}. Mild steel has been taken as a standard material for the calculation of economics of corrosion⁸ and soil corrosivity is generally evaluated in terms of the corrosion rate of steel⁹. Hence mild steel, a carbon steel with a maximum of about 0.25% carbon, has been selected as a representative metal. Schwerdtfeger's soil corrosion cell procedure¹⁰⁻¹² has been adopted as an accelerated test to evaluate the soil corrosivity data for mild steel. The results obtained with ten typical Indian soils are incorporated in this paper.

EXPERIMENTAL PROCEDURE

The physico-chemical properties of each soil pertaining to its corrosivity, have been reported in an earlier communication¹².

The electrodes of mild steel were prepared and the soil corrosion cells were assembled in quadruplicate. The short circuit currents at various intervals and the corrodibility data of the metal in the cells were determined and statistically analysed. All these operations were performed according to the procedures given in the earlier communication¹². The pickling weight loss of 0.0050 gm was deducted from the weight loss figure of each electrode in order to ascertain the net loss due to corrosion.

RESULTS AND DISCUSSION

Mean short circuit current-time curves for all the sets are given in Figs. 1 and 2 and the data on the corrosion loss; corrosion penetration and quantity of electricity passing through the cell is recorded in Table 1.

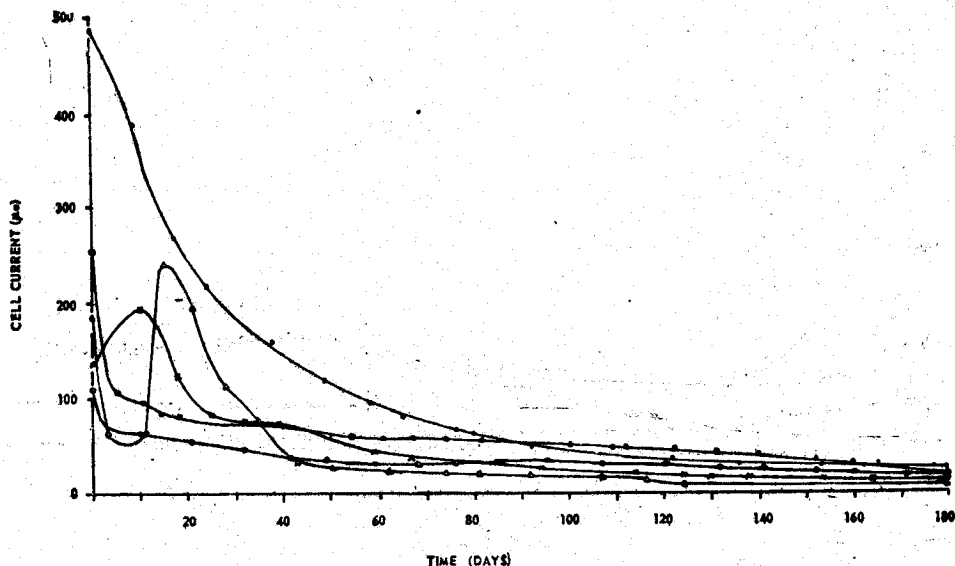


Fig. 2—Cell current Time-curves

Order of corrosivity

In order to determine whether a difference between the corrosivities of two different soils is significant or not, a statistical test¹², based on student 't' function has been performed. The results are given in Table 2.

Hence as regards the corrosivity towards the particular sample of mild steel, the order of the soils is :

Jodhpur desert < Sambalpur laterite < Delhi alluvial < Bangalore red < Coimbatore black < Nagpur black < Ratnagiri laterite < Trivandrum forest < Delhi saline < Alleppey peaty.

The corroded surface

The structure of steel is constituted by the crystals of ferrite, composed of almost pure iron surrounded by alternate layers of black pearlite which is composed of alternate layers of ferrite and cementite or iron carbide (Fe_3C). Free carbon constituent is not present in steel¹³. It is generally assumed that ferrite acts as anode and cementite as cathode of active corrosion cells¹⁴. Another cause of inhomogeneity on the metal surface to produce anodic and cathodic areas is the differential nature of the surface film.

