ON CORROSION OF FERROUS METALS IN TYPICAL INDIAN SOILS
PART I : CAST IRON

Brajendra Nath Tripathi & Shanti Sarup Vats

Defence Science Laboratory, Delhi

(*Received* 20 *March* 64; *revised* 25 *August* 64)

Corrodibility of cast iron in ten typical Indian soils, employing Schwerdtfeger's soil corrosion cell procedure and the physico-chemical properties of the soils responsible for their corrosivity have been determined. The results have been statistically analysed, interpreted and correlated with various factors. Corrosion of cast iron in non acidic soils (pH4—10) proceeds through electrochemical mechanism. Usually the rate of corrosion is maximum at the beginning and with development of the film of corrosion products, the rate gradually decreases with time until it becomes more or less constant. 'Even' general corrosion is observed in most of the cases. The maximum penetration is directly proportional to corrodibility. The corrosivity of soils *in situ* is directly proportional to the moisture equivalent or, in turn, to the clay content. The corrosivity of soils increases with the concentration at soluble electrolytes. Ferric oxide present in a laterite soil functions as a cathodic depolariser and hence increases its corrosivity. The corrodibility (M) increases with maximum cell current (I) or average cell current ($\bar{I}$) as $M^2 \propto I$ or $M^2 \propto \bar{I}$. In an acidic soil, the corrosion mainly proceeds through the mechanism of direct chemical reaction.

An assessment of the corrodibility of different metals employed in subterranean structures and corrosivity of different soils wherein the metal structures are buried, is of great importance from the economic and technological points of view. For this purpose programmes of burying different metals at various sites have been undertaken in different countries[1, 2]. These programmes are expensive and time consuming. Hence various accelerated tests have been devised which yield qualitative and quantitative assessments. The soil corrosion cell procedure, devised by Denison[3, 4, 5] and modified by Schwerdtfeger[6, 7, 8] has been found to be a very reliable accelerated test. It is, in fact, an accelerated corrosion test in the environments simulating the field conditions and in the case of ferrous metals the results obtained can be fairly well extrapolated to any desired area and period of exposure within reasonable limits. Most of the other accelerated corrosion tests yield results which are functions of a single soil property, none of which has been found to be a general quantitative index of soil corrosivity[9]. This test has been adopted by the workers in several countries including India[10–16]. Hence a programme of study of the corrosivity of typical Indian soils, employing this procedure, has been undertaken at this laboratory.

The results obtained by using cast iron as electrode material with ten typical Indian soils have been incorporated in this paper. The Soil Samples are: Delhi alluvial, Bangalore red, Ratnagiri laterite (West Coast Region), Nagpur black (Medium black), Trivandrum forest, Sambalpur laterite (East Coast Region), Coimbatore black (Mixed red and black), Delhi saline, Jodhpur desert and Alleppey peaty soils. Each soil has been selected to represent a typical class[17, 18] of Indian soils. The soils were collected mostly from depths ranging from 80 to 100 cm. The experiments have been performed in quadruplicate and the results statistically analysed. The physico-chemical properties which govern the corrosivity of a soil[19] viz. porosity, moisture equivalent, electrical conductivity, soluble salts and acidity or alkalinity, have also been reported for each soil.

EXPERIMENTAL PROCEDURE

Relative Density—In order to calculate the porosity and void ratio of each soil, its real and apparent relative densities were determined following the procedures recommended by A.S.T.M.[20] and adopted by Subba Rao *et al.*[21] respectively.

Moisture Equivalent—The moisture equivalent of each soil was determined by saturating a soil sample with water and subjecting it to a centrifugal force of 1000 g in a MSE soil centrifuge for an hour and determining the water retained by the soil, following A.S.T.M. procedure[22]. The water retained by a soil sample following the moistening procedure described later, was also determined. This gave slightly different values for moisture equivalents. As water-logging was observed in case of Delhi saline soil, the value of moisture equivalent obtained by the ASTM procedure is higher than that obtained by the suction procedure. In all other soils, the values obtained by centrifuge are less than those by the suction procedure. This is in accordance with known facts[23].

Electrical Resistivity—The resistivity of each soil was measured by recording potential and corresponding current, using 50 cycles A.C. across a soil block placed between two mild steel electrodes.

Mechanical Analysis—The percentages of sand, silt and clay present in each soil sample were determined by following the procedure given by Piper[24].

All the above determinations are listed in Table 1.

pH—A mixture of soil and water in a ratio of 1 : 2 was stirred for a period of 30 minutes and the *pH* of the suspension was determined by employing Beckmann *pH* meter following a procedure recommended by Hester[25].

Chemical Analysis—The amounts of Na^+, K^+, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-}, present in 1 Kg. of soil were determined by following the standard procedures recommended by Jackson[26]. The amounts of Mg^{2+} were determined Colorimetrically by using Azovân Blue[27] as colour reagent and the combined amounts of Ca^{2+} and Mg^{2+} by titration[26] against E.D.T.A. The amount of soluble iron present in Alleppey peaty soil was determined by titrating the aqueous extract, after reducing Fe^{3+} to Fe^{2+}, with standard potassium permanganate solution.

