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RELATIONSHIP BETWEEN SOIL ENGINEERING PROPERTIES AND CORROSION RATE IN ANDESITIC VOLCANIC SOILS, WEST LAMPUNG, SUMATRA, INDONESIA

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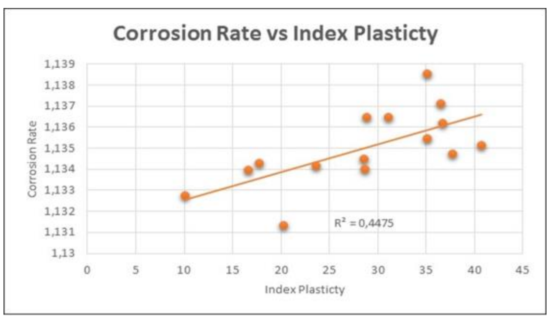
Graphical abstract



Abstract

Soil is the most diverse environment that can cause metal corrosion. Many researchers claim that soil is a corrosive environment that has complexity compared to other environments. With a background knowledge of soil engineering properties in a specific area and their effects on the metal corrosion process then corrosion problems can be prevented. This paper presents the relationship between andesitic volcanic soil engineering properties with an average corrosion rate based on geotechnical and statistical methods. In this paper, we propose a new average corrosion rate per year on that soil. The study area took place on the Sekincau-Way Tenong Transect Road, West Lampung, Sumatra, Indonesia. This area was composed of silty clay to clayey silt soils which weathering products from andesitic-basaltic volcanic breccia. This soil can store water that is moderate to high and has high plastic properties. Based on the statistical approach, it can be concluded that the corrosion rate in andesitic volcanic soils is 1.132 mm/yr. Soil engineering properties (water content, index plasticity, and clay content) simultaneously affect the average corrosion rate. The effective contribution of each independent variable (soil engineering properties) to the corrosion rate is a plasticity index of 39.5%, the water content of 24.79%, and clay content of 26.04%. Index plasticity and water content were found to raise the average corrosion rate at the soil samples, while clay content was on the side that lowered the average corrosion rate.

Keywords: Andesitic volcanic soils, average corrosion rate, soil engineering properties, Sumatra, Indonesia

1.0 INTRODUCTION

Soil is the part of the earth that results from the physical and chemical weathering of various types of rocks. It is consisting of grains which differ from one to another based on their size. Gravel, sand, silt, and clay are the particles that make up the soil. Gravel to sand particle size is about 2.00-0.02 mm, it is commonly called granular materials; silt particle size from 0.02 to 0.002 mm, while clay particle size < 0.002

mm, it is called cohesive materials. Granular soils have loose, easily separable, and grains characteristics, meanwhile, cohesive soils are plastic and deformed characteristics [28, 36, 4]. In addition to particle size, soil also contains organic and organisms matter, gases, and mineral particles [34].

The soil has an important role in the corrosion process [40]. Many researchers claim that soil is a corrosive environment that has complexity compared to other environments. Soil is the most diverse environment that can cause metal corrosion. Soil is an electrolyte that has high uncertainty, heterogeneous, dynamic, and will change every period. It has complex characteristics as the main agent causing external corrosion. Soil engineering properties have been identified as factors that influence the rate of external corrosion [11, 12, 25, 38, 32, 29, 40, 41, 42].

Corrosion is a process of degradation of the properties of a material due to reaction with the surrounding environment. The process is a complex phenomenon that involves many variables [26]. The corrosion process usually attacks metal structures that are in the ground, such as building metal structures and metal pipes [8]. Veleva (2005) stated that pipes in the ground could be perforated which causes leakage in one year due to corrosion. She concluded that soil engineering properties can determine the level of soil corrosion. Soil composed of silt and clay will have the highest level of corrosion compared to soil composed of coarse grains (gravel to sand), this is related to water content. Fine-grained soils will have poor drainage characteristics compared to coarse-grained soils, so fine-grained soils store more water [34]. On the other hand, Imafuku *et al.* (2013) discovered that uniform corrosion is observed in fine sand while ununiform corrosion is observed in clay, they conclude that the corrosion rate is much higher in clay [15].

