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Corrosion Behaviors of API 5 L Carbon steel Pipelines in Trinidad's Soil Environment

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ABSTRACT

This study involved evaluating the corrosion resistance of American Petroleum Institute (API) ⁽¹⁾ 5L grade B, X52 and X70 carbon steel coupons in localized areas of Trinidad's soil environments, to determine the most suitable pipeline to be used in different soils. The investigation was inspired by the fact that pipeline life in soils varied throughout the country. A comparison was made between the results of the laboratory electrochemical techniques and the field gravimetric weight loss method. It revealed that corrosion rate trends between coupons in similar types of soil were comparable and corroborative. However, the corrosion rate values did not compare well with the two methods, but they both revealed that the API X70 steel had the greatest corrosion resistance in all soils, at the same time no appreciable statistical difference in corrosion rates. This was followed by the X52 and finally the 5L grade B steel. The analysis showed that microstructures having finer grain sizes with less pearlite gave better corrosion performance. The analysis also indicated that the most corrosive soil was peaty clay soil followed by the Silty clay soil, and finally the sandy soil. After one-year retrieval of coupons, all displayed general and pitting corrosion. Additionally, coupons from the silty clay and the peaty clay soils showed irregular shaped pit morphology typical of Sulfate-reducing bacteria (SRB).

Key words: API 5 L line pipes, Carbon steel, Corrosion Rate, Soil Type

INTRODUCTION

Trinidad and Tobago being the largest producer of oil and natural gas in the Caribbean has the largest pipeline industry. Corrosion can severely affect the pipeline operations that can lead to loss in production, unscheduled downtime for maintenance or repair, and even catastrophic failures that impact on health, safety and the environment. The corrosion behavior of ferrous pipeline in soil depends primarily on the nature of soil and certain other environmental factors, such as the availability of moisture and oxygen.¹ The mineral composition of soil also influences the corrosion rate. External corrosion has been among the most dominant failure mechanism experienced by buried steel pipelines. The corrosion rate can be estimated based on the use of buried corrosion coupons and corrosion rate

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modeling using data derived from soil analysis. The metal loss information can be utilized to model the external corrosion experienced by ferrous pipelines exposed to various soil conditions (soil types, properties and contents) or to verify corrosion potential data gained through electrochemical techniques that include linear polarization resistance (LPR), and Potentiodynamic polarization (POD) methods.¹

EXPERIMENTAL PROCEDURE

The research duration for this study was designed to be completed in a fifteen (15) month period and was divided into several stages, one month for initial data collection, site visits and establishing of research method. This was followed by another one month for soil sampling, experimental set up and preparation of testing materials. Upon completion of the initial activities, corrosion experimental studies and simulation of corrosion growth rates were carried out in stage two (2) for another month. This included setting up similar grades of the steel coupons used in the field study with similar soil type environments and placing them in a corrosion cell to be analyzed using electrochemical techniques. Stage three (3) activities included setting up coupons for field study experiment using Gravimetric Weight Loss method, where coupons were collected and analyzed every three months (3) for the period of one (1) year. This method involved weighing the specimens before the exposure period and then reweighing them after retrieval.

Soil Sampling and Coupon Burial Sites

Soil samples were collected from three (3) different sites in Trinidad and brought to the laboratory immediately for soil analysis; samples were collected from holes dug one (1) meter in depth. The types of soil selected at the three (3) different sites include: Site #1 described as grey coarse sand with a trace of silt (sandy soil); Site #2 described as Dark grey clay and silt with traces of sand (silty clay soil); Site #3 described as black peat bogs silty clay with traces of fine sand (peaty clay soil).

The samples were stored in zip-lock polyethylene bags before being brought to the lab for analysis.

The procedures for the field work required twelve (12) holes dug one meter deep and one meter apart, at each one of the three site locations. Each hole accommodated three steel coupons of similar carbon grade steel and designated a, b and c respectively. They were then placed in open polythene bags containing the soil material of the site.