The *pH* and the concentration of various ions in the soils are given in Table 2.

Ignition Loss—Percentage of loss by ignition of a peaty soil is an approximate index of organic content. In case of Alleppey peaty soil the ignition loss is 21·1%

The Corrosion Cell

Materials—Cast iron anodes and cathodes (thickness 0·32 cm and dia. 4·4 cm) each having a screw hole were used. The cathodes had 19 holes, each 0·635 cm in dia., symetrically distributed in two circular paths with 6 and 12 holes respectively with one at the centre. Other aceessories and components of the cell, such as stainless steel screen discs (4·4 cm and 4·6 cm in dia.) brass cylinder (dia. 4·4 cm, height 4·5 cm), perspex cylinders (internal dia. 4·5 cm, height 2·54 cm. each having two screw holes and attached inner ridge of thickness 0·1 cm and width 0·2 cm. at the middle point) and water dispensers (external dia. 4·5 cm height 5 cm, each having glass beads filled up between two fixed stainless steel screens and an asbestos sheet at its base), were also made according to the design and dimensions given by Schwerdtfeger[8].

Moistening of Soil—To set up the cells in quadruplicate, 8 perspex cylinders were taken. Each cylinder was positioned over a filter paper placed on a Buchner funnel. The annular space between the cylinder and the funnel was sealed with molten paraffin wax. The soil passing through A.S.T.M. sieve No. 20 (maximum particle size 0·085 cm) was gradually poured into the cylinder and compacted with the help of a brass cylinder until

TABLE 1

PHYSICAL PROPERTIES OF THE SOILS

	Relative density determination				Moisture equivalent		Resistivity	Mechanical analysis			
Name of Soil (Soil Group)	Real	Apparent	Void ratio	Porosity	Centrifuge Method	Suction Method	(ohms. cm.)	Clay %	Silt %	Sand %	Texture
Delhi alluvial	2·66	1·41	0·89	0·47	12·9	14·5	3,600	16·4	12·4	71·2	Sandy Loam
Bangalore red	2·69	1·53	0·75	0·43	12·7	12·9	1,200	11·9	14·3	73·8	Sandy Loam
Ratnagiri laterite	2·95	1·41	1·09	0·52	29·2	30·2	2,900	18·7	37·3	44·0	Loam
Nagpur black	2·69	1·40	0·92	0·49	39·8	42·5	730	35·4	25·1	39·5	Clay Loam
Trivandrum forest	2·60	1·17	1·22	0·55	25·0	25·2	9,000	11·2	7·4	81·4	Loamy sand
Sambalpur laterite	2·97	1·53	0·94	0·49	16·2	18·3	22,000	21·7	10·6	77·7	Sandy Clay Loam
Coimbatore black	2·63	1·31	1·01	0·50	37·9	38·7	610	41·4	26·3	32·2	Clay
Delhi saline	2·72	1·50	0·81	0·45	35·2	27·0	300	23·6	20·3	56·1	Sandy Clay Loam
Jodhpur desert	2·68	1·75	0·58	0·35	3·5	6·1	9,000	4·8	1·9	93·3	Sand
Alleppey peaty	2·40	1·11	1·16	0·54	16·2	22·6	1,100	8·6	3·0	88·4	Loamy sand

it was properly filled with soil. In four cylinders, stainless steel screen discs were also placed just on the ridge during the packing of soil. A water dispenser was placed on a filter paper resting on the soil in the cylinder. The space between the water dispenser and the cylinder was sealed with paraffin wax. Distilled water, slightly in excess of the quantity required for moisture equivalent, was poured in each water dispenser. To allow a uniform permeation of water throughout the soil mass, vacuum, equivalent to 5 cm of mercury, was applied at the start for 5 minutes. This was gradually increased until the pressure difference was 30 cm. However, in the case of Jodhpur desert soil, pressure difference of more than 20 cm could not be achieved. At this stage suction was continued until the dripping of water from the funnel stem ceased. The total time required for completion ranged from 45 minutes to 4 hours. This procedure of moistening was not found to be suitable for Alleppey peaty soil as the water premeated only through some parts of the soil leaving the rest of it completely dry. Hence a weighed sample of the soil was thoroughly mixed with the requisite amount of distilled water with the help of a spatula and then packed in a cylinder and subjected to suction as above. In this case, the pressure difference gradually decreased as the excess water dripped off.

TABLE 2

CHEMICAL PROPERTIES OF THE SOILS

Ionic concentration

(mg. eq. per Kg. of Soil)