With a background knowledge of soil engineering properties in a specific area and their effects on metal corrosion process (such as moisture content, liquid limit, plastic limit, index plasticity, clay content, soil PH, etc) then corrosion problems can be prevented [27, 10, 7]. Usually, the corrosion process is determined by the average corrosion rate per year (mm / yr).

The Effect of Soil Engineering Properties on Corrosion (Literature Review)

Many researchers have suggested how the soil engineering properties in a specific area determine the rate of corrosion. Research conducted by Myers and Cohen (1984) yielded several conclusions, one of which is corrosion generally associated with soils that have high water content characteristics and are in areas with an average rainfall of more than 76 cm/day [24]. Veleva (2005) mentioned that the two conditions necessary to initiate metal corrosion in the soil are water and oxygen, after these factors, several variables can affect the corrosion process [34]. Yahaya *et al.* (2011) found that based on the qualitative evaluation, soil moisture content was found more influential towards corrosion dynamic as compared to clay content [37]. Norhazilan *et al.* (2012) concluded that according to Multiple Regression and Analysis of Variance (ANOVA) test was performed at a 95% confidence level to examine the combined effect of moisture content, clay content, and index plasticity to corrosion dynamic [26]. In line with this, through soil properties multiple regression analysis, Kim *et al.* (2013) concluded that the equation obtained provides valuable information on the degree and rate of external pipe corrosion [17]. In Nigeria, Ikechukwu and friends (2014) suggest that research on the corrosion process involves other parameters such as moisture content, chloride content, soil, pH microbial load, sulfate content, organic content, and salinity [14]. In Saudi Arabia, Noor and Al-Moubaraki (2014) revealed that the corrosion rate of steel in soil tends to increase with increasing soil moisture content up to a maximum value of 10%, it then decreases at the moisture content of more than 10% [25]. Yan *et al.* (2014) conducted a study on acidic red soils and concluded that the corrosion rate of the steel increases with the water content up to a critical limit of 30% and then it decreases with a further increase of the soil water content [39]. The research which Chen *et al.* (2015) have done, shows that corrosion potential, potential gradient, total soluble salt content, and moisture content are the major factors affecting soil corrosion at slope nets in China [9]. On the other hand, research on alkaline soils carried out by Shabangu *et al.* (2015) results in the conclusion that the corrosion rate will be high in soils that having high moisture content, low resistivity, low redox potential, high chloride, sulfate, and bicarbonate contents [33]. Saupi *et al.* (2016) recorded that moisture and strong acidic pH shows the effective corrosion condition [32]. Mohammed (2016) in his thesis in Iraq concluded that the moisture content ratio has the primary role in causing corrosion of steel coupons, and this was followed by a lesser extent with pH and a very small percentage with the clay content [23]. Mary *et al.* (2017) suggest further research work to study better the influence of moisture content, soil pH, and microbial load of soil as it affects corrosion of underground steel [21]. In the tropics, Lim *et al.* (2017) conducted a study and produced a conclusion that moisture content has the strongest influence on the metal loss caused by corrosion in soil. The other parameters produce minor effects, with PI as the least influential factor [18]. Results from Kibria and Hossain (2017) show that subsoil corrosion potential can be evaluated from geotechnical properties for a preliminary assessment, planning, and budgeting of pipeline projects, but it is recommended that the estimated corrosion exposure level using this method should be validated using field and laboratory testing of the soil samples. One of the soil geotechnical properties that affecting the corrosion process is soil type and moisture content [16]. Meanwhile, Rodriguez *et al.* (2018) argue that there are eight (8) parameters to determining corrosion dynamic, which are: soil texture, presence of water, aeration, soil pH, resistivity, redox potential, ion contents, and bacteria [31]. Qin *et al.* (2018) stated that the corrosion rate law of X70 steel in each studied soil tends to be different with the change of water content, the corrosion rate will increase when the soil water content is at 20% [30]. Liu and Cheng (2018) found that the corrosion rate of steel increased with the moisture content of the soil due to the increased conductivity [19]. Marusic *et al.* (2018) stated that corrosion in soils resembles atmospheric corrosion with corrosion rates usually higher and depending on the soil type [22]. In the next research, Wasim and Shoaib (2019) revealed that varying moisture and chloride contents can cause corrosion problems [35]. Accordingly, Liu *et al.* (2019) argue that the corrosion is accelerated with the increasing soil thickness due to more water contained in the soil [20].