The three soil samples together with one set of three coupons, from each grade of steel were then retrieved from each site every three months to be analyzed at the laboratory. This process was repeated for a period of 1 year.

Coupons Preparation and Documentations

The steel coupons, each 40 mm x 60 mm, were sectioned from actual segments of carbon steel as pipeline material that were typically used in the oil and gas industry, and include API 5L grade B steel; X52; and X70 respectively. A typical coupon displaying steel grade (red arrow), site # (blue arrow) and time for retrieval (yellow arrow) is shown in Figure 1.

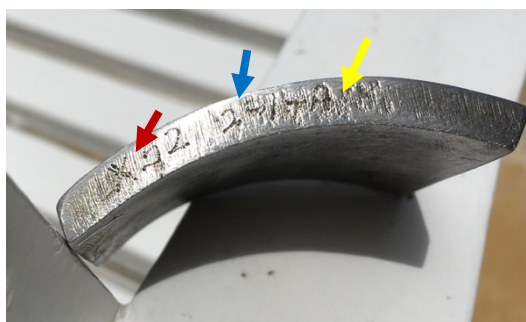


Figure 1: Typical ground steel coupon displaying the steel grade

Each sample coupon was ground on all sides using silicon carbide emery papers through grits 150, 240, 400, to 600, then rinsed with deionized water, and degreased with acetone. The samples were then engraved by means of a vibratory marking tool at the sides to identify the coupons grade of steel. To identify the microstructure of different grade steels, metallographic samples were prepared in accordance with ASTM E 3 Standard ² i.e. they were ground; polished and etched to reveal the phases. The microstructures of (a) API 5L B; (b) X52; & (c) X70 all display a ferrite/pearlite structure. The ferrite is identified with the red arrows while the pearlite shows a spheroidized grain structure and is identified with the white arrows in Figure 2.

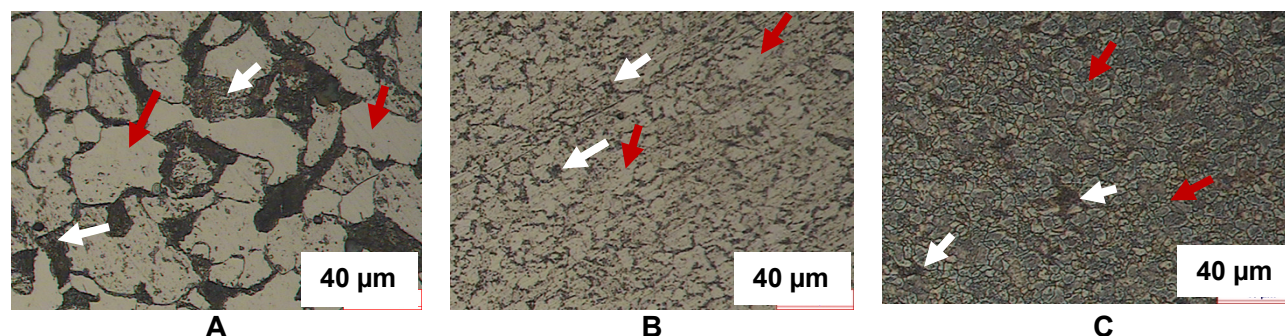


Figure 2: Microstructures of (A) API 5L Grade B, (B) X52 and (C) X70 carbon steel at magnifications x500

All studied materials were formed principally from ferrite grains. The grain sizes were measured in accordance with ASTM E 1 standard ³ and ranged in grain sizes ASTM #2 for API 5L B; #5 for X52; & #7 for X70 respectively, grain size #2 being the largest grain and #7 being the smallest. The presence of low quantities of niobium, titanium and vanadium in the steel composition helped to generate these fine-grained structures. By allowing the hot-rolling process to occur at lower temperatures, a finer austenite grain microstructure was produced, which resulted in finer ferrite grain sizes after transformation during cooling. There was also less pearlite being formed in the finer grain structures due to the gradual lowering of the carbon content that limits the rate of corrosion.⁴

Properties of API 5L carbon steel

The tensile properties i.e. the Yield Strength (YS) and Tensile Strength (TS) values (MPa), together with the elemental analysis (% composition by weight) of the different steel grades is shown in Table 1.