TABLE I
DATA ON CORROSION OF MILD STEEL IN SOILS

Soil	Mean corrosion Loss (g/dm ² ½ Year)	Standard deviation (σ)	Coefficient of variation (%)	Penetration		Quantity of electricity delivered by the cell in six months (milliamp days)
				Maximum (10 ⁻⁵ m)	Average maximum (10 ⁻⁵ m)	
Delhi alluvial	3.486	0.040	1.1	61	56	9.8
Bangalore red	3.735	0.091	2.4	52	45	5.9
Ratnagiri laterite	4.476	0.131	2.9	55	52	6.5
Nagpur black	3.851	0.453	11.8	70	55	18.5
Trivandrum forest	4.685	0.414	8.8	80	75	8.4
Sambalpur laterite	2.068	0.234	11.3	45	30	2.5
Coimbatore black	3.748	0.078	2.1	48	40	15.6
Delhi saline	5.560	0.696	12.5	55	45	29.2
Jodhpur desert	1.254	0.067	5.4	23	18	1.1
Alleppey peaty	7.204	0.202	2.8	40	35	12.0

As the electrodes were mechanically abraded before experiment with No. 0 emery, the surface was covered with a Bialby layer^{15,16} or according to the latest views with a layer of disoriented crystal fragments of the metal^{17,18}. The contribution of surface finish to the corrodibility of mild steel in the soil environments for a period of six months is expected to be negligible^{12,16}.

In most of the mild steel electrodes uneven general corrosion¹⁹ or pitting form of corrosion distributed all over the surface has been observed. The cathodes in Coimbatore black soil corrode in the form of local corrosion. Under a soil environment mild steel surface develops numerous spots because of breaks and discontinuities in the surface film. Such areas constitute anodic points. They tend to grow and spread as corrosion proceeds. Finally the entire surface is covered up by anodic, cathodic and electrochemically inert areas. The film of corrosion products on the metal surface is comparatively more tenacious and less impermeable to ions. Hence the anodic and cathodic areas are not evenly distributed and uneven general or localised corrosion is usually observed.

Both the anodes and cathodes in Alleppey peaty soil corrode in the form of even general corrosion. As the soil is acidic (pH=2.5), direct chemical corrosion *i.e.* dissolution of iron with liberation of free hydrogen is prominent which results in even general corrosion.

The perforated electrodes in Jodhpur desert soil corrode in the form of even general corrosion and non-perforated ones in the form of narrow pittings distributed all over the surface. The behaviour of the cell current indicates that after a short initial period of 8 days the perforated electrodes behave as anode and non-perforated ones as cathode consistently for the remaining period. Hence the non-perforated electrodes corrode

TABLE 2

SIGNIFICANCE TEST ON THE CORROSIVITY OF SOILS

Name of soil	't' with respect to the previous soil	Significance value	Remarks
Jodhpur desert			
Sambalpur laterite	6.7	<0.005	Very significant
Delhi alluvial	12.0	<0.005	—do—
Bangalore red	5.0	<0.005	—do—
Coimbatore black	0.22	0.82	Not significant
Nagpur black	0.75	0.46	—do—
Ratnagiri laterite	2.7	0.035	Significant
Trivandrum forest	0.96	0.37	Not significant
Delhi saline	2.2	0.07	—do—
Alleppey peaty	4.5	<0.005	Very significant

only due to local action and perforated ones due to differential aeration as well as local action. Jodhpur desert soil has very small amount of water and a good air permeability so that for local corrosion, the cathodic or aerated area is much larger as compared to the anodic or less aerated area. Consequently, local corrosion of non-perforated electrode develops in a highly localised form as narrow pitting. The perforated electrodes corrode principally by differential aeration mechanisms in the form of even general corrosion.

The maximum depth of penetration of corrosion is qualitatively proportional to the corrodibility of the metal. The average maximum penetration has a better correlation with corrodibility. The scatter diagram of the two parameters given in Fig. 3 indicates a linear relationship. The regression equation has been calculated to be

$$\bar{P}=13 \cdot 0M$$

where \bar{P} = the average maximum penetration in terms of decamicros and M = mean corrosion loss in the terms of $\text{gm}/\text{dm}^2 \frac{1}{2}$ year.

In the calculation of this equation, the point for Alleppey peaty soil is excluded as the penetration is very low because of the acidic nature of the soil which results in heavy even general corrosion with low penetration.

Mean short circuit currents

The prominent features of mean cell current-time curves are

(a) Initial short circuit currents are different for different soils. In many cases the initial currents are maximum. But in three cases—Trivandrum forest, Delhi saline and Alleppey peaty soils—the maxima are attained in periods extending up to ten days. These cells take this period for stabilisation.