Based on the literature review, a study of the average corrosion rate in andesitic volcanic soils was carried out. The research took a case study on Sekincau-Way Tenong West Transect Road, West Lampung, Sumatra, Indonesia (Figure 1) on the reason that in this area there were residential infrastructure and buried water supply carbon steel pipelines (Figure 2). In this paper, we investigate the correlation between on-site local soil properties (water content, clay content, and index plasticity) with the corrosion rate. We compared the result with the result of granitic volcanic soil properties. We propose a new average corrosion rate per year on andesitic volcanic soil based on the soil engineering properties and statistical approach.

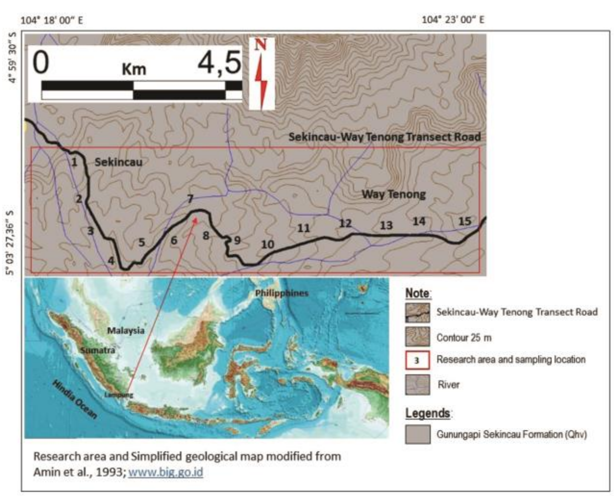


Figure 1 Location and soil samples map

Figure 2 Buried water supply carbon steel pipelines on Sekincau-Way Tenong West Transect Road [2]

2.0 METHODOLOGY

To fulfill the purpose of this paper, the materials and methods were described together with the pointer. The methodology used was:

1. 15 disturb soil samples were collected from different points along Sekincau-Way Tenong West Transect Road using a 1 kg plastic sample. Soil samples were taken at a depth of 50 cm from the slope and road surface close to buried water supply carbon steel pipelines (see Figure 1 and Figure 2). The soil samples were classified as 1 to 15. The method to collect the samples is terrain orientation.
2. The samples are then analyzed at the engineering geology laboratory, Geotechnology Research Center, LIPI, Bandung, Indonesia based on ASTM. The analysis included water content analysis (ASTM D2216-19) [6], Atterberg limit (ASTM D4318-17e1) [5], and grain size analysis (ASTM D422-63) [3] to obtain soil grains that passed mesh 200 (clay percentage).
3. The physical properties of the soil that have been obtained are then entered into the corrosion rate formula (hereinafter referred to as CR1). CR (hereinafter referred to as CR2) is obtained through formulas that have been made by Norhazilan *et al.* (2012) [26], namely:

$$CR = 0.124 + 0.002\,(M{,}C) - 0.003\,(C{,}C) + 0.004\,(P{,}I) \quad \text{Equation 1}$$

where;
CR = corrosion rate (mm/y)
M.C = moisture content (%)
C.C = clay content (%)
P.I = index plasticity (%)

4. Then the statistical method was used, the T-test and multiple-regression correlation test. The t-test between CR1 (CR Norhazilan *et al*., 2012) and CR2 (CR of this paper) and the multiple-regression correlation test between CR2 with parameters controlling the average corrosion rate (water content, clay content, and index plasticity).