Table 1
Tensile and Elemental Properties of API 5 L Carbon Grade Steel

Grades	YS (MPa)	TS (MPa)	C %	S %	P %	Si %	Mn %	Cr %	Cu %	V %	Ti %	Al %	W %	Nb %
5 L B	240	415	0.21	0.009	0.013	0.20	0.46	0.01	0.11	-	-	-	-	-
X52	358	455	0.20	0.006	0.009	0.20	0.99	0.04	0.13	0.06	-	0.01	0.01	-
X70	482	565	0.18	0.001	0.007	0.17	1.37	0.05	0.16	0.04	0.01	0.02	-	0.03

The yield and tensile strength values from Table 1 confirm the classification of API 5L steels as a high strength pipe material.⁵

Soil Properties Test

Soil properties tests were performed to determine the type of soil, with respect of their parameters comprising moisture content, liquid limit, plastic limit and plasticity index. Moisture content of the soil samples was performed using the weight loss technique according to BS 1377.⁶ The plastic limit (PL) is

determined by rolling out a thread of the fine portion of a soil on a flat, non-porous surface. The procedure is defined in ASTM Standard D 425.⁷ The plastic limit is defined as the moisture content where the thread breaks apart at a diameter of 3.2 mm. A soil is considered non-plastic if a thread cannot be rolled out down to 3.2 mm at any moisture possible. Sandy soil (site #1) could not be rolled out so it is considered non-plastic. The liquid limit (LL) is defined as the water content at which the behavior of a clayey soil changes from plastic to liquid. The cone penetrometer test was used. The liquid limit is defined as the water content of the soil which allows the cone to penetrate exactly 20 mm during that period of time. The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit ($PI = LL - PL$). Soils with a high PI tend to be clayey, those with a lower PI tend to be silty, and those with a PI of 0 (non-plastic) tend to have little or no silt or clay. The properties of the investigated soils at the sites are included in Table 2.

Table 2
Soil Properties from different sites

Sites	Moisture Content	Liquid Limit	Plastic Limit	Plasticity Index
Site 1	21.5	30	0	0
Site 2	26.3	89	27	62
Site 3	26.9	39	15	24

Soil Corrosivity Test

This test is conducted to determine the effect of soil towards buried pipelines in the studied areas. Adopting the BS 1377,⁶ for soil corrosivity testing, the following parameters were analyzed: pH; temperature; soil type; moisture content; resistivity; oxidation-reduction potential (ORP); Sulphur and chloride content. The pH and temperature were determined in-situ using a multi-parameter quality monitor according to ASTM G51.⁸ Redox potential of the soil samples was measured according to BS 1377;⁶ it was carried out immediately after sampling to avoid the changes of its characteristics. Chloride (Cl⁻) and Sulphate content of the soil samples were determined according to BS 1377. The Sulphate content was determined by the gravimetric method. Barium chloride solution was added to the water extract and the precipitate of barium sulphate was collected, dried and weighed. Whereas the Chloride was extracted with water and a titration process occurred with silver nitrate. The soils corrosivity test is shown below.

Table 3
Soil Corrosivity Test Results

Sites	pH	Resistivity (Ohm cm)	Temp °C	ORP (V vs SHE)	Chloride (ppm)	Sulphate (ppm)
Site 1	7.82	9,260	21.5	0.60	37.3	42.8
Site 2	6.59	825	22.0	0.053	59.5	225.8
Site 3	6.43	597	22.1	0.055	154.7	668.4

Compound Analysis of Soils

Soil samples from each of the three sites were prepared by first grinding representative samples of the soils to a powder, then compressing them to form powdered discs, finally analyzing the soil compounds with the use of X-Ray Diffraction (XRD). A qualitative analysis technique was employed that uses in-built software from the X-ray powder diffraction data to determine the compounds present. Compound analysis of the soil samples from the three sites are shown below.

