

CORROSION OF MILD STEEL BY SOILS OF SHELBY COUNTY, TENNESSEE, AND THEIR INFRA-RED SPECTRA: A CORRELATIONAL STUDY

GLADIUS LEWIS, G. ED AUSTIN, AND TONY PINSON

Department of Mechanical Engineering, Memphis State University, Memphis, TN 38152
Dover Elevator Systems, Inc., Memphis, TN 38101
Memphis Light, Gas, and Water, Memphis, TN 38145

ABSTRACT--From a study of the infra-red spectra of six soil types found in Shelby Co., Tennessee, and the corrosion of mild steel in contact with the soils, it was found that strong relationships exist between the corrosion rate and the concentration of either Si-OH (absorbed water) or Al-O (alumina) species in a soil. It was concluded that either of these concentrations may be used as a predictor of the corrosivity of a soil.

There are extensive networks of buried steel pipelines and tanks used for transportation and storage of natural gas, gasoline, water, or chemicals. In general, corrosion rates of these structures by soils are not high, but, over long periods, such corrosion (if unchecked) can result in catastrophic consequences (such as loss of product and contamination of the soil), necessitating either replacement or extensive retrofitting. The economic liabilities associated with the long-term corrosion of underground gasoline storage tanks in service stations illustrate this point.

Part of the decision to bury a metallic structure should be predicated upon the results of either long-term tests of the corrosion of the metal/alloy at the proposed site or short-term electrochemical tests of the metal/alloy-soil system. The former methods are limited by cost, while the latter may only be conducted in laboratories that have the requisite equipment, such as potentiostats and alternating current impedance instrumentation. An alternative approach to both of the aforementioned methods involves identifying some easily-measured properties of soil which may be used as predictors of its corrosivity toward metals.

Over the years, some research has been devoted to finding such predictors, and three are in popular use: pH, electrical resistivity, and redox potential. However, for a variety of reasons, there is a lack of unanimity with regard to their utility.

In exceptionally acidic soils, corrosion occurs notably because, under these conditions, hydrogen depolarization can proceed with considerable speed. Then, electrical conductivity is unimportant since the cathodic points on the metallic structure where hydrogen is formed will be close to the anodic points where corrosion occurs. However, a low soil pH is not necessarily an indication of high corrosivity since, unless the soil possesses a strong buffer action, the pH will increase concomitantly with the initiation of corrosion. Probably, therefore, total acidity of a soil is a better index of its corrosivity.

Where the soil is insufficiently acidic and microbial corrosion is not expected, soil resistivity becomes important for two reasons. First, current may flow long distances from the cathodic points on the structure immersed in the soil to the anodic points. Second, oxygen is the major cathodic reactant, and sections of the immersed structure that are accessible to air may be well removed from anodic corrosion sites. A correlation between soil resistivity, ρ , and corrosivity has been sought, but very limited success has been achieved in this area (Jones, 1992).

The indications are that soils with ρ less than about 500 Ω .cm are potentially very corrosive, but, at $\rho > 1,000 \Omega$.cm, it is difficult to assess soil corrosivity from its resistivity.

The redox potential, θ , of the soil (measured in situ with the aid of a suitable probe) gives some indication of the soil's corrosivity. In general, it has been found (Miller, 1970) that water-saturated, biologically-active soils with values of θ of <100 mV (versus the standard hydrogen electrode, SHE) and >400 mV (versus SHE) are, respectively, very corrosive and noncorrosive.

The present work is a contribution to this search for predictors of soil corrosivity. The objective was to investigate whether the heights of some functional groups in the infra-red spectrum of a soil specimen are strongly correlated to the corrosion rate of mild steel in the soil.

METHODS

Representative specimens of six types of soils (see Table 1 for some relevant characteristics) in Shelby Co., Tennessee, were collected from a depth of 0.3 m and brought to the laboratory. There they were properly dried (to a constant weight over a 14-day period), pulverized, and passed through a no. 100-mesh sieve. This final product constituted the "test soil specimen." The infra-red spectra of these test specimens were obtained using an infra-red spectrophotometer (Polaris model; Mattson Instruments, Inc., Madison, Wisconsin) and the KBr Mull method (Fritz and Schenk, 1974). In each mull, the concentration of the dried soil was a constant value (2 mg of soil/200 mg of KBr). A pressure of 460 MPa was used in pressing a mull disc. On each infra-red curve, the absorbance peaks at different wavelengths were noted, and the height of each peak was measured using the base-line method (Fritz and Schenk, 1974). The various infra-red peaks (functional groups) of interest are presented in Table 2.