Soil	pH	Na^+	K^+	Ca^{2+}	Mg^{2+}	CO_3^{2-}	HCO_3^-	Cl^-	SO_4^{2-}	Any other ion	Concentration
Delhi alluvial ..	7·9	10·3	0·1	6·9	1·2	0·0	8·1	0·7	1·6		
Bangalore red ..	7·4	3·0	0·5	3·1	1·0	0·0	5·4	0·9	6·4		
Ratnagiri laterite ..	7·8	13·0	0·7	10·2	1·1	0·0	14·9	2·2	4·4		
Nagpur black ..	7·4	22·2	1·4	3·1	7·3	0·0	5·2	1·4	7·0		
Trivandrum forest	7·3	4·1	0·2	4·4	0·8	0·0	4·0	2·9	1·6		
Sambalpur laterite	7·0	1·6	0·5	4·0	0·6	0·0	2·2	1·3	3·4		
Coimbatore black ..	7·1	4·3	0·2	3·7	3·3	0·0	4·6	0·9	8·7		
Delhi saline ..	8·9	28·4	1·8	4·4	0·5	0·1	19·8	22·7	1·9		
Jodhpur desert ..	7·6	2·9	1·9	5·3	0·7	0·0	8·8	1·0	0·0		
Alleppey peaty ..	2·5	364·2	8·9	42·2	33·1	0·0	0·0	26·4	579·1	Fe^{2+} and Fe^{3+}	165·6

TABLE 3

DATA ON CORROSION OF CAST IRON IN THE SOIL

Soil	Mean Corrosion loss (g/dm² ½ year)	Standard Deviation (σ)	Coefficient of variation (%)	Penetration (decamicrons)		Quantity of electricity delivered by the cell in six months (milliamp. days)
				Max.	Ave. Max.	
Delhi alluvial ..	3·201	0·049	1·6	36	36	16·1
Bangalore red ..	2·859	0·042	1·5	25	23	6·2
Ratnagiri laterite	3·854	0·203	5·4	45	41	9·0
Nagpur black ..	6·702	0·430	6·4	100	74	38·2
Trivandrum forest	3·433	0·193	5·6	75	64	5·6
Sambalpore laterite	1·993	0·079	3·9	30	23	2·2
Coimbatore black	5·728	0·365	9·1	100	76	33·5
Delhi saline ..	5·188	0·350	6·8	100	69	22·8
Jodhpur desert ..	0·592	0·041	6·9	20	13	1·0
Alleppey peaty ..	6·566	0·419	6·4	30	25	4·7

Setting up of the cell—Each water dispenser was removed and the cylinder packed with moistened soil having a screen disc was placed on a porcelain plate. The surface of the soil at the upper end was puddled and smoothened with the help of a spatula occasionally moistened with distilled water until there was no evidence of porosity and the soil surface presented a water-logged appearance.

The electrodes were polished with emery cloth No. 0, degreased thoroughly with sulphur-free toluene, weighed and painted on one side and at the outer rim with bituminous paint. The anode was lightly scratched with emery cloth No. 0, moistened with water and positioned on the smooth soil surface. This was then inverted and the cathode was positioned on the other end. The holes in the cathode were filled with dry soil and another cylinder packed with moistened soil was placed over it. Stainless steel screen disc was pushed in at the lower end, the assembled unit turned over and No. 15 rubber stopper was placed over the anode. Two rubber bands, diameter 3·0 cm, were wrapped around the stopper and the cell to hold all the cell components intact. The joint of the two cylinders and the space between the anode and the cylinder were sealed with bees wax.

In the case of Jodhpur desert soil, such a procedure always resulted in a cell with reversed polarity from the very beginning. The water during puddling sinks below immediately, thereby increasing the water concentration near the cathode and reversing the polarity of the cell. Hence the procedure for setting up of such a cell was modified. The anode was moistend with water and positioned below a cylinder containing the moistened soil. The rest of the procedure was the same except that the cell was always kept in the inverted position in order to prevent the water film leaving the soil region next to the anode.

The cells were placed inside a perspex cell box, capable of housing ten cells each, on a perforated sheet fixed 5cm above its base. Water was poured in the cell box to keep the inside atmosphere saturated with water vapour. The leads of anode and cathode were taken out through the holes in the walls of the cell box and connected with a socket and plug respectively and the cells were short circuited. After placing the requisite number of cells in the cell box, it was closed and sealed carefully by plasticine. Fig. 1 gives a line diagram of an assembled soil corrosion cell.

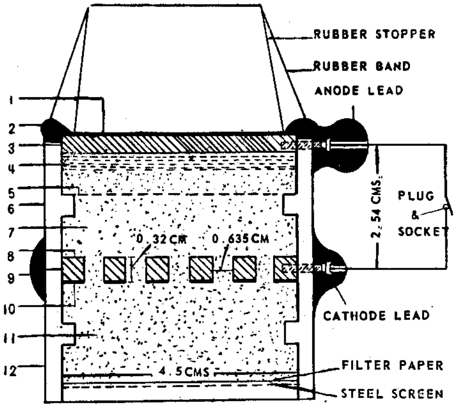

Fig. 1—The assembled soil corrosion cell. [1, painted side; 2, wax; 3, anode; 4, puddled soil; 5, steel screen; 6, cylinder I; 7, aerated soil; 8, cathode; 9, wax; 10, paited side; 11 aerated soil and 12, cylinder, II.]

Determinations with the cells—The short circuit currents were periodically measured for a period of 180 days with the help of a 'zero resistance micro-ammeter'. The reading of the micro-ammeter is recorded when the voltage drop across the two terminals of the soil corrosion cell is nullified by the adjustment of the two resistances (50 ohms and 5 M. ohms), as indicated by the null position of the galvanometer. The curves showing the variation of mean short circuit current or cell current of four cells in each set with time are given in Figs. 2 and 3.