Table 4
Compound Analysis of soil Particles

Compounds and Formulas	Site 1	Site 2	Site 3
Quartz [SiO ₂]	√	√	√
Montmorillonite [(Na,Ca) _{0.3} (Al,Mg) ₂ Si ₄ O ₁₀ (OH) ₂ ·xH ₂ O]	0	√	0
Dickite [Al ₂ Si ₂ O ₅ (OH) ₄]	0	√	0
Muscovite [KAl ₃ Si ₃ O ₁₀ (OH) ₂]	0	√	√
Kaolinite [Al ₂ Si ₂ O ₅ (OH) ₄]	0	0	√
Pyrite [FeS ₂]	0	0	√

Laboratory Electrochemical Test Methods

Soils samples from the different sites were first air dried then passed through a No. 20 mesh (0.841 mm) sieve. The samples were then placed in a beaker and saturated by pouring distilled water to maintain moisture content of approximately 26% and temperature 22 °C. Steel coupons of different grades to be tested were secured with epoxy to the mouth of each plastic jar opening. Soil solutions from each site location were then placed in their containers and the electrodes were connected to form the corrosion cell. The cell included a conventional three electrode plastic cell with a carbon rod counter electrode, and a saturated Silver-Silver Chloride Reference Electrode. The working electrode was the steel coupon that formed the disk and had an exposed area of 3.14 cm². The density of steel used was 7.87 gm/cm³ and the equivalent weight used by the software was 27.92 grams/equivalent (considered dimensionless in the calculation). Electrochemical tests were carried out using a Potentiostat. The techniques included LPR and POD methods. For the LPR method, polarization resistance (R_p) measurements were performed by applying a controlled potential scan over a small range, typically ± 15 mV with respect to corrosion potential (E_{corr}). The resulting current was linearly plotted against potential; the slope of this plot at E_{corr} was determined to be the R_p .

The POD curves were recorded by changing the electrode potential from -1.25 V to 850 mV versus open circuit potential (OCP) with scanning rate of 0.166 mV/s.⁹ All tests were performed at 20 °C. An example of a typical corrosion cell is shown in Figure 3.

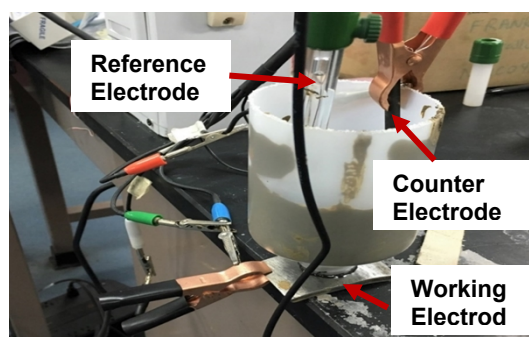


Figure 3: Corrosion cell attached to a Potentiostat

Gravimetric Weight Loss Test

The gravimetric weight loss test followed the procedures given in ASTM G 1,¹⁰ which were designed to remove corrosion products without significant removal of base metal. Corrosion products of the coupons were mechanically removed by scraping and brushing with the use of a nonmetallic bristle brush and mild abrasive-distilled water slurry. After that the specimens were rinsed in distilled water, dried in cold air and then weighed to obtain their final weights (W_1). Replicate un-corroded control specimens were cleaned by the same procedure being used on the test specimen. By weighing the control specimen before and after cleaning, the extent of metal loss resulting from cleaning was utilized to correct the corrosion mass loss. The weight loss (WL) was calculated using the formula: