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Corrosivity of Earthing Electrode (Galvanized Tape) in Various Soil Locations for TNBR Transmission Tower

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Tenaga Nasional Berhad (TNB) transmission towers carrying electrical lines are earthed by earthing electrodes. They are at risk of corrosion due to being fully submerged in soil for long periods and periodical maintenance of these towers can be a challenge as some of the sites of these towers are hard to access. Previous research on galvanized tape as earthing electrodes was limited to certain locations, and subsequently, only focused on certain types of soils. Moreover, there is no prediction of the lifespan of earthing electrodes using galvanized tape, which is crucial information for industry. Hence, the objective of this study is to determine the corrosion rate of galvanized tape in various soil types in Malaysia by the Weight Loss Method (ASTM G1-03). Soils from four locations from Ulu Bernam, Teluk Kalong, Merlimau, and Gelang Patah are analyzed to identify the soil types and compositions, followed by a corrosion lab-based experiment for 14 days. The mass reductions of the corroded galvanized tapes were measured to determine the corrosion rate with pH values monitored daily. Results revealed that the soil type and area influence the corrosion of the galvanized tape with the average lifespan of galvanized tape in Malaysian peat soil being 7.2 years.

1. Introduction

Tenaga Nasional Berhad (TNB) provides and supplies electricity to Malaysia through transmission lines supported by transmission towers, (*Transmission Division - Tenaga Nasional Berhad*, n.d.). Due to the tall nature of the towers, the towers must be equipped with proper earthing which involves an electrode attached to the tower buried deep in the soil (Rahman et al., 2014). Proper earthing will enable to mitigate the complications due to lightning strikes, (Pereira et al., 2015). However, these earthing electrodes are prone to corrosion which may occur due to the soil properties or due to the nature of the earthing electrode material, (Ghavamian et al. 2015). Consequently, this corrosion may lead to a decreased efficacy of the lightning protection system and lead to a higher risk of complications (Lindsey et al., n.d.). Earthing electrodes using galvanized tapes are a common practice in industry in terms of cost preferable compared to copper rods. However, it is still susceptible to corrosion once the zinc oxide coating is stripped off, exposing the bare metal to the environment.

The inconclusive results from previous research regarding the significance of soil properties towards corrosivity led to more questions for example, the unknown correlation between soil type and the corrosion rate of metal (in this case galvanized tape) which subsequently undetermined the lifespan of galvanized tape as an earthing electrode in various soil types for the maintenance purposes. This unknown information leaves gaps that become issues for the industry. Hence, the objective of this study is to determine the corrosion rate of galvanized tape (Weight Loss Method (ASTM G1-03)) in various soil types that are characterized using the soil textural analysis (pipette method) and CHNSO (carbon-hydrogen-nitrogen-sulfur-oxygen) elemental analysis. The lab-based experiments were conducted on soils from four locations in Malaysia: (1) UB, Ulu Bernam, Perak. (2) TK, Teluk Kalong, Terengganu. (3) ML, Merlimau, Melaka. (4) GP, Gelang Patah, Johor. The sites in which the soil samples were taken are shown in Figure 1.

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Figure 1: Location of Site Sampling

2. Methodology

The soil sampling sites were chosen at selected TNB transmission towers i.e. at Ulu Bernam (UB), Teluk Kalong (TK), Merlimau (ML), and Gelang Patah (GP). Soil samples were obtained at a depth of 60cm, the depth at which the electrodes were buried (Nasir et al., 2021) and the water samples were also collected on-site. The pH, electroconductivity (EC), and moisture content (MC) were measured and recorded in situ using a pH meter and EC/MC meter, respectively. Soil characteristics were conducted using soil textural analysis through the pipette method and CHNSO analysis. Concurrently, corrosion rate analysis was performed for galvanized tapes for 14 days, and with a control test using carbon steels for 7 days. A preliminary test was conducted using a galvanized tape for 7 days as followed by the standard of ASTM G1-03("ASTM G1-03 Standard Practice for Preparing, Cleaning, and Evaluating Corrosion Test Specimens," 2017; "ASTM G31-72 Standard Practice for Lab Immersion Corrosion Testing of Metal," 2014), however, the corrosion rate was unable to be determined as the mass reduction after the test was insufficient to be measured using a weight balance, hence a-14 day corrosion test was conducted for all galvanize tape.