At the end of a period of 180 days, the cells were opened. The electrodes were thoroughly cleaned by dissolving out the paint, brushing off the corrosion product and finally pickling in 10% ammonium citrate made alkaline at 80±2°C for 45 minutes. The electrodes were then washed with distilled water, dried and weighed. The pickling weight loss of 0·0550 gm was deducted from each weight loss figure in order to ascertain the loss due to corrosion. The weight loss figures of anode and cathode of each cell were added to give the net loss due to corrosion. The results are reported in terms of mean corrosion loss per unit area per half year, standard deviation and co-efficient of variation which is an index of reproducibility of the results.

The general appearance of the corroded surfaces of the electrodes were recorded and the maximum penetration of corrosion in each set was determined with the help of Baty Depth gauge. Average maximum penetration was determined by taking the average of the maximum penetrations in the four electrodes of a set. All the above data are recorded in Table 3.

DISCUSSION

Order of Corrosivity—To determine whether a difference between the results of two sets is significant or it has arisen simply due to chance, a statistical test[28] based on Student's *t* function has been performed.

The values of *t* and the corresponding significance values are given in Table 4. The significance values are classified as very significant if less than 0·005, significant if between 0·005 and 0·05, and not significant if more than 0·05.

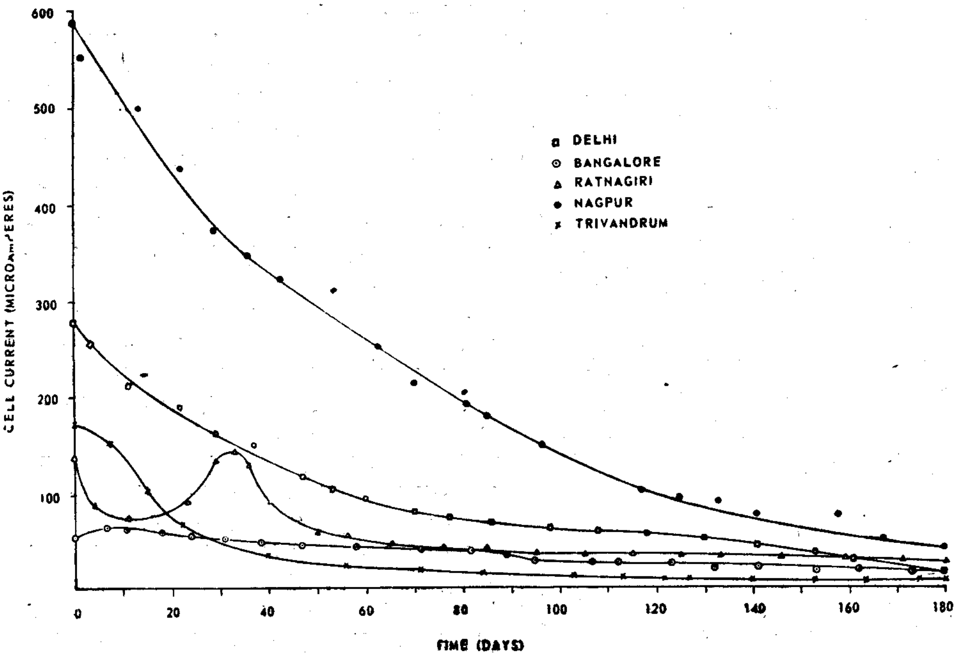

Fig. 2—Time—Cell current curves.

Hence as regards the corrosivity towards the particular sample of cast iron the order of the soils is : Jodhpur desert $<$ Sambalpur laterite $<$ Bangalore red $<$ Delhi alluvial $\leqslant$ Trivandrum forest $<$ Ratnagiri laterite $<$ Delhi saline $\leqslant$ Coimbatore Black $<$ Alleppey peaty $\leqslant$ Nagpur black soil.

The Corroded surface—In order to give a standard surface finish to all the electrodes they were abraded mechanically with the help of emery cloth No. 0. Hence the surface was either covered up with Bielby film consisting of the metal, metal oxide and the polishing material mixed intimately$^{29, 30}$ or had undergone plastic deformation in which the base crystals are broken up into several small subgrains^{31}. The former mechanism proceeds by flow of the metal into microscopic depression and latter by cutting off of the microscopic projections. Recent studies on the cold working of the metal surfaces indicate that such surfaces can be completely described in the form of plastic deformation^{31}. There is a definite evidence that comparatively large particle of abrasives are enbedded in surfaces finished by the action of abrasives. These particles constitute a major electrochemical discontinuity in the surface^{32}. Both the Bielby layer or the deformed layer of disoriented subgrains in plastic deformation of metal, are easily corroded as compared with the unchanged metal ^{29}. The surface conditions of the metal do not have much practical effect on total corrosion loss of the metal in these experiments as the surface layers would be removed in the initial stages and then the rate of attack would depend on the structure of the interior metal^{29}.

