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## Relationship Between *in-situ* Measurement of Soil Parameters and Metal Loss Volume of X70 Carbon Steel Coupon

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### ABSTRACT

Corrosion in soil environments is a serious threat to underground metallic structures such as oil and gas pipelines, waste containers and pilings. This study investigates the relationship between *in-situ* soil parameters and metal loss of X70 carbon steel. A total of 207 carbon steel coupons of X70 were installed underground at five sites for 18 months and have been retrieved every 3 months to measure the metal loss as a function of time. This study focused on *in-situ* corrosion parameters, namely, soil resistivity (Res), pH, moisture content (Mc) and chloride content (Cl). The results of corrosion metal loss and *in-situ* parameters were analyzed using statistical methods to obtain the relationship of the studied parameters to metal loss. Extreme data were removed through proper outlier's detection technique: Box plot, Dixon test and t-test. Corrosion test were then carried out to examine the relationship between *in-situ* measurement of soil parameters and metal loss. The results indicated that Mc, Cl and Res were found to be the most influential variables on the observed metal loss. An increase in Mc and Cl is likely to promote corrosion growth whereas higher resistivity will reduce the corrosion risk. Nevertheless, pH was found to be relatively insignificant to the corrosion process.

**Key words:** Carbon steel, soil corrosion, *in situ* parameters, soil environment

### INTRODUCTION

Corrosion in the soil environment is a serious threat to underground metallic structures such as waste containers, pilings, oil and gas pipelines and other structures (Noor *et al.*, 2011; Norhazilan *et al.*, 2012; Li *et al.*, 2013). Networks of pipeline systems have been employed as the most efficient method to transport many substances such as liquids and gases all around the world. Pipelines that are buried or located above the ground throughout their service life are susceptible to corrosion. As the pipeline structures are exposed underground, they are potentially subjected to external corrosion.

External corrosion is recognized as one of the major causes of underground pipeline failures (Beavers *et al.*, 2006; Velazquez *et al.*, 2009; Noor *et al.*, 2008; Yahaya *et al.*, 2011). Unprotected underground pipelines tend to corrode externally due to corrosion cell development between soils

and pipes (Alamilla *et al.*, 2009). Soil corrosion is recognized as the fundamental cause of the deterioration of underground pipelines (Norin, 1998; Katano *et al.*, 2003). Incidents related to pipeline failures can have severe consequences such as human casualties and environmental and economic impacts (Rim-Rukeh and Awatefe, 2006; Alamilla *et al.*, 2009).

Mughabghab and Sullivan (1989) stated that there are four major areas that contribute to underground corrosion: Soil texture and aeration (control of the amount of oxygen and moisture), electrolyte factors (e.g., dissolved salts, pH and resistivity), electrical factors (e.g., pipe-to-soil potential) and miscellaneous factors (e.g., microbial corrosion and non-uniform backfilling). Each of these factors can contribute to the formation of anodic and cathodic areas on a metal surface in a soil environment.

Information on soil parameters is important for the assessment of soil corrosivity. *In-situ* methods utilize assumptions of increasing importance and have been recognized by practicing engineers. The advantages of *in-situ* tests may be classified in a number of ways, including cost, less time consumption, simplicity of use and real-time information for on-site decision making. They can reduce the time and cost of soil sample transportation for soil parameter analysis in laboratory and are hence more time-efficient and cost effective. According to Escalante (1989), ideally such a measurement is non-destructive, can be made *in situ* and is reproducible. *In-situ* measurement of soil parameters can help provide instant assessment of soil corrosiveness and decision making on site.

The accuracy of the available *in-situ* equipment such as pH, redox potential and soil resistivity is better than in the laboratory (Hem, 1985; Edgar, 1989; Palmer, 1990). Hem (1985) mentioned that *in-situ* pH measurements are considered to be more accurate assessments in precipitation chemistry than subsequent laboratory measurements. According to Palmer (1990), redox potential testing on a removed sample is unreliable and a waste of time if the sample is bagged, tossed in the trunk and tested in the lab days later. Besides that, the soil resistivity values of soil-sample testing in the laboratory are known to be much lower than the actual resistivity in the field due to the disturbed samples (Edgar, 1989; Palmer, 1990). Moreover, the results from *in-situ* measurement of chloride content, moisture content and salinity are comparable with laboratory results. Therefore, this research has been carried out to investigate the relationship between soil corrosivity parameters and metal loss based on *in-situ* measurements.

## MATERIALS AND METHODS

**Steel coupons preparation:** A total of 207 carbon steel coupons were installed underground at five sites located in the east coast of Peninsular Malaysia for 18 months. The coupon materials used in this research were X70 carbon steel pipes machined from actual pipe sections. The pipe segments were cut into the desired dimensions (60×80 mm) for fieldwork purposes as shown in Fig. 1. A repetitive retrieval of the coupons was done every 3 months to measure the time-function metal loss volume.

***In-situ* parameters measurement:** Four environmental factors were studied: Soil resistivity (Res), pH, moisture content (Mc) and chloride content (Cl). The *in-situ* parameters measurement was carried out repeatedly during coupon retrieval to develop the relationship between metal loss and the studied parameter. The selected parameters with their equipment are shown in Fig. 2 and Table 1.