2.1 Soil Characteristics

Soil texture analysis was conducted using the pipette sedimentation method (Guldner et al., 2011) to determine the sand and clay mass fractions to obtain the silt fraction and subsequently, the ternary diagram was plotted using Soil Texture Calculator (Natural Resources Conservation Service, n.d.). 10 mg of each soil sample went through a CHNSO analysis where samples were combusted at 900ºC for 15min to determine the element percentage of carbon, hydrogen, nitrogen, sulfur, and oxygen (Mettler Toledo, n.d.).

2.2 Corrosion Test (Weight Loss Analysis)

For each experiment, two metals were used. ("ASTM G31-72 Standard Practice for Lab Immersion Corrosion Testing of Metal," 2014) . To mimic the condition of the burial soil of the site, a total mass of soil is determined by a typical bulk density of selective soil type under its natural condition which is 1.5 g/cm^3 (Zeri et al., 2018). The overall setup and dimensions of metal samples are illustrated in Figure 2. Daily routine parameter (DRP) is also obtained where parameters of pH, EC, and MC of the soil are measured and recorded daily.

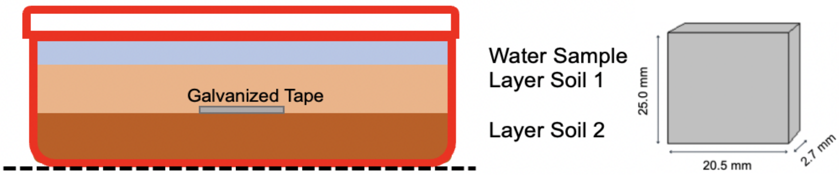

Figure 2: Cross-section view of contents of the container for corrosion analysis & metal dimension

Once the corrosion test was completed, metals were retrieved from the soil and were cleaned using a cleaning solution, i.e. Clarke's solution for carbon steels and acetone for galvanized tapes following the ASTM G1-03 standard. The corrosion rate is determined using Eq. 1, while the lifespans of the galvanized tape can be determined using Eq. 2 until Eq. 4

$$Corrosion\ rate\ \left(\frac{mm}{year}\right) = \frac{87600 \times W}{A \times t \times \rho} \tag{1}$$

Where,

W	=	The difference in mass of coupon before testing and after cleaning, in gram
K	=	Corrosion rate constant
A	=	Surface area of coupon, in cm^2
t	=	Duration of the test, in hour
ρ	=	The density of metal coupon, in $\frac{g}{cm^3}$

$$Lifespan, GT = Lifespan_{ZnO} + Lifespan_{CS} \tag{2}$$

$$Lifespan_{ZnO} = \frac{T_{ZnO\ coating}}{CR_{GT}} \tag{3}$$

$$Lifespan_{ZnO} = \frac{\left(\frac{T_{Carbon\ steel}}{2}\right)}{CR_{CS}} \tag{4}$$

Where,

$Lifespan_{GT}$	=	Lifespan of galvanized tape
$Lifespan_{Zno}$	=	Lifespan of zinc oxide coating
$Lifespan_{CS}$	=	Lifespan of carbon steel
$T_{ZnO\ coating}$	=	The thickness of zinc coating (0.168 mm as measured using a magnetic thickness gauge)
$T_{Carbon\ steel}$	=	Thickness of carbon steel (2.7 mm)
$CR_{,GT}$	=	Corrosion rate of galvanized tape
$CR_{,CS}$	=	Corrosion rate of carbon steel

3. Results

3.1 Soil Characteristics

Soil Texture Analysis

From the quantitative analysis of the soil texture analysis, the percentage of sand, silt, and clay was obtained for each soil sample and is illustrated by the Ternary Diagram as in Figure 3 and the overall results are summarized in Table 1.

The soil type is an important factor as it may influence the properties of the soil. The overall findings from the soil texture analysis are that GP soil is sandy clay loam, UB is clay soil, TK is a sandy loam, and ML is sandy clay soil.