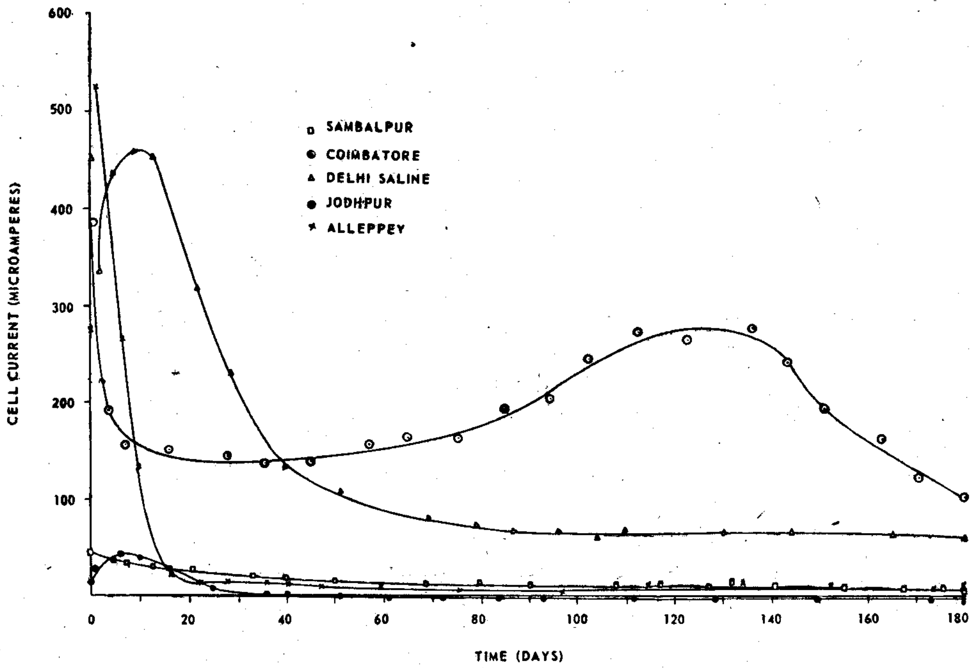

Fig. 3 —Time—Cell current curves.

TABLE 4

SIGNIFICANCE TEST OF THE CORROSIVITY OF SOILS TOWARDS CAST IRON

Name of Soil	't' with respect to the previous soils	Significance value	Remarks
Jodhpur desert			
Sambalpur laterite	14·1	<0·005	Very Significant
Bangalore red	11·1	<0·005	—do—
Delhi alluvial	4·8	<0·005	—do—
Trivandrum forest	2·3	<0·06	Not Significant
Ratnagiri laterite	3·1	<0·022	Significant
Delhi saline	6·6	<0·005	Very Significant
Coimbatore black	2·1	0·08	Not Significant
Alleppey peaty	3·0	0·026	Significant
Nagpur black	−0·45	0·66	Not Significant

In the absence of the differential properties in the environment, the differential properties of the metal surface decide the occurence of anodic and cathodic areas. In the case of cast iron, the ferritic constituents function as anodes and graphitic as cathodes[33]. The differential nature of the oxide film over a metal surface is another important property which gives rise to anodic and cathodic areas.

Under a soil environment, an iron surface readily develops numerous spots because of the breaks and discontinuities in the film. Such areas constitute anodic points, which tend to grow and spread over the metal surface. The cathodic areas get covered up with adsorbed hydrogen and are surrounded by hydroxyl ions. Finally the entire surface is covered up by anodic, cathodic and electrochemically inert areas. The film on cast iron is only slightly protective. The electrochemically inert area do not continue for a sufficient period of time and the corrosion usually proceeds in the form of general corrosion.

The usual form of corrosion in the cast iron anodes and cathodes is 'even' general corrosion[34]. In a few cases like anodes in Trivandrum forest and Delhi saline soils and cathodes in Sambalpur laterite soil local corrosion has been observed. In the case of the highly corrosive Nagpur black and Coimbatore black soils, deep pittings are associated with general corrosion. In Jodhpur desert soil the corrosion is in the form of narrow pittings. This is a soil with good aeration. In such a case, the cathodic or aerated areas are much greater as compared with the anodic or poorly aerated areas. Consequently the corrosion occurs in highly localised or pitting form.

The maximum depths of penetration of corrosion or the maximum pit depths are qualitatively proportional to the corrodibility of the metals. The average maximum penetration appears to have better correlation with corrodibility. The scatter diagram of the two parameters given in Fig. 4 indicates a linear relationship. The regression equation has been calculated to be

$$\overline{P} = 12{\cdot}3\,M$$

Where $\overline{P}$=the average maximum penetration in terms of decamicrons and M=mean corrosion loss in terms of g/dm² ½ year. In the calculation of this relationship the point for Alleppey peaty soil is excluded as the penetration is exceedingly low because of the acidic nature of the soil which results in uniform heavy corrosion.

Mean short circuit current—The prominent features of Mean Cell Current—Time Curves are: (*a*) The initial cell currents, which are usually the maximum, are different for different soils. In three cases of Bangalore red, Delhi saline and Jodhpur desert soils, the maxima are attained at the end of about a week. (*b*) The cell currents gradually decrease with time. In several cases, almost a constant value is attained in about 60 days, though slight decrement is always found throughout the total period. (*c*) In the cases of Ratnagiri laterite and Coimbatore black soils, the currents rapidly fall, remain constant for some time, increase to a maximum value and then again gradually decrease.