For the corrosion (mass loss) tests, mild steel specimens (50 by 25 by 2 mm) were used. Specimens were carefully polished with emery paper, degreased with acetone, and air-dried, and then their masses were obtained. The specimens were then buried at 0.3 m below the surface at each of the sites from which the soil specimens had been taken. After 70 days, the specimens were removed and properly cleaned. This cleaning procedure involved: a gentle scrub with a smooth-bristled

TABLE 1. Some characteristics of the test soil types in Shelby Co., Tennessee (from Sease et al., 1970).

Soil type	Permeability of water (mm/h)	Available water capacity (mm/mm of soil)	pH	Texture ¹	Unified soil classification ²	AASHTO classification ³
Bonn	5-16	0.22	6.1-7.3	Silt loam	ML	A4
Collins	16-51	0.22	5.1-5.5	Silt loam	ML	A4
Falaya	16-51	0.20	5.1-5.5	Silt loam	ML or ML-CL	A4
Graded	16-51	0.20	5.1-6.5	Silt loam	ML or ML-CL	A4
Memphis	16-51	0.22	5.1-5.5	Silt loam	ML	A4
Tunica	5-16	0.17	6.1-7.8	Clay	CH or MH-CH	A7

¹United States Department of Agriculture grain size classification system that specifies a soil in terms of its sand, silt, and clay contents (by weight).

²ML = silt with low plasticity; CL = clay with low plasticity; MH = silt with high plasticity; CH = clay with high plasticity.

³A4 = silty soil; A7 = clayey soil.

brush (to remove loose soil particles); a wash in a 3:1 (by volume) ethyl alcohol:water solution; a rinse in tap water; a very gentle rub with emery paper (to remove all rust layers); a wash in acetone; a rinse in tap water; and drying in ambient air. Then their masses were obtained. Linear regression analysis was conducted on the body of data comprising the heights of each of the infra-red peaks of interest (deemed to be proportional to the concentration of the absorbing species) in a test specimen and the corrosion rate of the mild steel (in milligrams per square centimeter per day) in the corresponding soil type.

RESULTS AND DISCUSSION

A typical infra-red spectrum of a test specimen is presented in Fig. 1. The heights of the infra-red peaks of interest and the corresponding corrosion rates for mild steel in the soils are given in Table 3. It is recognized that the test period used in the present work is short. However, whatever changes occur in a soil over time are not expected to significantly affect the corrosion mechanism (and, hence, rate) of a material in it. The corrosion rates for mild steel obtained in the present work are, in fact, within the range of values reported for steels in comparable soils, obtained after exposure for periods of several years (Uhlir and Revie, 1985).

The results of the linear regression analysis are given in Table 4. The dependence of corrosion rate on the height of the Si-OH(2), Si-O, or Al-O peak is statistically significant. However, in the case of the Si-O peak, it should be noted that the regression equation was computed

from data obtained on only four of the six test soils (the peak was absent from the other two; see Table 3). In addition, the level of confidence in the regression equation for height of the Si-O peak (99%) is lower than that in the regression equations for heights of the Si-OH(2) and Al-O peaks (99.9%). It is, thus, uncertain whether the regression equation for height of the Si-O peak represents a true relationship. For these reasons, it is not recommended that the Si-O peak height be used for estimating corrosion rates.

This leads to consideration being focused on the regression equations using height of Si-OH(2) or Al-O peaks for predicting corrosion rates. A consequence of this result is that soils having high peak heights of the Si-OH(2) and Al-O functional groups in their infra-red spectra, due to high amounts of either absorbed water or attachment of humic substances with alumina in the soil structure, will be very corrosive toward mild steel. In general, corrosion of a metallic material in a soil is controlled by diffusion of dissolved oxygen in the water entrapped in the soil; thus, it is suggested that high absorbed water will result in high

TABLE 2. Peaks of interest in the infra-red spectrum of a soil (from Cross and Jones, 1969).