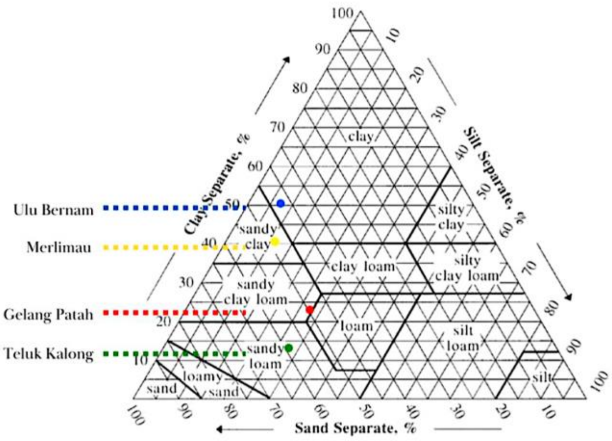

Figure 3: Ternary Diagram of Soil Samples from Four Locations

Table 1: Soil textural analysis results summary

Soil Sample	Ulu Bernam	Teluk Kalong	Gelang Patah	Merlimau
Sand %	43.4	60.35	50.8	49.65
Clay %	50	12.6	22.5	40
Silt %	6.6	27.15	26.7	10.35
Soil Texture	Clay	Sandy Loam	Sandy Clay Loam	Sandy Clay

CHNOS Analysis

From the CHNSO Analysis, the elemental compositions of the soil samples are tabulated in Table 2. High carbon content was detected from the soil of UB, TK, and GP. The carbon percentage is correlated to the organic content, which is the main composition of the peat soil. Peat soils are high in organic matter content (Raghunandan & Sriraam, 2017; Rinaldi et al., 2019), usually are anaerobic due to high moisture saturation and usually have high water holding capacities, high permeability, high pore ratio, high compressibility and low pH due to the presence of organic acids (Gowthaman et al., 2022; Zainorabidin & Wijeyesekera, 2008).

Table 2: Soil textural analysis results summary

Elemental %	Ulu Bernam	Teluk Kalong	Gelang Patah	Merlimau
Carbon	78.87	67.29	78.37	39.20
Nitrogen	0.14	9.66	0.44	10.61
Hydrogen	21.00	23.05	21.19	50.18
Sulfur	0.00	0.00	0.00	0.00

3.2 Weight Loss Analysis

Figure 4 shows the corrosion rate and the lifespan for all samples, and the most corrosive to the least corrosive soils are GP, TK, UB, and ML. As such, the metal lifespans in increasing order are GP at 6 years, TK at 7 years, and UB and ML at 8 years. Many factors can influence the corrosion rate of galvanized tape in soils such as soil type, soil resistivity, ionic content, and soil pH.

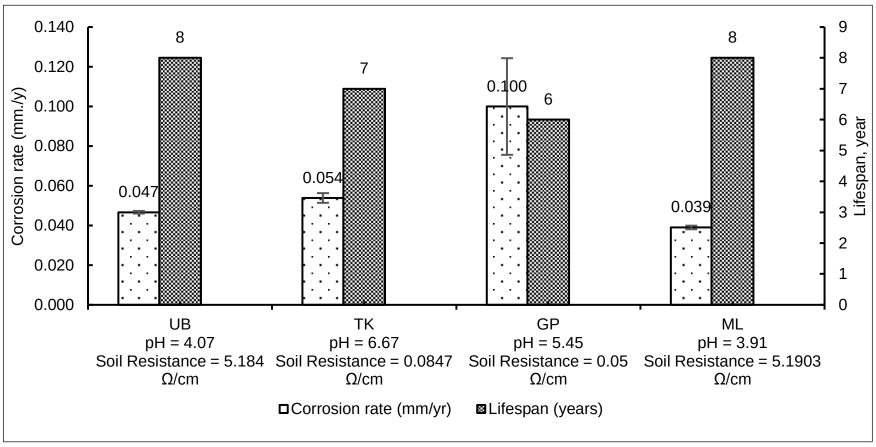

Figure 4: Corrosion Rates and Lifespans of Galvanized Tape

The resistivity of soil reflects how easily currents flow in the soil (Salam et al. 2017), and one of the factors affecting soil resistance is the ionic content of the soil which carries electrical charges, contributing to a lower resistivity value as the ions are able to conduct a greater amount of current, (Testing Conductivity, 2018). The soil resistance is obtained by taking the inverse of the average daily value of EC, which follows Ohm's Law, and with increasing soil resistivity, the corrosion rates decrease. This is consolidated by the fact that a higher resistance impedes the corrosion process.