The rate of corrosion is maximum at the beginning. As the corrosion proceeds, partly protective films of the products of corrosion reactions cover the electrodes and the corrosion rate decreases with time[35]. Initially the polarisation increases with the thickness of the film. But in most of the cases, beyond a certain thickness of the film, further polarisation is fairly independent of it. In the cases of Ratnagiri laterite and Coimbatore black soils the cell current behaviour is not a factor of chance as all the cells of the sets behaved in a similar pattern. The depolarisation after some time may be occurring because of the flaking off of the film of the corrosion product and exposure of a fresh metal surface or the action of depolarising agents present in the soils. Rust or iron oxides accelerate the corrosion of iron electrolytically and also because of its depolarizing action[36]. A laterite soil contains free oxides of iron and aluminium. Hence the depolarization observed in Ratnagiri laterite soil may be due to iron oxides.

The scatter diagram of Maximum mean cell current given in Fig. 5 as a function of Mean corrosion loss per unit area exhibits a second degree relationship. It is given by the regression equation

$$M^2 = 0{\cdot}0731$$

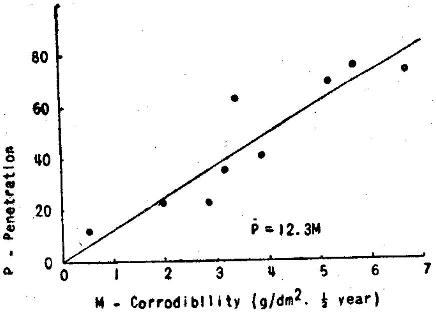

Fig. 4—Average maximum penetration—Corrodibility curve.(Penetration is given in terms of decamicrons)

where M=mean corrosion loss in terms of gm/sq. dm. ½ year and I=maximum mean cell current in terms of micro-amperes.

The total amount of electricity passing through the short circuit for a period of 180 days, represented by the area between the Mean Short Circuit Current—Time curve and Time axis bears a close relationship with corrodibility. The scatter diagram is given in Fig. 6. The relationship between two parameters is given by the regression equation:

$$M^2 = 1{\cdot}10\,Q$$

where M = mean corrosion loss in terms of gm/sq. dm. ½ year and Q = amount of electricity in terms of milliamp. days for ½ year. A correlation between the corrodibility and average cell current can be derived from this relationship. It is given by $M^2 = 0{\cdot}2\,\bar{I}$ where $\bar{I}$ = Average cell current in microamperes.

The point of Alleppey peaty soil is excluded from this curve as it is far removed from the general pattern of other points. In this case, the direct action corrosion is abnormally high as the soil is very acidic and hence the point represents excessive corrosion as compared with other soils.

Soil properties and corrosivity—The corrosivity of a soil towards a metal is represented by the corrodibility of the metal in the soil. It is a function of a number of inter-related variables which depend upon several factors including the physio-chemical properties of the soil. Hence any one soil property cannot be a general index of its corrosivity. But under certain conditions, some properties, either individually or collectively, have been found to be fairly good indices[9].

The corrodibility of the cast iron in various non-acidic soils has been correlated with some individual soil properties. The Alleppey peaty soil has been found to be an exception in these correlations.

The scatter diagram of corrodibility in relation to moisture present in a soil is given in Fig. 7. The relationship is linear and accordingly the corrodibility is directly proportional to the moisture present. The regression equation has been calculated to be $M = 0{\cdot}15W$ where W = moisture in gm/100 gm of soil). Hence it is concluded that the corrosivity of the soils *in situ* is directly proportional to the moisture equivalent.

The amount of clay in a soil is a fairly good index of its moisture equivalent. The regression equation for these soils is $M = 1{\cdot}1\,C$ where C is percentage of clay. The tested soils contained water approximately to this level. Hence a scatter diagram of corrodibility in relation to clay percentage is given in Fig. 8. The relationship is linear and the regression equation has been calculated to be $M = 0{\cdot}17C$.

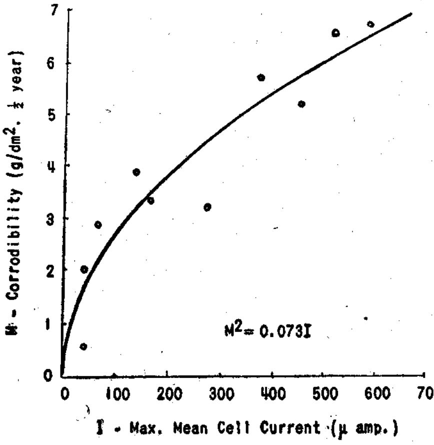

Fig. 5—Maximum mean cell current—Corrodibility curve.

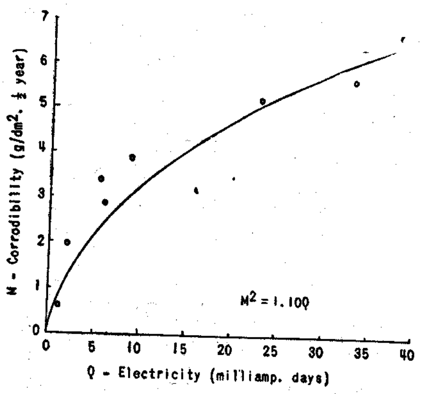

Fig. 6—Curve showing the relationship between corrodibility and amount of electricity passing through the cells.