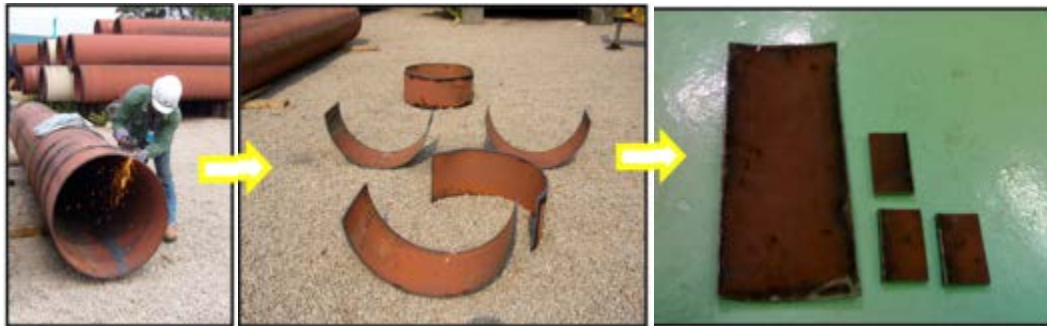


Fig. 1: Pipe segments cut into smaller size



Fig. 2(a-d): *In-situ* parameter measurement, (a) Soil resistivity, (b) pH, (c) Chloride and (d) Moisture content

Table 1: *In-situ* parameters and instruments

<i>In-situ</i> parameters	Unit	Instruments
Resistivity	Res ( $\Omega$ .cm)	Wenner 4 electrode method
pH	-	pH meter
Chloride	Cl (ppm)	Chloride strip
Moisture content	Mc (%)	Moisture meter

**Metal loss measurement:** The corrosion products of all retrieved coupons from fieldwork were removed to determine the Metal Loss (ML) based on weight due to the corrosion process. The methods of corrosion product removal followed the procedures as stated in ASTM G1-03 (ASTM International, 2003).

**Statistical analysis:** Statistical analyses were performed on the measured data of *in-situ* parameters and metal loss to achieve the objective of this study. Outlier's detection was performed using proper techniques such as box plot, Dixon test and t-test to minimize data error and avoid bias result. It was followed by correlation analysis to study the relationship between the independent variable (*in-situ* parameters) and the dependent variable (metal loss) by using statistical software SPSS 16.

**RESULTS**

**Metal loss and *in-situ* soil parameters:** A number of eight coupons were dug-out for each retrieval to measure the metal loss. The results of that eight were then averaged as a single data to represent the metal loss for the particular retrieval. At least three measurements of each *in-situ* soil parameters were also conducted during the retrieval and the value were averaged. Table 2 shows the averaged results of metal loss (dependent variable) and *in-situ* soil parameters (independent variables).

Table 2: Result of average metal loss and *in-situ* soil parameters

Site	Time (month)	ML (g)	Mc (%)	pH	Res (Ω.cm)	Cl (ppm)
A	3	3.441	3.3	5.96	57805	0
A	6	4.287	0.3	5.76	94248	0
A	9	4.477	8.0	5.96	81681	0
A	12	5.225	0.9	6.36	81681	0
A	15	7.173	7.5	5.76	67230	0
A	18	8.209	3.3	5.76	65345	0
B	3	5.472	35.0	6.05	459	84
B	6	8.729	45.0	6.61	559	66
B	9	10.049	31.0	6.05	496	84
B	12	14.927	50.0	6.73	503	43
B	15	17.552	50.0	5.05	503	75
B	18	32.258	35.2	5.65	440	36
C	3	3.574	37.0	4.79	94	455
C	6	9.664	36.7	4.36	82	0
C	9	10.719	50.0	6.00	94	1488
C	12	21.708	50.0	5.63	104	0
C	15	33.067	50.0	5.87	622	84
C	18	21.927	37.3	5.79	352	395
D	3	1.981	8.0	6.03	4335	0
D	6	2.865	6.5	6.44	53721	0
D	9	5.417	14.9	6.39	63774	0
D	12	5.384	11.4	7.02	25133	0
D	15	5.760	7.0	6.03	17593	0
D	18	8.024	8.0	6.39	40212	0
E	3	3.202	11.4	4.78	16965	0
E	6	4.667	20.2	4.43	13195	0
E	9	5.773	15.5	5.54	18221	0
E	12	7.554	9.7	5.19	21677	0
E	15	8.894	11.3	5.48	9425	0
E	18	8.507	11.4	5.81	21363	0