3.0 RESULTS AND DISCUSSION

3.1 Soil Engineering Properties and Corrosion Rate of the Soil of the Study Area

Based on the regional geological map of the Kotaagung sheet [1] the Sekincau-Way Tenong Transect Road is in the Gunungapi Sekincau volcanic rock formation, composed of andesitic-basaltic volcanic breccias which are medium-acid volcanic rock (see Figure 1). The rock produces reddish-brown soil (Figure 3).

Figure 3 The soil of the study area

Laboratory analysis of soil engineering (Table 1) shows that the soil of the study area has a water content of 19.16% to 67.14%, clay content of 9.50% to 60,00%, and index plasticity of 10.13% to 40.74%. This implies that the study area is composed of silty clay to clayey silt soils with the ability to store medium to high water and has high plastic properties.

Table 1 Soil engineering properties

Sample No	Water Content (%)	Clay Content (%)	IP (%)
1	67,14	25,95	31,11
2	56,04	22,71	17,82
3	40,50	30,86	35,17
4	30,80	15,50	36,60
5	62,08	14,67	35,20
6	31,18	15,54	16,70
7	25,82	20,60	23,64
8	30,30	26,62	28,65
9	49,05	43,10	28,74
10	50,51	19,50	28,95
11	66,80	60,00	37,82
12	19,16	35,00	20,29
13	21,87	9,50	10,13
14	50,21	29,50	36,71
15	48,61	47,00	40,74

The CR1 formula (equation 1) produced by Norhazilan *et al.* (2012) [26] is then used as the main reference to produce the average corrosion rate in the study area (Table 2). In Table 2 it can be seen that the average corrosion rate of the study area (CR2) ranges between 1.13131 to 1.13855 mm/yr, with Central tendency: Mean: 1.13499; Median: 1.13472, and Standard Deviation: 0.0018.

Table 2 Corrosion rate

Sample No	CR2 (mm/year)
1	1,13648
2	1,13426
3	1,13543
4	1,13713
5	1,13855
6	1,13396
7	1,13414
8	1,13446
9	1,13399
10	1,13648
11	1,13472
12	1,13131
13	1,13272
14	1,13617
15	1,13512

3.2 Soil Engineering Properties Affecting Corrosion Rate Based on Simple Linear Regression Test

Figure 4, 5, and 6 shows the soil engineering properties affecting the corrosion rate based on simple linear regression analysis. Figures 4 and 6 show the effect of water content and index plasticity on the corrosion rate. The R^2 values obtained were 0.3607 for the water content and 0.4475 for the index plasticity, respectively, with the trendline heading upwards. This indicates that water content and index plasticity simultaneously affect CR2 of 36.07% and

44.75%, which mean an increase in water content and index plasticity will increase the average corrosion rate.

In contrast to Figures 4 and 6, Figure 5 shows a different trendline. In Figure 5 the R2 value obtained is 0.0381, with the decrease trendline. This illustrates that clay content only affects CR2 of 3.81%, which means the higher the clay content, the average corrosion rate will decrease.