These correlations are based on a small number of observations. Hence they should be regarded as tentative.

There is no definite general correlation between soil corrosivity and soil resistivity. It can be only qualitatively stated that soil corrosivity decreases with increase in its resistivity. A sandy soil of the same resistivity is comparatively less corrosive than a loam. Fairly good correlation between the two parameters is possible only for soils with low resistivity. The range of corrodibility becomes divergent with soils of high resistivity.

According to Pourbaix diagram for iron[37], dividing Potential—*pH* regions into corrosive, immune and passive regions, the soils having *pH* more than 9·5 will not be corrosive, except in a small region beyond 12·2. All the tested soils have their *pH* in the corrosive range. The soils having *pH* more than 9·5 are very rare. Hence in natural soils the passivating influence due to *pH* will be rarely observed. The corrosivity of soils in the *pH* range 4 to 10 is independent of *pH*. In this region the corrosion proceeds only by electrochemical mechanism and depends upon the rate of diffusion of oxygen to the cathodic surface. But in the acidic region ($pH<4$) both, direct chemical corrosion by hydrogen evolution and electrochemical corrosion, will occur. Consequently the corrosivity of such a soil will be enhanced[38]. Because of this reason, Alleppey peaty soil ($pH=2 \cdot 5$) exhibits significantly high corrosivity.

The nature and concentration of soluble salts present in a soil are one of the principal factors which control corrosion reaction[9, 35]. The corrosivity of a soil towards ferrous metals usually increases with increase in the concentration of soluble salts, like chlorides, sulphates and nitrates of soluble alkali and alkaline earth metals[39]. This is due to the enhanced conductivity of soil[9], change in film properties to become more permeable for ions[39] and activating influence of anions due to preferential adsorption[40]. Salts like ferrous sulphate

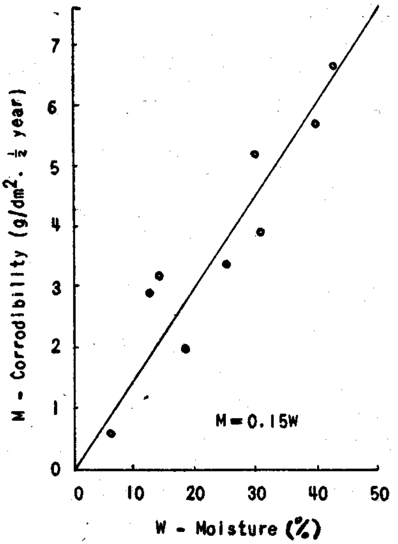

Fig. 7—Moisture—Corrodibility curve.

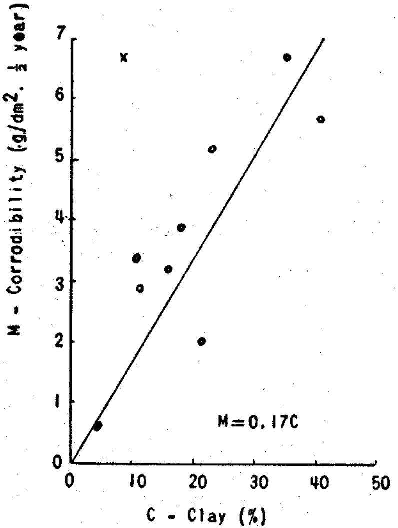

Fig. 8—Clay content—Corrodibility curve.

hydrolyse and lower the soil *pH* and hence increase soil corrosivity[39]. Certain oxidising ions like Fe^{3+} increase soil corrosivity by functioning as cathodic depolarisers[39, 41]. High corrosivity of Delhi saline soil is primarily due to high concentration of soluble electrolytes. High concentration of ferrous sulphate in Alleppey peaty soil has the effect of lowering the *pH* of the soil, increasing thereby its corrosivity Fe^{3+} ions present in the same soil exert the depolarising influence over cathodic areas.

No index of soil corrosivity based on the concentration of soluble salts has been found to be of general applicability. Soil corrosivity, as given by Schwerdtfeger's soil corrosion test, has been found to be directly proportional to an index 'Anion' concentration/Moisture[14]. In the case of the results presented in this paper such a relationship has not been found. The index was based on observations of ferrous metals in Durgapur-Calcutta (Bengal) soils. This relationship may be applicable in the cases of similar soils belonging to one class but differing in salt content. Absence of any correlation between soil corrosivity and a factor based on soluble salts concentration is easily understandable because of multiplicity of influences exerted by salts on corrosion, viz. resistivity, electrode potential, film properties, adsorption, etc.

ACKNOWLEDGEMENTS

The authors are thankful to Dr. K. Subba Rao, Assistant Director Defence Science Laboratory, Delhi for his keen interest in the work and Dr. S. Govindarajan, Chief Soil Survey Officer, Indian Agricultural Research Institute, New Delhi for help in the procurement of soils.