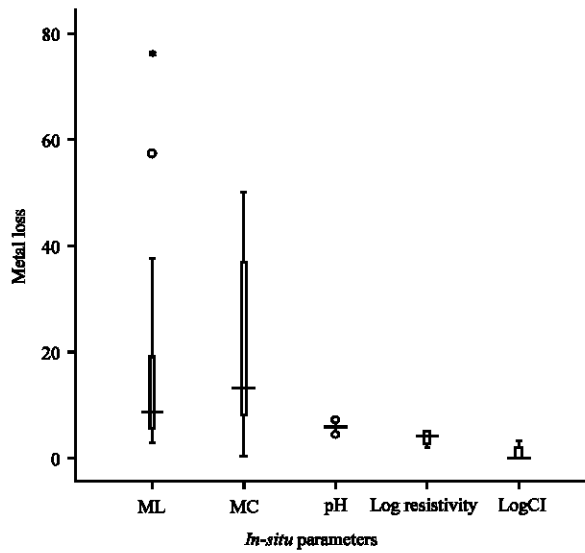


Fig. 3: Summary of box plot for metal loss and *in-situ* soil parameters

Table 3: Outliers calculation using dixon and t-test

No.	Metal loss data	Dixon test			Mean	S	T-test		
		$\frac{X_n - (X_n - 2)}{X_n - X_3}$	5% Sig. level	Conclusion			$\frac{X_n - \text{mean}}{s}$	5% Sig. level	Conclusion
16*	21.708	0.366	<0.393	Not outlier	7.527	4.552	3.115	>2.698	Outlier
18*	21.927	0.234	<0.387	Not outlier	8.041	5.231	2.654	<2.714	Not outlier
12*	32.258	0.363	<0.381	Not outlier	8.876	6.827	3.425	>2.730	Outlier
17*	33.067	0.373	<0.376	Not outlier	9.638	8.032	2.911	>2.745	Outlier

No.	pH data	Dixon test			Mean	S	T-test		
		$\frac{X_n - (X_n - 2)}{X_n - X_3}$	5% Sig. level	Conclusion			$\frac{X_n - \text{mean}}{s}$	5% Sig. level	Conclusion
14*	4.36	0.146	<0.381	Not outlier	5.888	0.536	2.068	<2.730	Not outlier
26*	4.43	0.165	<0.387	Not outlier	5.838	0.592	2.379	<2.714	Not outlier
22*	7.02	0.183	<0.376	Not outlier	5.789	0.641	1.920	<2.745	Not outlier

\*Indicates the data number as presented in Table 2

**Outlier’s detection:** Proper outlier’s detection techniques were performed to decide if doubtful results needed to be retained or rejected. The potential outliers for independent variables may be due to human error in measurement during fieldwork, whereas extreme potential outliers inherent in the metal loss data may be due to the overcleaning work (mechanical brushing) done to remove soil and rust on the coupon. Figure 3 presents the boxplot analysis for dependent and independent variable. The potential outliers which need further investigation were marked with asterisks and circles in Fig. 3.

The result of box plot indicates there are four and three potential outliers for metal loss and pH, respectively. These potential outliers were then rechecked using Dixon test and t-test and the results are shown in Table 3. Data found to be outliers in 2 of the 3 tests were considered spurious

Table 4: Results of pearson correlation test

Parameters	Metal loss	Log resistivity	Log Cl	Mc	pH
Metal loss	1	-0.541**	0.462**	0.652**	-0.027
Log resistivity		1	-0.760	-0.917	0.242
LogCl			1	0.778	0.031
Mc				1	-0.113
pH					

\*\*Significant correlation

and were removed because they could affect the later outcome, hence the removal of data No. 16, 12 and 17 for metal loss (bold value in Table 3) prior to correlation analysis.

**Pearson correlation test:** Table 4 shows the correlation coefficient results of a Pearson correlation test between each corrosion parameter. The first observation gleaned from the correlation table was the relative degree of influence exerted by each of the predictor variables on the observed corrosion metal loss. The analysis shows that there was a close correlation exhibited between the metal loss and soil variables such as Mc, Cl and Res.

## DISCUSSION

Based on the results, it was found that moisture content, resistivity and chloride content are the parameters that have a high correlation with metal loss. Resistivity showed a negative correlation, which indicates that metal loss increases when resistivity decreases, whereas an increase in moisture content and chloride content will increase the value of metal loss. The relationship of these three parameters with corrosion growth was in agreement with previous findings (Li, 2003; Rim-Rukeh and Awatefe, 2006; Velazquez *et al.*, 2009) and general soil corrosion theory. Water content plays an important role in the formation of hydroxyl ions that further react with ferrous ions to promote corrosion, whereas soil resistivity is closely related to the presence of electrolyte conductivity which is capable of transferring electrons from anode to cathode. This contributes to the weight loss of steel coupons.

The existence of chloride in soil increased the ability of electrolytes to conduct current and consequently enhanced the corrosion process. On the other hand, the contribution of pH showed a low relationship between this parameter and corrosion growth. This result exhibited a contradiction with previous findings, where pH had a significant effect on corrosion (Mughabghab and Sullivan, 1989). The result of pH value from on-site measurement indicated that the soil pH mostly ranged from 5 to 7. According to Ismail and El-Shamy (2009), a pH range of 5-8 is generally not considered to be a dominant variable affecting corrosion rate.

## CONCLUSION

In conclusion, moisture content, chloride and resistivity are the most influential factors on metal loss, whereas pH is relatively insignificant on underground corrosion. Underground metallic structures should be fully protected and maintained to avoid any interaction between aggressive soil parameters and metal surfaces in soil environments.

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