Peak	Comment	Wavelength (μm)
Si-OH(1)	Bonded and unbonded water peak or absorbed water peak	2.7-3.0
Si-OH(2)	Absorbed water peak	5.0-8.0
Si-O	Silica peak	8.5-9.5
Al-O	Alumina peak	9.5-10.3
Si-H	pH peak	11.0-11.3
Si-C(3)	Carbon peak	12.0-15.0

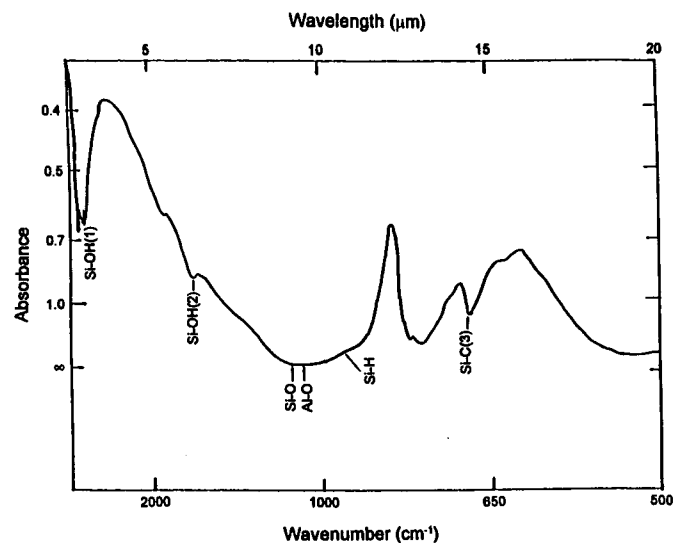


FIG. 1. Infra-red spectrum of soil sample from the Bonn site, Shelby Co., Tennessee. The relevant functional groups are labeled.

TABLE 3. Heights of infra-red peaks or functional groups of soils and corrosion rate (in milligrams per square centimeter per day) of mild steel in soils from Shelby Co., Tennessee.

Soil type ¹	Height of functional group in infra-red spectra ²						Corrosion rate of mild steel ($\bar{X} \pm 1 SD$)
	Si-OH(1)	Si-OH(2)	Si-O	Al-O	Si-H	Si-C(3)	
Bonn	22.60	23.00	13.81	1.21	2.81	7.51	0.226 \pm 0.046
Collins	24.81	11.80		1.01	3.62	7.90	0.101 \pm 0.006
Falaya	9.10	7.01	3.01	0.86	4.81	7.31	0.048 \pm 0.004
Graded	16.20	11.20	2.51	0.96	5.32	8.70	0.097 \pm 0.005
Memphis	8.81	6.01	1.10	0.70	1.51	3.81	0.035 \pm 0.004
Tunica	19.00	15.41		1.00	6.20	10.90	0.137 \pm 0.027

¹Specific locations of soils in Shelby Co., as used in the present work, are: Bonn (Shelby County Penal Farm); Collins (8 m E Germantown Road, 276 m N I-40); Tunica (Ensley Bottoms; 2 m S Memphis Steam Plant); Falaya (30 m N Raines Road, 1.2 km E Outland Road); Graded (Overton Crossing, Memphis); Memphis (5 km N Eads, 18 m W Collierville-Arlington Road). Si-O peak was absent in spectrum for Collins and Tunica soil types.

²Arbitrary units; range of coefficient of variation of heights of infra-red peaks = 4-7%.

corrosion. Attachment of humic substances is an indicator of the quantity of organic matter in a soil which, in turn, translates to bacterial activity in the soil. High bacterial activity in a soil leads to high corrosion of materials by the soil (Jones, 1992). The main finding of the present study is that, in the case of mild steel corroding in soils in Shelby Co., Tennessee, there is a strong direct relationship between the corrosion rate of the alloy and the height of either the Si-OH (absorbed water) peak or the Al-O (alumina) peak in the infra-red spectra of the soil.

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TABLE 4. Results of linear regression analysis of height of infra-red peak and corrosion rate of mild steel.

Regression equation ¹	R ²	SE of estimate of Y
Y = -0.022 + 0.0077X ₁	0.751	0.051
Y = -0.031 + 0.0111X ₂	0.999**	0.003
Y = 0.028 + 0.0143X ₃	0.962*	0.029
Y = -0.260 + 0.3835X ₄	0.943**	0.026
Y = 0.095 + 0.0030X ₅	0.075	0.077
Y = 0.002 + 0.0137X ₆	0.458	0.069

¹Y = corrosion rate of mild steel (milligrams per square centimeter per day); X₁ = height of the Si-OH(1) peak (arbitrary units); X₂ = height of the Si-OH(2) peak (arbitrary units); X₃ = height of the Si-O peak (arbitrary units); X₄ = height of the Al-O peak (arbitrary units); X₅ = height of the Si-H peak (arbitrary units); X₆ = height of the Si-C peak (arbitrary units).

²Coefficient of correlation (adjusted for degrees of freedom).

*Significant at the 1.0% level.

**Significant at the 0.1% level.

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