REFERENCES

1 Romanoff, M., "Underground Corrosion", (National Bureau of Standards Circular 579, Department of Commerce, USA) 1957.

2 "Corrosion of Buried Metals", Spl. Report No. 45, (The Iron and Steel Institute, London), 1952.

3 Denison, I.A., *J. Res. nat. Bur. Stand.*, **17** (1936), 363.

4 Denison, I.A. & Ewing, S.P., *Soil Sci.*, **40** (1953), 287.

5 Denison, I.A. & Romanoff, M., *Corrosion*, **9** (1953), 141.

6 Schwerdtfeger, W.J. & McDorman, O.N., *J. Electrochem. Soc.*, **99** (1952), 407.

7 *id.*, *Corrosion*, **8** (1952), 391.

8 Schwerdtfeger, W.J., *j Res. nat. Bur. Stand.*, **50** (1953), 329.

9 Tripathi, B.N., "Accelerated Testing Procedures for the Electrochemical Corrosion of Metals in Soils" *Symp. Testing and Evaluation*, (Govt. Test House, Calcutta), 1964.

10 Solti, M. & Harvath, J., *Magyar, Kemiai. folyoirat.*, Hungary, **61** (1955), 427.

11 Langhi. P.F., *Rev. fae. cience. quim. Univ. nasl. La Plata.*, 31 (1959), **81**, *Chem. Abstr.* **54**. (1960). 22298^1.

12 Lejeune, G. & Arnold, G., *Compt. rend.*, **240** (1955), 343.

13 Chatterji, B. & Gupta, U.P., *Indian J. appl. Chem.*, **22** (1959), 159.

14 Roy, K., Sarkar, M. & Chatterji, B., *Indian J. appl. Chem.*, **24** (1961), 113.

15 *id.*, *J. Indian Chem. Soc.*, **39** (1962), 581.

16 —— *ibid*, **39** (1962), 568.

17 Roychowdhury, S.P., "*Final Report of All India Soil Survey Scheme*, Bull. No. 73" "(The Indian Council of Agricultural Research, New Delhi)" 1953 p. 13, *J. Indian Soc. Soil Sci.*, **10** (1962), 1.

18 Govindrajan, S.V., "Soil Map of India", (The Indian Agricultural Research Institute, New Delhi) 1962.

19 Uhlig, H.H., "Corrosion and Corrosion Control" (John Wiley and Sons, New York) 1963, p. 150.

20 "Procedure For Testing Soil" (American Society for Testing Materials, Philadelphia, Pa, U.S.A.) 1950, p. 70.

21 SUBBA RAO, K., RAMACHARLU, P.T. & TALWAR, P.S., *J. Indian Soc. Soil Sci.*, **3** (1955), 1.

22 "Procedure for Testing Soils", (American Society for Testing Materials, Philadelphia, Pa, U.S.A.) 1950, p. 61.

23 BOUYOUCOS, G.J., *Soil Sci.*, **40** (1935), 165.

24 PIPER, S., "Soil and Plant Analysis" (The University of Adelaide, Adelaide) 1950, p. 59.

25 HESTER, "Diagnostic Techniques" (American Potash Institute, Washington, D.C.) 1948, p. 112.

26 JACKSON, M.L., "Soil Chemical Analysis" (Constable and Co. Ltd., London) 1958, p. 227.

27 RAI, R.M., PANDE, P.C. & TRIPATHI, B.N., Analytical Aspects of Azovan Blue: Colorimetric Microestimation of Magnesium, *Indian J. Chem.*, (1965).

28 BENNET, C.A. & FRANKLIN, N.L., "Statistical Analysis in Chemistry and Chemical Industry" (John Wiley and Sons, New York) 1954.

29 GRUNBACH. A, *Journess dess Etate de Surface*, 1946, 3739.

30 EVANS, U.R., "Properties of metallic surfaces" (The Institute of Metals, London) 1953, p. 253.

31 SAMUELS, L.E., *J. Inst. Met.*, **85** (1956) 51; *Research*, **21** (1959), 163; "Finishing of Aluminium" (Reinhold, London), 1963, p. 192.

32 WILLIAMS, K.J., "Proc. Conference on Lubrication and Wear" (Institute of Mechanical Engineers, London) 1959, p. 602,

33 GIRADET, L.R., *Journess Fonderie* Paris, (1945), 197.

34 GREENE, N.D., & Fontana, M.G., *Corrosion*, **15** (1959), 25 *t*.

35 PALMER, E., *Iva*, **17** (1946), 48.

36 Herzog, E., *Metaux et. Corrosion*, **24** (1949), 119.

37 POURBAIX, M., "Proc. Seventh Meeting of the International Committee of Electrochemical Thermodynamics and Kinetics, Lindau 1955" (Butterworths Scientific Publication, London) 1957, p. 189.

38 UHLIG H.H., "Corrosion and Corrosion Control" (John Wiley and Sons, New York), 1963, p. 85.

39 UHLIG H.H., *Ibid*, p. 98.

40 KABANOV, B., BURSTEIN, R. & FRUMKIN, A., Electrode Process, Discussion of Faraday Society, No. 1. 1947 (Butterworths Scientific Publication, London) 1961, p. 268.

41 GATOS, H.C., *Corrosion*, **12** (1956), 322 *t*.