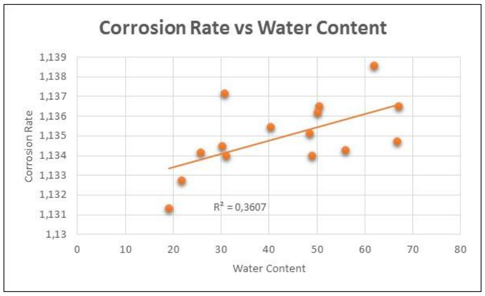


Figure 4 Water content vs corrosion rate

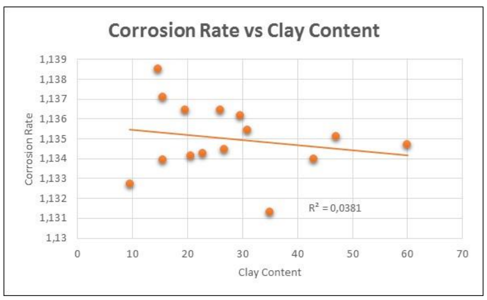


Figure 5 Clay content vs corrosion rate

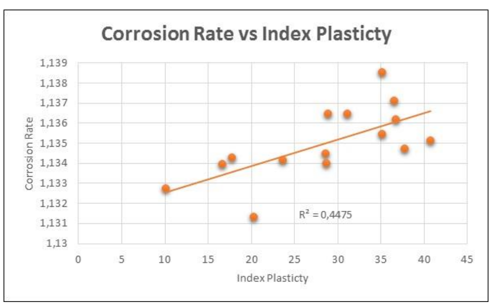


Figure 6 Index plasticity vs corrosion rate

3.3 The t-test

A T-test was used to analyze the significant difference between the average of the two groups. This test needs a central tendency from Norhazilan *et al.* (2012) [26] data. The central tendency from Norhazilan *et al.* (2012) [26] data is: Mean: 1.13223; Median: 1.13248; Standard Deviation: 0.00276.

In Table 3 it can be seen that the data variance between CR1 and CR2 is homogeneous or equal (0.149 > 0.05). Mean data between CR1 and CR2 are different (0.0027 < 0.05), it can be concluded that CR1 and CR2 are different or independent. This difference explains that soil genetic influence the average corrosion rate. It can be seen that Norhazilan *et al.* (2012) [26] researched in Malaysia (granitic volcanic soil), while we researched in the West Lampung area, Indonesia (andesitic volcanic soil).

3.4 Multiple Regression Correlation Test

Multiple regression correlation analysis tests were used to investigate the influence of soil engineering properties. In Table 4, we can see that the coefficient of determination (R^2) obtained for 0.903, or equal to 90.3%., on the other side the Adjusted R Square decreased to 0.889 or 88.9%. It shows that 88,9% of the dependent variable could be explained by the independent variables. That figure implies that CC, WC, and IP simultaneously affect CR2 of 88.9%.

Table 5 and Table 6 shows a summary of the ANOVA analysis and the t-test between the significance of constants and each independent variable (water content, clay content, and index plasticity). In Table 5, it is known that the significance value (Sig.) in the F test is 0.000. Because of Sig. 0.000 < 0.05, it can be concluded that independent variables (water content, clay content, and index plasticity) simultaneously affect the dependent variable (corrosion rate). Thus, the requirement to be able to interpret the coefficient of determination in multiple linear regression analysis has been fulfilled. On the other side, Table 6 column Sig. shows that all variables (water content, clay content, and index plasticity) are 0.00 below a (0.05), which means that each variable affects the corrosion rate (CR2).

Table 6 also shows the coefficient of the regression model of all predictors towards response. The regression model equation is shown in equation (2):

CR2 = 6.205E-5*WC + 12.15E-05*IP - 9.265E-5*CC + 1.132 ……………….…………………………..Equation 2

where;
CR2 = corrosion rate (mm/y)
WC = water content (%)
CC = clay content (%)
IP = index plasticity (%)

Equation 2 explains that a constant of 1.132 is the corrosion rate if there were no additional water content, clay content, and index plasticity. In other words, the corrosion rate will be 1.132 mm/yr when the value of water content, clay content, and index plasticity is equal to 0 (zero). If there is an addition of each soil engineering properties variable, it can be explained as follows: the index plasticity coefficient index of 0.0001215 means that every 1% addition of index plasticity will increase the corrosion rate by 0.0001215. Likewise, the water content coefficient of 0.00006205, each addition per 1% of water content will increase the corrosion rate by 0.00006205. Conversely the clay content coefficient of -0.00009265, each addition per 1% clay content will reduce the corrosion rate by 0.00009265.