The cell currents gradually decrease with time and in several cases decrement after about 60 days is much less though a slight decrement is usually found up to 180 days.

The rate of corrosion is maximum at the beginning. As the corrosion proceeds protective films of the products of corrosion reactions partly cover the electrodes. Initially the polarisation increases with the thickness of the films. But in several cases, beyond a certain thickness of the films, the polarisation is not further enhanced appreciably by the increment of film thickness.

(b) In Ratnagiri laterite soil, the current rapidly falls but again increases to more than initial value within 15 days and then again decreases gradually. In all probabilities this is due to the chemicals exerting depolarising action at the electrodes,

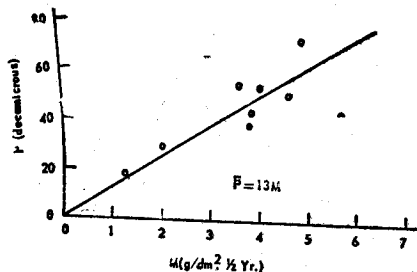


Fig. 3—Average maximum penetration-corrudibility curve.

Free iron oxide present in the laterite soil may be the depolarising agent as rust or iron oxide is found to act as depolarising agent in the corrosion of iron²⁰.

(c) In Coimbatore black, Delhi saline and Alleppey peaty soils, the current increases from a minimum to a maximum and then finally decreases gradually again. In these cases the depolarisation occurs because of enhancement in the overall permeability of the film for the corrosive ions, which may be due to spontaneous breaking of the film²¹ or loosening of the adherent film of the corrosion products or both. In case of Alleppey peaty soil, the depolarisation effect is only slight.

(d) The polarity of the cell constituted by Jodhpur desert soil reverses within 10 days and remains so upto 180 days. In such a cell, the concentration of water (which is not saturated with air), is initially more in the vicinity of the unperforated electrode in comparison with perforated electrode (which has less water, but is air-saturated). Hence the net concentration of oxygen at unperforated electrode is comparatively less and it functions as an anode. As the permeability of the soil for air is high, the oxygen concentration difference at the two electrodes is not produced because of difference in the rates of replenishment of oxygen. But with time more and more air dissolves in the water in the vicinity of the unperforated electrode. Consequently, its potential changes in the cathodic direction. As a result the polarity of the cell changes after sometime and then remains so for the rest of the test period.

The scatter diagram of maximum mean cell current and corrodibility is given in Fig 4. The regression equation for the two parameters has been calculated to be

$$M^2 = 0.053 I$$

where M = Mean corrosion loss in terms of gm/dm.² $\frac{1}{2}$ year and I = Maximum mean cell current in terms of microamperes.

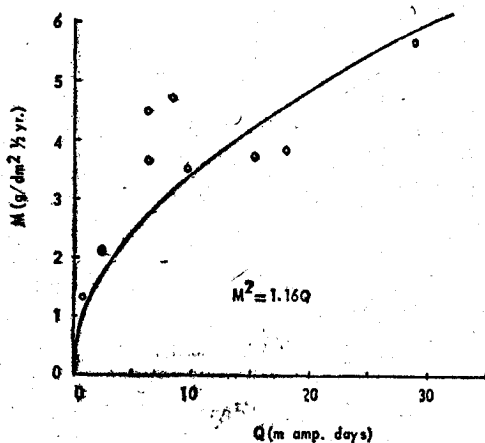


FIG. 4—Maximum mean cell current corrodibility.

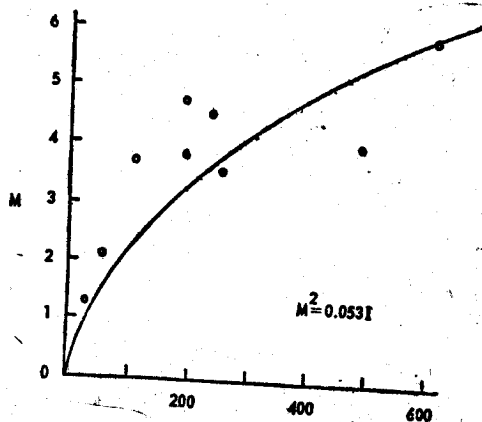


FIG. 5—Relationship between corrodibility and amount of electricity passing through the cell.