As is noticeable from Figure 4, GP and TK have significantly low values of soil resistance which can be explained by the location of the site. TK soil was sampled near a river that leads to the sea (Figure 1b), while GP soil (Figure 1d) was obtained on the land where mangroves are abundant (swamp area), signifying that both soil location is saturated with salt molecules. As salt is water soluble, the salt molecules will dissociate into Na^+ and Cl^- ions. Hence, the soil in GP and TK are extremely conductive due to the abundance of the ions. As such, the corrosion rates in these two locations are high as the resistance of the soils is low due to the abundance of the ions contributing to the conductivity of the soil.

Another factor mentioned contributed to the corrosion is the pH of the soil, and these pH values throughout the experiment are shown in Figure 5. It can be observed that the pH of the soils increases over the 14-day period. Fundamentally, pH is defined as the concentration of H^+ ions, (Newnes Engineering and Physical Science Pocket Book, 1993). Hence, it can be deduced from the progression of the pH of the soil that initially, the concentration of the H^+ ions was at the highest as the cathodic reactions occurred, saturating the solution with H^+ ions. The increase of the pH over time signifies that the anodic reactions are taking place and the H^+ ions are decreasing due to the anodic Zn and Fe atoms donating electrons to neutralize the H^+ ions. The plateau of the pH at around day 5 shows that equilibrium has taken place, and the metal is now covered by a layer of corrosion product that is in equilibrium with the surrounding soil. Hence, there is no exchange of electrons after that time, the concentration of H^+ is constant and the pH is constant.

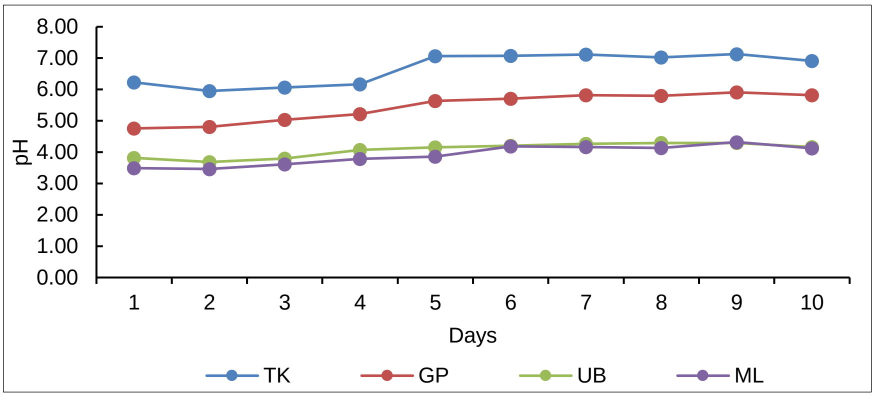

Figure 5: pH Soil Samples over Time

4. Conclusions

In conclusion, it was also found that the galvanized tape corrodes at 0.039 mm/yr in Merlimau, 0.047 mm/yr in Ulu Bernam, 0.054 mm/yr in Teluk Kalong, and 0.1mm/yr in Gelang Patah with lifespans of 8, 8, 7 and 6 years at each respective location that was identified as peat soil location. Hence factors affecting the corrosion rate of galvanized tape are much more related to the area where the sample was taken. In addition, soil type, soil resistivity, ionic content, and soil pH can be indicators of the ongoing corrosion of the transmission tower that uses galvanized tape as earthing electrode. Overall, it was determined that the average lifespan of galvanized tape in Malaysian peat soil is 7.2 years.

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