To calculate the effective contribution [13] of each variable, the Coefficient B (Unstandardized Coefficients) value of each variable in Table 6 and Sum of Squares and Cross-products water content (WC), index plasticity (IP), and clay content (CC) in Table 7 was used. The equations used to calculate effective contributions are:

EC = (B x cross-products x R2) / Regression) x 100% Equation 3

Table 3 Summary of T-test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
CR1_CR2	Equal variances assumed	2.191	.149	3.374	30	.002	.00270	.00080	.00106	.00433
	Equal variances not assumed			2.476	7.121	.042	.00270	.00109	.00013	.00526

Note : CR1 = Norhazilan *et al.* (2012)
CR2 = this paper

Table 4 Summary of multiple regression analysis

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.950[a]	.903	.889	.000521870

a. Predictors: (Constant), CC, WC, IP
b. Dependent Variable: CR2

Table 5 Summary of ANOVA analysis

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	.000	3	.000	65.279	.000[b]
	Residual	.000	21	.000		
	Total	.000	24			

a. Dependent Variable: CR2
b. Predictors: (Constant), CC, WC, IP

Table 6 Summary of parameters estimation

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	Correlations Zero-order	Partial	Part
1	(Constant)	1.132	.000		2896.903	.000			
	WC	6.205E-5	.000	.546	7.333	.000	.455	.848	.498
	IP	12.15E-05	.000	.970	10.359	.000	.407	.915	.703
	CC	-9.265E-5	.000	-1.110	-11.665	.000	-.235	-.931	-.792

a. Dependent Variable: CR2
b. Predictors: (Constant), CC, WC, IP

Table 7 Correlations WC, IP, and CC to CR2

		WC	IP	CC	CR2
WC	Pearson Correlation	1	.355	.393	.455*
	Sig. (2-tailed)		.082	.052	.022
	Sum of Squares and Cross-products	4573.635	1470.904	2443.894	.236
	Covariance	190.568	61.288	101.829	.010
	N	25	25	25	25
IP	Pearson Correlation	.355	1	.682**	.407*
	Sig. (2-tailed)	.082		.000	.044
	Sum of Squares and Cross-products	1470.904	3754.528	3844.602	.192
	Covariance	61.288	156.439	160.192	.008
	N	25	25	25	25
CC	Pearson Correlation	.393	.682**	1	-.235
	Sig. (2-tailed)	.052	.000		.259
	Sum of Squares and Cross-products	2443.894	3844.602	8474.081	-.166
	Covariance	101.829	160.192	353.087	-.007
	N	25	25	25	25
CR2	Pearson Correlation	.455*	.407*	-.235	1
	Sig. (2-tailed)	.022	.044	.259	
	Sum of Squares and Cross-products	.236	.192	-.166	.000
	Covariance	.010	.008	-.007	.000
	N	25	25	25	25

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

Calculation results from the effective contribution of each independent variable to corrosion rate are a plasticity index of 39.5%, the water content of 24.79%, and clay content of 26.04%. So the total effective contribution to the corrosion rate is 90.3% (the same as R Square in Table 4).

4.0 CONCLUSION

Soil engineering properties (water content, index plasticity, and clay content) simultaneously affect the average corrosion rate. The corrosion rate would be 1.132 mm/yr in andesitic volcanic soils if water content, clay content, and index plasticity equal to 0 (zero). The corrosion rate will increase if there is an addition of 1% of the index plasticity and water content. Conversely, if there is an additional 1% clay content, then it will reduce the corrosion rate. The effective contribution of each independent variable (soil engineering properties) to the corrosion rate is a plasticity index of 39.5%, the water content of 24.79%, and clay content of 26.04%.

This research has been able to reveal the average rate of corrosion in andesitic volcanic soils. Furthermore, stakeholders can use these results to predict how long the pipeline will take, especially carbon steel pipes in andesitic volcanic soils. In the future, research needs to be carried out in other type of pipe and other soils (sedimentary soil for example).

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