The scatter diagram of corrodibility and the amount of electricity passing through the short circuit for a period of six months, represented by the area between the mean short circuit current time curve and the time axis, is given in Fig. 5. The relationship between the two parameters is given by the regression equation.

$$M^2 = 1.16 Q$$

where M = mean corrosion loss in terms of gm/dm.² $\frac{1}{2}$ year and Q = amount of electricity in terms of milliampere days.

The point for Alleppey peaty soil has been excluded from the calculation of this curve as in this case heavy direct chemical corrosion also occurs.

Soil properties and corrosivity

The corrosivity of soils towards ferrous metals including mild steel is a function of several independent and interrelated variables depending upon several factors including certain physico-chemical properties. Hence no soil property has been found to be a general index of its corrosivity. But under certain conditions some properties either individually or collectively have been found to be fairly good indices¹.

Some correlations of the soil corrosivity towards mild steel, expressed as corrodibility of the metal in soils with some individual soil properties, have been obtained in case of non-acidic soils. Alleppey peaty soil (pH = 2.5) has been found to be an exception in these correlations because of its highly acidic nature which results in direct chemical corrosion in addition to electro-chemical corrosion.

The scatter diagram of corrodibility in relation to moisture present in a soil is given in Fig. 6. The corrodibility increases with increase in the moisture content and the soils having a moisture content in the region about 25-30% are most corrosive. This is in accordance with the observation of Mamedov²². With enhancement of moisture content beyond this range the corrodibility again decreases. Such dependence of soil corrosivity towards mild steel supports the conclusions of Markovic^{23,24} that the soils low in water and high in air or *vice versa* are less corrosive, but in the optimum region where a soil has enough water to form electrolyte and enough air to act as cathodic depolariser, the corrosivity is maximum. For the soils *in situ* the moisture equivalent is to be regarded as an index for field capacity.

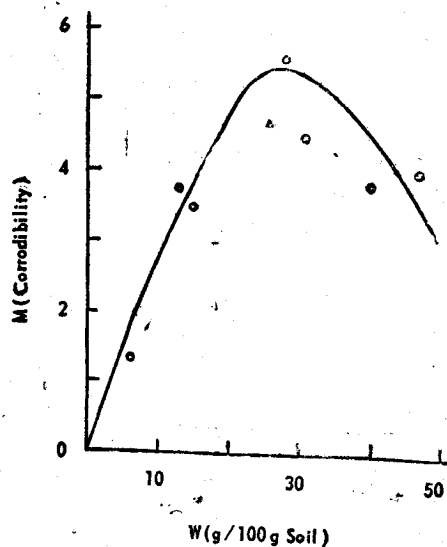


Fig. 6—Moisture corrodibility curve.

The tested soils contained water approximately to the extent of moisture equivalent. The amount of clay present in a soil is fairly good index of its moisture equivalent. In all the soils tested except Alleppey peaty soil, the two parameters are correlated by a regression equation $W = 1.1 C$, where 'W' is the moisture equivalent in terms of gm of water per 100 gm of soil and 'C' is the percentage of clay. Hence corrosivity of soil towards mild steel depends on the clay content. This relationship conforms to a pattern similar to the corrodibility moisture curve (Fig. 6).

There is no definite general correlation between soil corrosivity and soil resistivity. However, as in the case of the corrosivity towards cast iron¹², it can only be quantitatively stated that the soil corrosivity decreases with increase in its resistivity. A sandy soil of the same resistivity is comparatively less corrosive than a loam. The range of corrodibility becomes divergent with soils of higher resistivity.

The effect of soil pH on the corrodibility of mild steel is the same as on cast iron as evidenced by Pourbaix diagram²⁵, which indicates that passivating influence will be observed in case of soils beyond pH 9.5. Such soils are rare in nature. The corrosivity of soils in the pH range 4 to 10 is independent of pH. But at pH less than 4, both the direct chemical corrosion and electro-chemical corrosion will occur. Hence soil corrosivity will be much enhanced. Alleppey peaty soil exhibits significantly high degree of corrosivity because of low pH.

The nature and the concentration of soluble salts present in soil exert multiple influences viz. resistivity, electrode potential, film properties, adsorption etc., on the corrosion of mild steel. The effects are similar to those on cast iron¹².

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